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PROCEEDINGS

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Hosted by İTÜ

TABLE OF CONTENTS

PREFACE

Project and Construction Management Conference (in Turkish abbreviated as PYYK) was formerly held in Ankara, İzmir, Eskişehir and Antalya. The 5th conference was organized as an international conference, entitled as International Project and Construction Management Conference (IPCMC) and it was first held in Cyprus. The 6th International Project and Construction Management Conference (IPCMC 2020) would have been held in Istanbul, but due to the outbreak of COVID-19 pandemic, this year's conference is organized as a fully virtual conference.

In order to prepare IPCMC 2020, the organizing committee, the reward assessment committee, reviewers, authors and presenters have made a lot of efforts and contributions. We are very grateful for the support and participation of our Construction Management community. We could not have pulled off this convention without all of your hard work and dedication.

Since their inception, IPCMCs have been attracting many delegates from all over the world. This year's conference consisted of 2 keynote speeches, from USA and Hungary, has received 234 abstracts. After a thorough review process, 139 papers of 271 authors from 20 different countries were accepted and published in the conference proceedings.

We sincerely hope that the academic community and industrial practitioners will continue to support us in our attempts to provide even more meaningful conferences with numerous critical idea exchanges, diverse opportunities for fruitful networking and future collaborations between the delegates.

Hoping to meet in much healthy and joyful days, in the future.

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Emerging Challenges of Environmental Issues in Hilly Snow-Covered Areas of North Western Himalayas

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Abstract

Snow cover in the North western Himalayan (NWH) region is highly variable with respect to space and time, which influences the environmental and climatic issues at regional and global scale. Seasonal snow plays an important role in earth's climate system. Snow covers affects the temperature of earth by regulating it, and once that snow melts, water starts flowing to fill the rivers and reservoir available in that region. The Himalaya has the highest as well as largest mountains system on the earth, whose length is about 2400 km and 300 km in width, with extreme variation in topography and climate. There are so many big rivers like the Ganges, Indus and Brahmaputra originates from the snow and glacier covered mountains and they have sufficient amount of seasonal and annual water supply. It is hard to think about an asset which is more essential to the good health of the people and their economies than water; still management of water resources is complex and one of the most challenging tasks. People living in hill areas are heavily dependent upon water resources for irrigation and agriculture, preparing food, generating hydropower, maintaining sanitation as well as proper functioning of many ecosystem services. Despite this, most emerging challenge for people living in hill areas has limited access to water for drinking, cooking and agriculture.

Keywords: *AWiFS, BHUVAN, MODIS, North western Himalaya, snow cover.*

Introduction

The Himalaya and its nearby high-altitude regions are the vital source of major river system in India together with Ganga, Beas, Brahmaputra, Indus, Chenab, Jhelum, *etc*. As huge areas of Himalayas are covered by snow and glaciers, these areas play a crucial role in regulating the climate change seasonally as well as annually. Himalayan region is very susceptible to climate change if we study its climatic conditions in terms of large-scale warming. The ice accumulation present in this particular region is the world's 3rd largest on earth, after Antarctic and Arctic ice mass region (Barnet et al., 2005). Some current assessments have shown that warming and fluctuations of heat in Himalayan area (Bhutiyani et al., 2007) is mounting rapidly as compared to the global average over the last few decades.

North western Himalayan region is extremely vast and largely out of reach for researchers, however snow cover affects the temperature of earth by regulating it, and once that snow melts, water starts flowing to fill the rivers and reservoirs available in that region. It is hard to think about an asset which is more essential to the good health of the people and their economies than water; still management of water resources is complex and of the most challenging tasks. Any change of snow balance and ice mass in world's highest and largest mountain system will impart a visible effect on climatic conditions, ecosystem and water system of the nearby densely populated region downstream, however the extent of its effect varies exceptionally in various other river basins. Agriculture and water-based development systems like hydropower plants get affected directly by the change in hydrological regime and just because that long-term assessment and short-term assessment of change in snow cover dynamics in Himalayas is necessary.

Snow cover is very important for ground water recharge as well as river run offs and water availability for locals especially in the high latitudes (Jain et al., 2008). Due to low temperature and high altitudes in winter's large areas of Himalaya receives precipitation in the variety of snow. The snow which melts down contributes annually to the river flow as 70% for Chenab up to Akhnoor, 60% from Sutlej up to Bhakra Dam and 30% for Ganga river up to Devprayag (Singh & Singh, 2001). These rivers play significant role in energy supply as they are the major source of hydropower in Northern India. Regular mapping, assessment and monitoring of this seasonal snow cover by conventional method is very difficult due to isolated terrain during peak winters, rough and high-altitude topography and inaccessibility of these mountains. However, space based remote sensing satellites has proved that they have the facility of mapping and monitoring ice mass, snow cover, glacier extents and lakes at higher altitudes with high temporal and spatial resolution (Aggarwal et al., 2013).

Data Used

The MODIS temporal snow cover information depends upon snow mapping algorithm that to a great extent uses Normalized Difference Snow Index (NDSI). This NDSI appraisal is unwavering by the help of reliance reflectance in MODIS band 4 (0.545-0.565 μm) and MODIS band 6 (1.628-1.652 μm). The actual type of the cell as snow and non-snow is decided on the basis of NDSI value, the reflectance in MODIS band 2 (0.841-0.876 μm) as well as the Normalized Difference Vegetation Index (NDVI) value for vegetation areas (Hall et al. 1998,2002). The NDVI values are determined in the comparative way as the NDSI using reflectance in visible red and near-infrared bands (Running et al. 2004).

Weekly snow cover maps are prepared using NDSI method over daily MODIS data on-board NOAA Terra are available in public domain from 2000 to present date, same have been used to plot map and calibrate the status of snow cover in north western Himalayas. In our present studies the winter seasonal months (November to March) months MODIS Snow cover products (MOD10A2, https://nsidc.org/data/MOD10A2) has been analyzed using automated snow cover extraction tool. Weekly snow covers data of each winter season from 1 November to 30 March has been analyzed and status of each north western Himalayan sub-basin has been calculated and compared. The bi-monthly snow cover area maps are developed by the help of AWiFS data, available on Bhuvan, has also been used in this study to calculate the total area under the snow.

Methodology

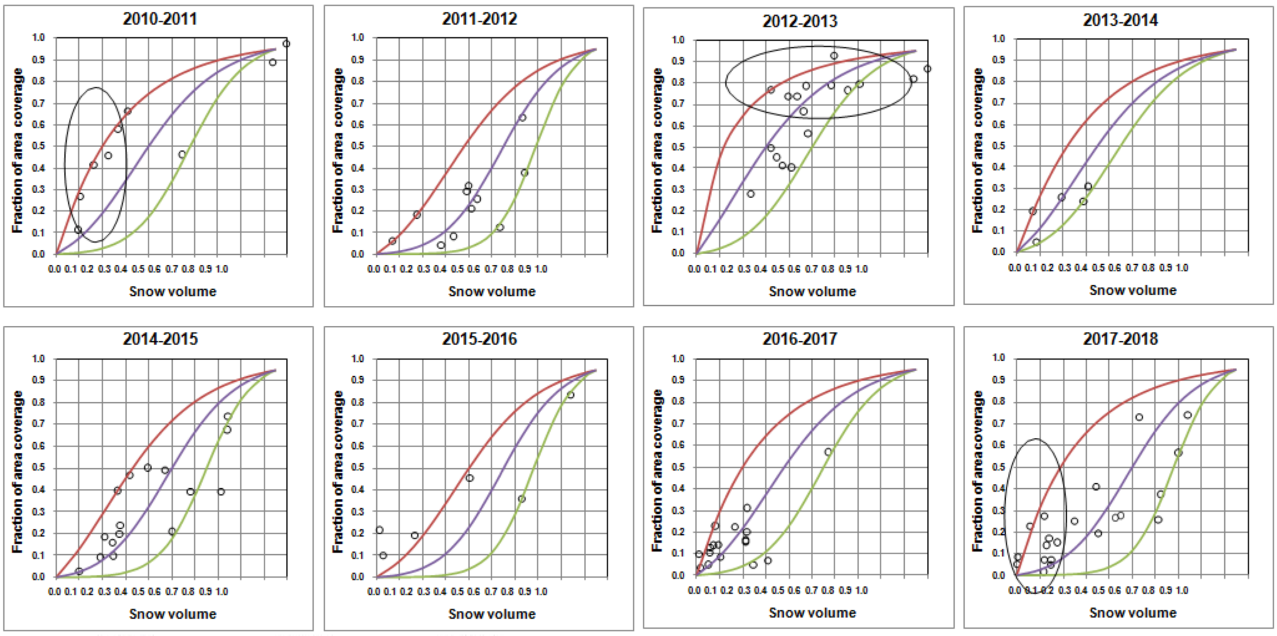
One of the most widely used method for analysis and research of snow cover data using optical remote sensing is Normalized Difference Snow Index (NDSI), which gives an idea about green and SWIR spectral bands of EMR as (Dozier & Marks, 1987):

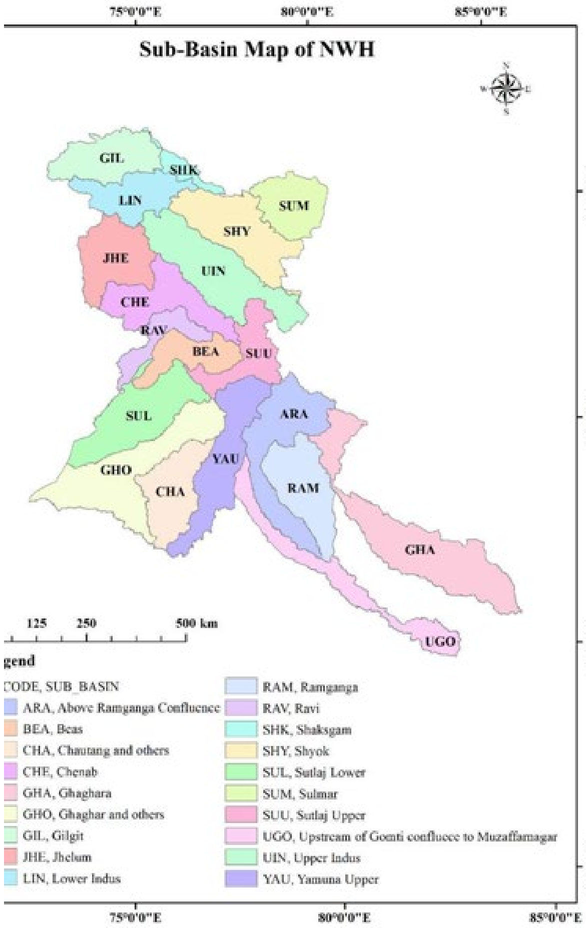
$$NDSI = (R_G - R_{SWIR}) / (R_G + R_{SWIR})$$

Where, R_G represents reflectance in green and R_{SWIR} represents reflectance in SWIR. If the NDSI exceeds a value of 0.4 then snow is considered to be present (Dozier, 1984, 2009; Kulkarni et al., 2006) and recent studies have shown that the most favorable value of the threshold may fluctuates seasonally (Vogel, 2002). Comparably, existence of water bodies, forest cover and cloud cover give rise to an error in final reported SCA, if only NDSI is used for SCA mapping. To control these errors, a rule-based algorithm was suggested and implemented by Hall et al. 2002, for useful mapping of snow cover area using MODIS sensor on-board Terra and Aqua satellites, which prepares daily 8-days and 16-days SCA product from 24 February 2000 to present. We are going to use MOD10A2 product which lies in the range of spatial resolution having 500 × 500 sq. meters in every eight-day interval that start on the initial day of apiece year and develops up to first few days of subsequently years. Which represents the highest snow cover proportion in the given 8 – days time interval. In addition, Resourcesat ½ based AWiFS sensor has been used by (Subramaniam & Suresh Babu, 2014) from NRSC, to produce 15 days 3 minutes spatial resolution snow fraction grids for north western Himalayas from 2014 to present.

Results

Till now the sub-basin wise analysis of SCA from 2001-2017 has been done for entire NWH. Figure 1 shows location of all sub-basins of NWH (source: IWRIS) and Fig. 2 highlights the 8-day maximum SCA during 2nd week of February 2017 having around 64% of total area under snow. The detailed analysis of fractional SCA has revealed around 20% increase in SCA during winter season of 2016-17 especially in the months of January to March 2017 as compared to previous year. The temporal increase in SCA in NWH region from November 2016 to February 2017 can be visualize in the representative SCA maps shown in Fig. 3 (a-c). It was observed that maximum SCA occurred on 2nd week of January, 2nd and 3rd weeks of February. Substantial snowfall has been recorded in the month March 2017, with some of the location receiving highest snowfall for this duration in last 30 years. Figures 8, 9, 10 & 11 shows the comparative SCA maps of NWH highlighting increased SCA even in lower altitude regions. The sub-basin wise fractional SCA for 1st week of March 2017 and 2016 are also depicted in Figure 12 & 13, respectively. The average increase of 08% (approx.) was observed in SCA during 1st week of March 2017 as compared to 2016.





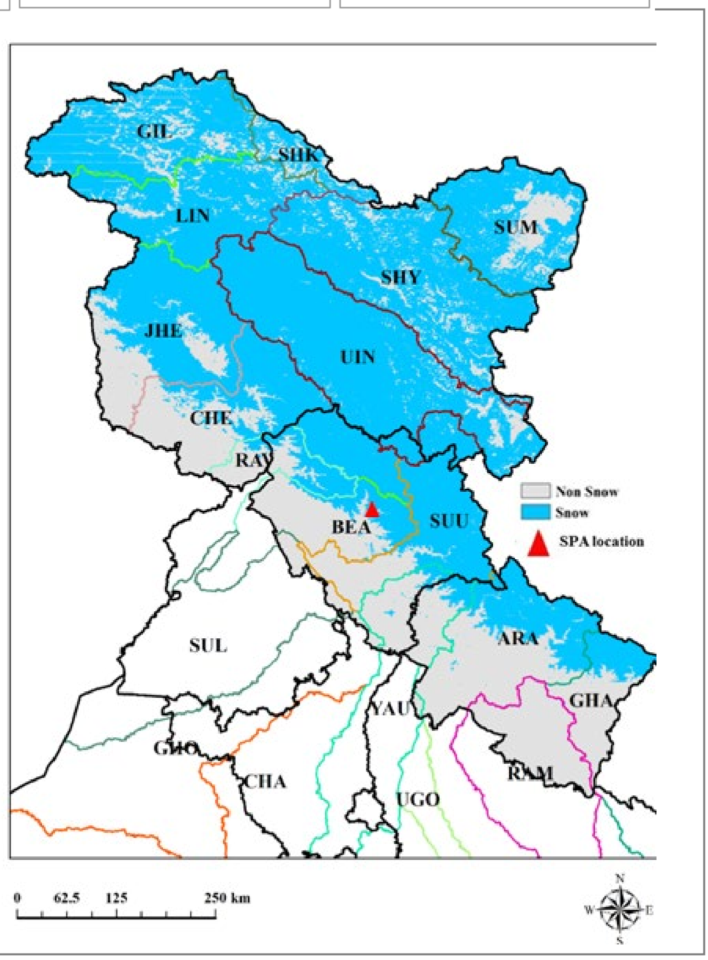


Figure 1: Sub basin map of NWH.

Figure 2: 8-Day Maximum SCA derived from MOD10A2 product in 2nd week of February 2017.

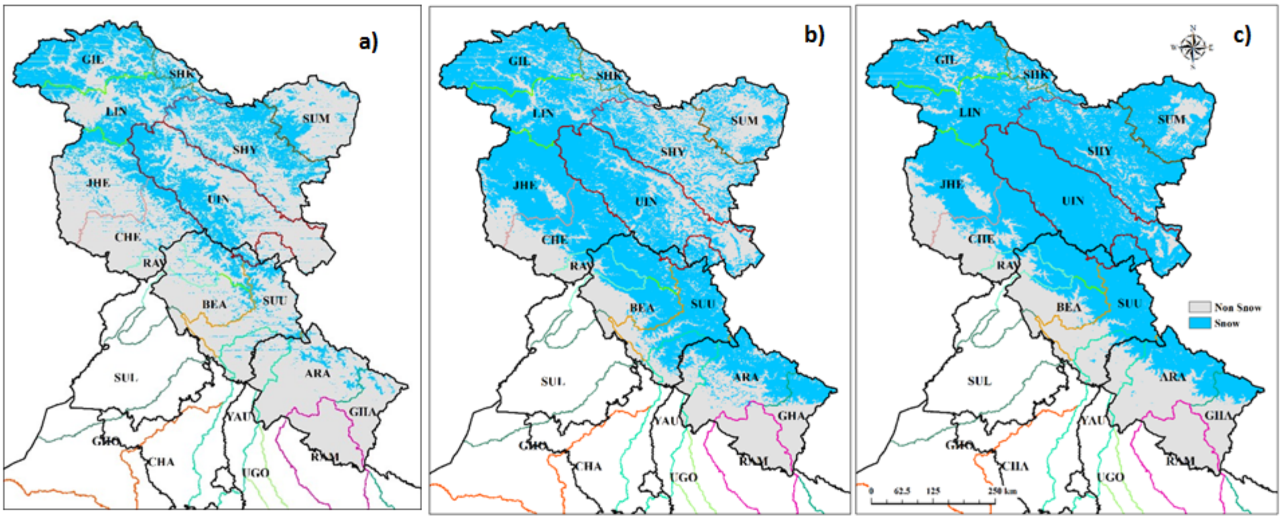


Figure 3: Temporal change in SCA during winter 2016-17
(a) 25 November – 2 December 2016 (b) 9 – 16 January 2017 (c) 10 – 17 February 2017.

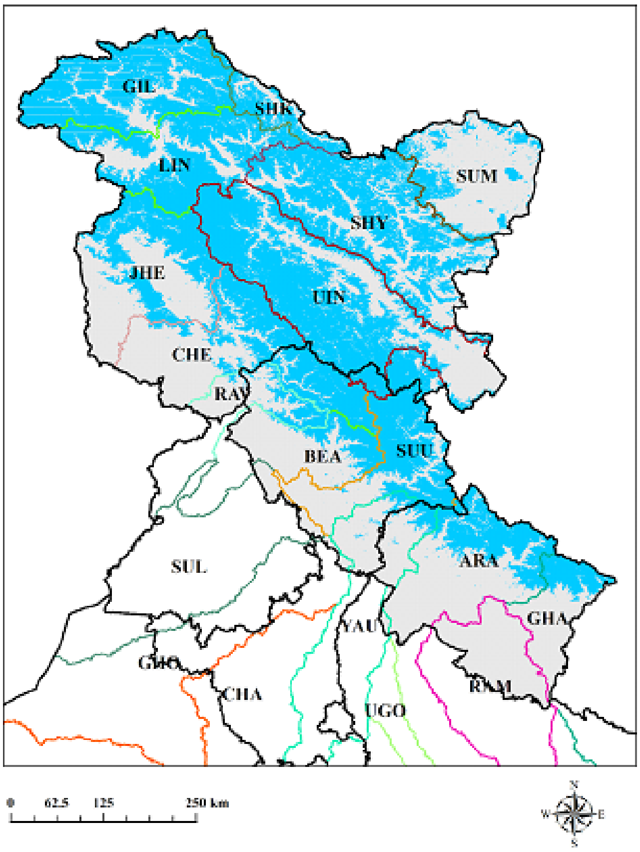


Figure 4: SCA in 1st week of March 2016.

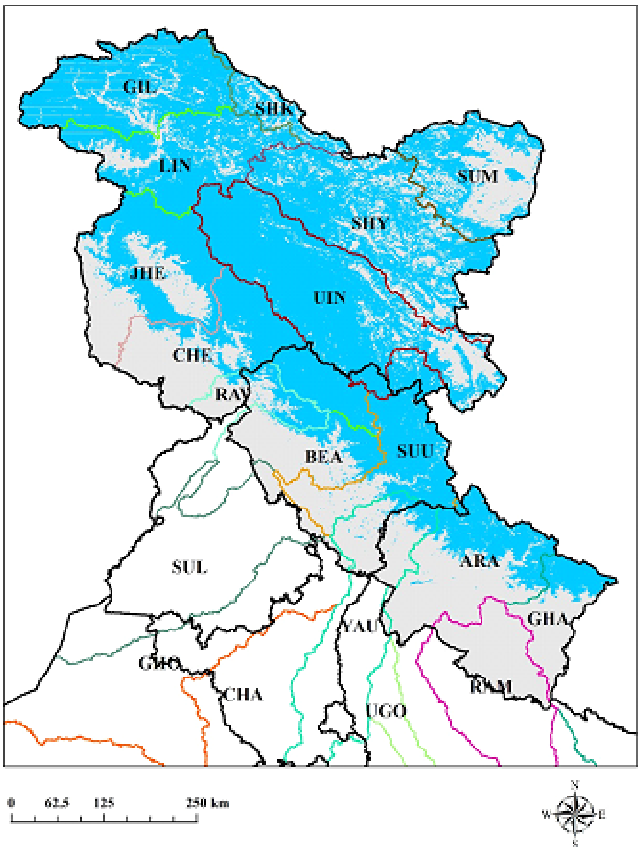


Figure 5: SCA in 1st week of March 2017
(10% increase has been observed in NWH).

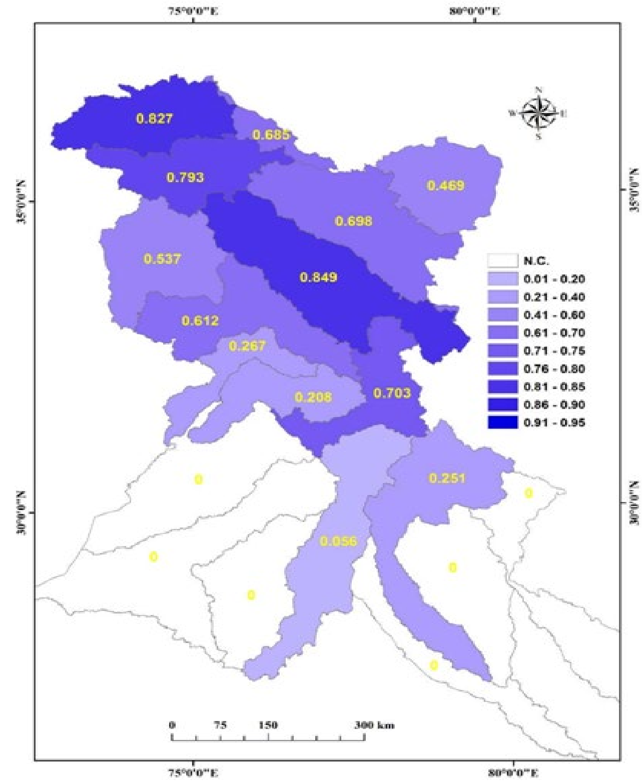


Figure 6: Status of SCA in 1st week of March 2017.

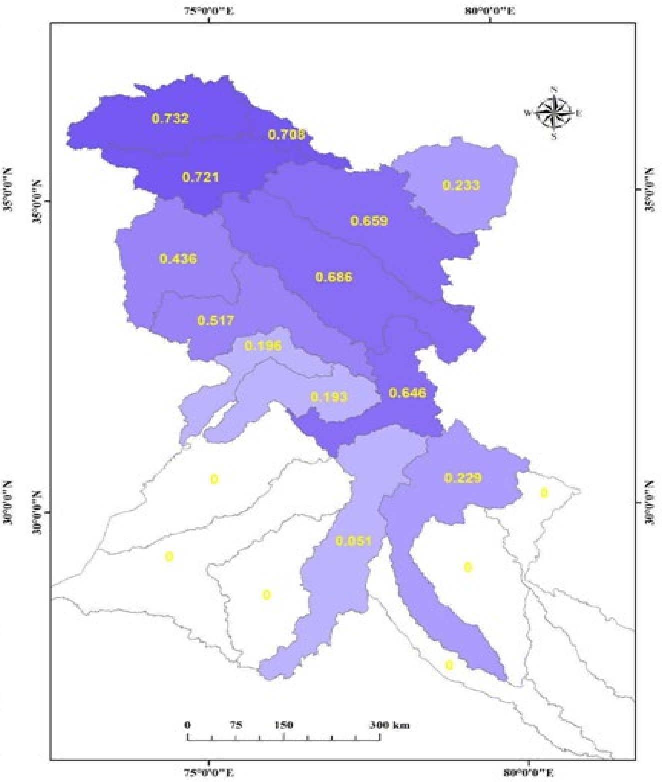


Figure 7: Status of SCA in 1st week of March 2016.

Discussion

This work will be continued for entire NWH with MODIS and AWIFS data and new SCA products from Suomi-NPP (S-NPP) Visible Infrared Imaging Radiometer Suite (VIIRS) snow cover algorithm (Hall et al 2015) will be used to improve SCA estimates mainly in spatial due to its higher (365 m as compared to 500m for MODIS). Additionally, Synthetic Aperture Radar (SAR) data can provide SCA especially during wet snow time (Thakur et al, 2012, 2016). Therefore, SAR data from RISAT-1 and Sentinal-1/2 can be used to map SCA in areas affected by persistent cloud cover and during melt season.

Conclusion

Heavy snowfall in NWH leading to higher SCA in spring season increase the chances of flash floods, landslide, and sudden increase in river flow associated with hazards in the region. From this analysis method we can expected that, the increased SCA, snow depth will produce higher snow melting during upcoming spring and summer season. This will require proper planning including hydrologic forecast will lead to increase in hydropower generation, reservoir storage and other associated activities. This study can be made more accurate and detailed with the help of suitable hydrological models if hydro-meteorological data, snow water equivalent, snow depth, snow density, location of water resources projects, baseline topographical data, *etc.*, of north western Himalayan region are made available.

It is therefore, suggested that the administrator, policy planner and local government must initiate local scale studies especially as hydropower and reservoir operations are planned to use ten-day river flow forecast.

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Determining and Evaluating the Factors Complicating Hydroelectric Power Plant Project Financing

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Abstract

Energy needs throughout the world have been increasing since the Industrial Revolution. Electrical energy, which is the most important type of energy needed, has been obtained through hydroelectric power plants (HEPP) for more than a century. During this long period of time, there have been transformations in the electricity market. With the privatization and liberalization of the electricity market, the financing structures have also changed, and the financial feasibility has begun to be questioned as HEPPs become an investment instrument. The construction and operation of state-owned HEPPs until the 90s were transferred to the private sector, and thus the financial viability of HEPPs became an important issue. In this context, some features of HEPP projects have been important factors in the difficulty of financing. In this context the aim of the study is to determine these factors and link them to certain loan criteria. So as to determine these characteristics, the literature between 2010 and 2019 was scanned. Through the content analysis of 16 studies, 12 factors complicating HEPP financing were identified. These factors are natural conditions, political conditions, equity return rates, technological costs, initial cost, transaction costs, production costs, construction risks, construction period, externalities, market conditions, and financing period. Then, these factors were evaluated by associating with 5 loan criteria, these are risk coverages, interest rate, grace period, maturity and leverage. As a result of the evaluation, the importance of the factors depending on the frequency of the factors in the literature, and how the ideal HEPP credits should be, were revealed. Accordingly, it was determined which features of the loans that constitute the majority of the HEPP financing package are critical for the financing of HEPP projects. At this point, this study contributes to the limited literature on HEPP financing and the improvement of the financing process by analyzing loan criteria from a different perspective.

Keywords: *hydropower finance, project finance, renewable energy finance.*

Introduction

The increasing energy need since the Industrial Revolution has been the most important driving force for the discovery of electricity and the development of electricity generation technologies. Water was the first renewable energy source to be discovered after the use of fossil fuels for electricity generation. For more than a century, hydroelectric power plants

(HEPP) have been used in electricity generation, making important contributions to energy security. Today, 15,9% of the electricity produced in the world is from hydroelectric sources (IHA, 2019), while more than 62.500 plant operating in the world. With these aspects, hydroelectric energy remains the most important electricity source worldwide.

Privatization and liberalization, which started in the electricity sector between 80s-90s, also had important effects on HEPPs. In the past, HEPPs built by the state have now become projects involving the private sector, which has led HEPPs to be considered as an investment tool, not just power plants (Hessler, 2005). While bringing profit is the most important feature of an investment tool, more lenders have started to take their place in financing. After those changes, HEPP projects have now become projects that involve many different actors and provide profit from their investors. Due to the peculiar features of HEPP projects, financing of those projects is complex and, the variety of debt instruments also made selection difficult. The aim of the study is to determine the characteristics of the features of the ideal loans for HEPP projects. At this point, this study contributes to the limited literature on HEPP financing and the improvement of the financing process by analyzing loan criteria from a different perspective by creating a new theoretical frame. In addition, this study will provide an initial guide for both public and private investors who will build a HEPP and have obstacles in project financing especially in emerging countries that require a lot of capital inflow.

Project Finance Method

Project finance (PF) is a financing technique that allows large infrastructure projects such as HEPPs and applied since 19th century. There are five distinctive characteristics of a PF deal, these are; legally independent project company (special purpose vehicle – SPV), limited or non-recourse to the sponsors, allocated risks to parties which can best manage them, necessity of cash flow that is sufficient to cover debt service and operational costs, given collateral as security for cash inflows (Gatti, 2008; Pinto, 2016).

There are many parties involved in the PF structure, such as special purpose vehicle (SPV), sponsors, lenders, governments, purchaser, operator, engineering- procurement- construction (EPC) contractor. Because of the scope of the study, the relationship between SPV, sponsors and lenders will be focused on (Figure 1).

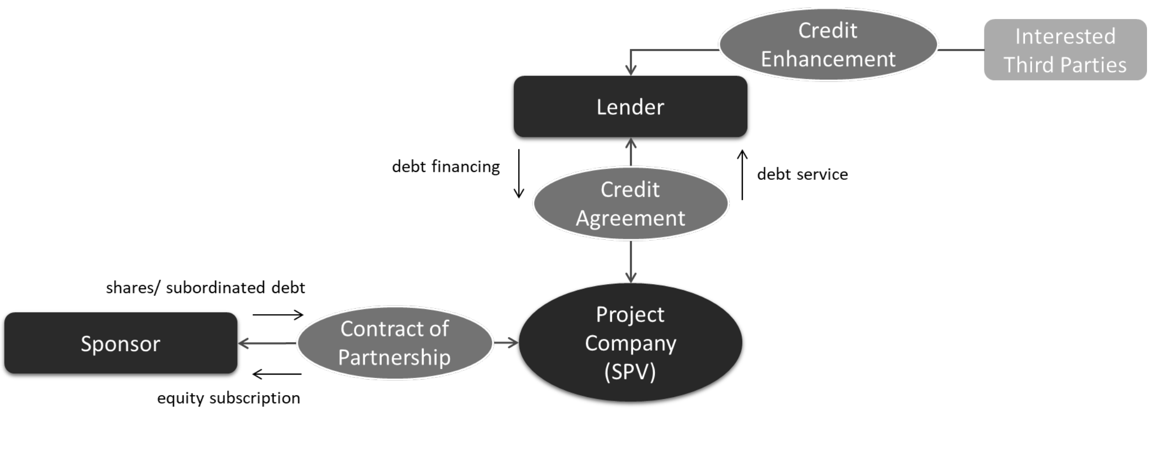

Figure 1: Relationship between SPV, sponsors and lenders.

In PF transactions for HEPP projects, the money required to finance the project is provided by sponsors and lenders. The sponsor provides equity to the project, while lenders ensure that the project can be financed by debt instruments. Due to the high leverage in PF transactions, lenders' contribution is larger. Generally, PF processes have more than one lender rather than a single one. Lenders and sponsors are contracted and funding SPV. A contract of partnership is signed between sponsors and SPV, while a credit agreement is signed between SPV and lenders. As a result, while those are funding SPV, credit repayment and dividend return to them afterwards.

The lender variety mentioned above causes diversity of financial products. With the development of the investment project scope and financial markets, lenders created various products that can be used in HEPP projects. The products of lenders vary in terms of the existence of risk guarantee products, interest rate, duration of the grace period and maturity. In addition, the leverage proposed by lenders may differ from each other due to the difference in risk perception among institutions. The main subject of this study is the evaluation of the products provided from different financial institutions that meet the difficulties encountered in financing HEPP projects.

Methodology

This study based on a qualitative research on exploring the underpinnings of difficulties encountered in financing HEPP projects. The articles and proceedings collected for the study were selected from the sample group consisting of 27 studies on renewable energy financing. As a result of the searches with the keywords "hydropower finance", "renewable energy financing" and "renewables finance" in 6 databases those are EBSCO, Emerald, IEEE, JSTOR, Springer and Taylor and Francis, 27 studies were obtained. In the database search made in terms of the actuality of the studies, the time interval was limited to 2010-2019. After determining the sample group, the content analysis method was employed in the study. The research focuses of the 27 studies obtained were determined as financing channels, finance-risk relationship and factors complicating finance. At this point, 16 studies host the factors complicating finance.

- *Stage 1:* 6 academic databases were designated as EBSCO, Emerald, IEEE, JSTOR, Springer and Taylor and Francis. Time interval is defined to 2010-2019 in searches for obtaining up-to-date information.
- *Stage 2:* Database search was performed with the keyword "hydropower finance". Due to the insufficient number of studies, studies found in searches with "renewables finance" and "renewable energy finance" keywords were also included in the sample group.
- *Stage 3:* Of the 27 studies found, 9 were excluded. The content of 16 studies consists of factors complicating HEPP finance.
- *Stage 4:* Content analysis was performed on 16 studies and a total of 12 factors were acquired.

As a result of the content analysis study, 12 factors those complicate finance the HEPP projects, which are a renewable energy type, were identified. Those can be listed as natural conditions, political conditions, equity return rates, technological costs, initial cost, transaction costs, production costs, construction risks, construction period, externalities, market conditions, and financing period (Table 1). Then, these factors were evaluated according to the 5 most frequently mentioned loan criteria in the literature. These criteria are determined as risk coverages, interest rate, grace period, maturity, and leverage.

<u>Natural Conditions:</u> Since natural conditions determine the production values of HEPP projects, it is the most important factor affecting project revenues. Natural conditions include hydrological factors, temperature and wind, evaporation, and global warming. It is possible to accurately estimate the production value of the project with proper and long-term measurements, but the effect of individual events on these values may sometimes cause difficulties in repayment therefore financing structure highly depends on natural conditions (Lam & Law, 2018; Xue & Sun, 2018; Matekanya, 2011). Since unexpected volatility in production can be considered a risk, it is important that the financing package includes risk coverage. In addition, low interest rates also help to compensate this effect.

Table 1. Factors found in literature that complicate HEPP financing.

		natural conditions	political conditions	equity return rates	technological costs	initial cost	transaction costs	production costs	construction risks	construction period	externalities	market conditions	financing period
1	Lam and Law (2018)	✓	✓		✓	✓							
2	Yildiz (2014)			✓	✓		✓						
3	Verma and Jagtap, (2015)							✓	✓				
4	Abolhosseini and Heshmati (2014)				✓			✓			✓		
5	Thierie and De Moor (2018a)		✓									✓	✓
6	Thierie and De Moor (2018b)												✓
7	Prislan et al. (2016)		✓	✓			✓						
8	Kulikova (2016)		✓			✓						✓	
9	Matekanya (2011)	✓			✓				✓			✓	
10	Brunnschweiler (2010)					✓		✓					✓
11	Green and Yatchew (2012)		✓		✓						✓	✓	
12	Garcia et al. (2012)							✓					
13	Antoniou and Strausz, (2016)					✓					✓		
14	Xue and Sun (2018)	✓							✓	✓			
15	Komurcu and Akpinar (2010)		✓			✓				✓			
16	Serencam (2017)					✓		✓					

Political Conditions: The political environment is crucial for investment projects such as HEPP projects. Conditions such as fluidity of macroeconomic indicators, government instability have wide effects on HEPP investments (Kulikova, 2016; Komurcu & Akpinar, 2010; Prislan et al., 2016; Green & Yatchew, 2012). In addition, the cost of borrowing can increase significantly in countries with risky political conditions (Thierie & De Moor, 2018b). Therefore, it is important that financing packages in HEPP projects contain risk coverages and availability of long maturity loans.

Equity Return Rates: Equity return rate sometimes called as return on equity (ROE), is obtained by dividing net income by equity. Compared to other investment projects, equity return rate is low in renewable energy projects (Yildiz, 2014; Prislan et al., 2016) and this may decrease investors' interest in such projects. For equity return rate optimization, the debt / equity ratio should be set well and the debt rate in the project should be increased if possible, this means high leverage. Low interest rates will also increase project revenues, helping increase equity return rate.

Technological Cost: Technological costs become important due to the rapid changes in renewable energy technologies (Matekanya, 2011; Lam & Law, 2018; Green & Yatchew, 2012; Abolhosseini & Heshmati, 2014; Yildiz, 2014). This is partly true since the technology used in HEPP projects is in its mature age. Compared to other renewable energy projects, technological costs are lowest in HEPP projects, but they are higher than conventional energy projects. In order to reduce the impact of technological costs on the project, leverage should be high and long maturity loans should be preferred.

Initial Cost: Until renewable energy projects are implemented, different and costly processes such as permission, expropriation, resettlement and resource assessment operate (Lam and Law, 2018). In addition, since the construction costs are high and the construction period is long for HEPPs, initial cost is quite high, and those projects are considered as capital intensive. Therefore, the existence of grace period will increase the financial strength of the project while the construction works are going on. The high leverage ratio determined to be high enough to cover the construction costs, low interest rates and long maturity term also contribute to the financial strength of the project.

Transaction Cost: In renewable energy projects, the transaction costs are higher than conventional ones (Yildiz, 2014; Prislan et al., 2016). Most of the transaction costs arise from the preliminary transactions in the project. Performing the essential works for the realization of the project causes certain costs and these items are very diverse in HEPP projects. For example, most roles in the project exist on both the owner and the lender side, resulting in double the costs. Also, the increase in the project size causes the transaction cost to increase, in order to compensate this, interest rates should be low.

Production Cost: Renewable energy production costs are higher than conventional energy. The lack of subsidies and excessive construction costs are among the reasons for this situation (Brunnschweiler, 2010; Verma & Jagtap, 2015; Serencam, 2017; Abolhosseini & Heshmati, 2014; Garcia et al., 2012). Also, the fact that the resource is not always available increases the production costs. Although the production cost of HEPPs is the lowest among all renewables, long maturity and low interest loans are required to compensate for this situation.

Construction Risks: The fact that 60-70% of the total cost of HEPP projects is the construction cost is proof that those projects are actually large construction projects. These projects contain many construction risks, such as completion risk, cost over-run, performance related risks (Matekanya, 2011; Xue & Sun, 2018; Verma & Jagtap, 2015). It is very important that there is a risk coverage for construction risks in the financing package of HEPP projects. The existence of a grace period and low interest rates can help mitigate construction risks.

Externalities: It is difficult to price the environmental benefits of HEPPs other than reducing carbon emissions. Examples of these benefits include flood prevention, water and energy security, drinking water and agricultural irrigation. In addition, pricing cannot be made for situations such as expropriation caused by HEPPs, damage to flora and fauna. The fact that externalities cannot be priced prevents the real unit cost of energy (Abolhosseini & Heshmati, 2014; Antoniou & Strausz, 2016). For this reason, it is necessary to conduct studies in which environmental and social risks are analyzed to appropriate standards and the financing package should include risk coverage. In addition, low interest rates help eliminate these effects.

Market Conditions: Market conditions are critical to the financing of all type energy projects. Poorly designed markets cause problems in financing projects (Green & Yatchew, 2012) due to the uncertainty of electricity sales prices. In order for loan repayment to be established, a long-term fixed price is required, and this can only occur in stable markets (Matekanya, 2011; Thierie & De Moor, 2018a, Kulikova, 2016). Risk coverages, high leverage, long maturity and lower interest rate loans mitigate the risk of price uncertainty.

Financing Period: Long construction period and capital-intensive projects like HEPPs need loans those have long maturity (Brunnschweiler, 2010; Thierie & De Moor, 2018a; Thierie & De Moor, 2018b). The due date of the debt should be long enough to finance both the whole construction period and the initial phases of operation period. Given that the construction period may take up to 10 years, especially for large HEPPs, the loans should be medium-term at best, and these loans are more difficult to obtain than short-term. In addition, high leverage eases the effect of this situation.

Findings of the Content Analysis

Factors complicating financing are also mentioned in the literature and these include natural conditions, political conditions, equity return rates, technological costs, initial costs, transaction costs, production costs, construction risks, construction period, externalities, market conditions and financing period. Factors are considered equally important to each other. Accordingly, the criterion, which eliminates a large number of factors that make HEPP financing difficult, was determined as the most important loan criteria for financing.

Five criteria have been gathered from literature to evaluate the negative effects of these factors on financing. The first criterion is determined as interest rates and is the criterion that diminishing the adverse effects of the most factors (Table 2). It is important for negativities such as natural conditions, equity return rate, initial cost, transaction cost, production cost, construction risks, externalities and market conditions. The second criterion is maturity which covers political conditions, technological costs, initial cost, production cost, construction period, market conditions and financing period. The third criterion is leverage, which is very important for renewable energy projects. It helps mitigate the effects of negative conditions such as natural conditions, equity return rates, technological costs, initial cost, market conditions and financing period. The fourth criterion is risk coverages those help reducing the effects of uncertain conditions such as natural conditions, political conditions, construction risks, externalities and market conditions.

The last factor in order of importance is the grace period, only the initial cost includes construction risks and construction period.

Table 2. Factors complicating HEPP financing and related criteria.

Factors	**Risk Coverages**	**Interest Rate**	**Grace Period**	**Maturity**	**Leverage**
Natural Conditions	✓	✓			✓
Political Conditions	✓			✓	
Equity Return Rates		✓			✓
Technological Costs				✓	✓
Initial Cost		✓	✓	✓	✓
Transaction Costs		✓			
Production Costs		✓		✓	
Construction Risks	✓	✓	✓		
Construction Period			✓	✓	
Externalities	✓	✓			
Market Conditions	✓	✓		✓	✓
Financing Period				✓	✓
importance	***4th***	***1st***	***5th***	***2nd***	***3rd***

According to the result of the research, low interest rates should be sought primarily in the loans to be received for HEPP projects. Low interest loans can overcome the highest number of difficulties in HEPP projects. Secondly, long-term loans must be included in the HEPP financing package. Given the construction period of the HEPPs, the loan should be medium term at worst. Providing high leverage financing packages is important for both reducing investor risks and eliminating negative conditions. The presence of risk coverages is also important for reducing the effects of uncertainty situations and ranks fourth among the five criteria examined. The least important criterion for HEPP loans is determined as grace period and affects only three factors. All in all, the indispensable features for HEPP projects loans are determined as low interest rates and long maturity.

Concluding Remarks

Privatization and liberalization in the electricity market has been the driving force for changing the financing method of HEPP projects. At this point, it is important to match the characteristics of HEPP projects and loans. Factors complicating HEPP finance were identified from the sample group consisting of studies published on renewable energy financing between 2010-2019. In the content analysis, 12 factors were determined as natural conditions, political conditions, equity return rates, technological costs, initial cost, transaction costs, production costs, construction risks, construction period, externalities, market conditions, and financing period. Then, these factors were evaluated by associating with 5 loan criteria, these are risk coverages, interest rate, grace period, maturity and leverage. During evaluation, the importance weights of the factors relative to each other were considered equal. As a result, the two most important features for HEPP loans were determined as low interest rate and long maturity. Debt price is determined by two components, namely interest rate fixed and floating which is the first variable of debt structuring. Since the fixed component is already constant, the floating component is in the decisive position. In this case, since floating component determines cost of funds, it affects the feasibility of the project significantly (Thierie & De Moor, 2018a). Another variable in debt structuring is maturity of the loan. Loan maturity can be classified into 3 categories, those are short-term, medium-term and long-term. Although short-term maturity loans enable raise debt financing from the market more quickly, increase the risk of project default. In contrast, long-term maturity loans reduce the project's exposure to refinancing risk, thereby reducing the default risk (Thierie & De Moor, 2018b). While the high leverage was important in the 3rd rank, the risk coverage in the financing package was found to be important in the 4th rank. The least important feature in HEPP loans was the existence of grace period. Therefore, the first thing to do in financing HEPP projects is the provision of low interest rates and long-maturity loans. With this study, it is aimed to determine the features of the ideal loans for HEPP financing. At this point, this study contributes to the limited literature on HEPP financing and the improvement of the financing process by analyzing loan criteria from a different perspective.

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Blockchain based Concept Model for Construction Quality Management

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Abstract

Poor quality in construction could lead to the cash flow disruption, project delays, profit loss in projects due to rework, and some time to the property damage or human loss due to accidents. In order to ensure the quality of work, quality control (QC) departments inspect the construction work compliance with best practices, defined procedures, and specifications. These inspections rely on manual procedures, post-construction evaluation, document-based, and are carried out through a supervisory manner approach from top-down. However, this top-down control-oriented approach does not provide enough motivation for quality control managers, operators, and workers to voluntarily follow quality procedures and specifications. Besides, document-based quality specification compliance assessments have limitations that are difficult to determine whether the required specifications have actually been implemented and are not reliable to measure their real performance as well. In this regard, this study proposes a conceptual framework for Blockchain-based quality management at construction sites, which could ensure security and reliability of information generated through while implementing quality-related specification and procedures by managers and workers using Distributed Ledger Technologies (DLT) and also to encourage them by establishing a compensation structure through performance assessment for activities of each task. The Block chained quality management approach would greatly help shift the traditional top-down and passive quality control process to bottom-up and voluntary manner. It might open a new innovative value-chain structure in the construction quality domain which provides securing reliability of activities required for quality assurance procedures and specification implementation.

Keywords: *blockchain, construction quality, defect management, distributed ledger technologies (dlt).*

Introduction

Rework of poor-quality construction work is regarded as a non-value adding activity that is utterly affecting the productivity and performance in construction projects that spend inessential enormous costs, materials, time, and manpower (Alwi et al., 2002). Many researches have extensively focused on construction defect management to enhance the poor quality in construction. Previous studies revealed that 5% to 15% of costs in construction projects are caused due to poor-quality work (Netscher, n.d.). The rework does not only costs but might charge additional expenses due to delay in the project, and sometimes consume those resources which are allocated to other parts of the project. Poor quality does not only affect costs but also severe accidents. In the case of Korea, accidents due to poor quality of construction work have been reported in many projects such as the collapse of Pyenogtaek international bridge and the fall of the exterior wall of the National University Museum, both of which cause many deaths. Also, the number of dispute related to defects in apartment buildings are increased from 69 cases in 2010 to 3,880 cases in 2016.

Generally, in construction, to make sure the quality of work and prevent defects, the manager inspects the completed work, identify the defects if any, and records them with information of drawings and locations or in the form of documents such as checklist and punchlist. After identifying defects in the field, they discuss the quality of work with the subcontractors and instruct them for actions such as repair or rework. This cycle of rework and quality inspection continue until to gain the defined level of quality conformance advised by the agreed quality specification document between stockholders. On the contrary, documentary evidence of events, activities, and tasks carried out to ensure the quality of work are often prepared for the purpose of responding to quality inspections by the management, and it is difficult to determine the authenticity of the actual acts and events being done to make sure the quality of work. Previous studies revealed that the capacity of government agencies responsible to ensure the quality of construction work is limited to 400,000 sites per year in Korea, which is unable to cover the total projects. Moreover, the data shows that 67% of projects had experience in missing inspection work due to excessive workload or shortage of personnel, even if professional quality control personnel are deployed to inspect the sites. It is practically impossible to inspect all work steps for the required quality conformance events at each site, thus, there is high probability to have post- work inspection in a supervisory manner (top-down approach).

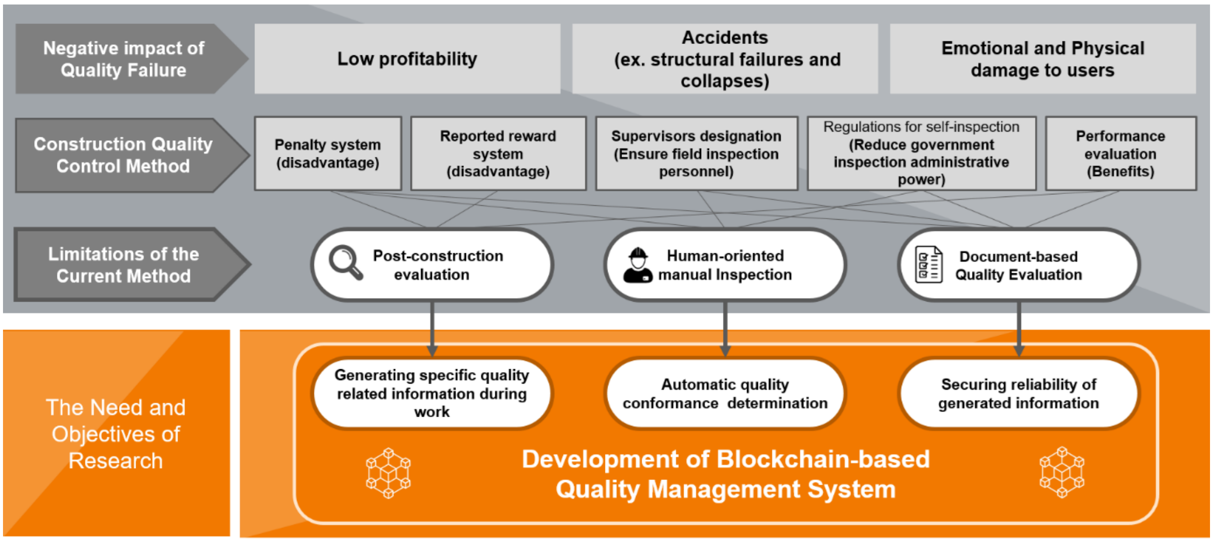

Figure 1: Limitation in Current Quality Management System and research objectives.

Even though various quality management systems are currently in practice to ensure the quality of construction work. However, there are several inherent limitations in the current practice such as physical inspection of work, manually observing and recording the quality-related events and activities, data loss during communication between the office and field, reactive approach for rework. The top-down approach, in which the quality inspector/auditor enforce the standards and specification to achieve certain quality conformance level using supervisory manner is another significant limitation of the current practice. To address this, the following systemic approaches are required. 1) The construction information related to quality conformance of work can be produced at the worker level performing the actual work. 2) The quality-related information generated during the course of work is automatically determined by the system, not by inspector. 3) The reliability of the generated information can be secured at the same time. Therefore, this study aims to propose an innovative quality management system model that utilizes blockchain technology, which has a lot of interest in the construction field.

Issues in current quality management systems

One of the critical components in a successful construction project management is quality management (Abdul-Rahman, 1997). In construction, the occurrence of quality non-conformance is comparatively high and can negatively affect the firm's profit and its competitiveness (Abdul-Rahman et al., 1996). Poor quality is the consequence of non-conformance to the quality standards and specifications during construction work, which results in additional time and cost to all in a project (Olawale and Sun, 2010). In order to sort out the issue, this area is being extensively studied by many researchers. However, the problem of data loss, reactive approach, and substantial workload still exist. For instance, the process of manual observation and recording the non-conformance or defect information at the site and re-putting to the computer in the office for discussion is cumbersome and could be less accurate due high chance of data errors, omission and miswrite (Park et al., 2013). Quality conformance inspection consumes a major portion of construction manger's work efforts, which is accounted for around 38 percent of their total work (Lee et al., 2012). To reduce the workload of the construction managers in checking quality conformance, radio frequency (RF) technology (Wang, 2008), personal digital assistant (PDA) (Kim et al., 2008) and laser scanner (Yu et al., 2007) have been developed. However, these systems work with reactive approaches after non-conformance already been happened, and it is vital to control and apply all the required events and activities for quality conformance during the construction process so that to ensure the specified quality before the defect occurs.

Over the last decade, many researchers have devoted vital attention to enhance the quality management system in construction. Several concepts and their enabling technologies such as building information modeling (BIM) and augmented reality (AR) have been investigated for proactive and automatic quality inspection during the construction work. The augmented virtuality (AV) based tele-inspection system for non-conformance detection has been developed by Wang and Chen (2008). Similarly, Dong et al proposed a mobile-based telematic digital workbench system for construction quality management that integrates the location of visual information on the job site with the 3D model (Dong et al., 2009). However, a categoric, transparent, and reliable approach is inevitable to solve the before mentioned issues in the current quality management system.

Blockchain technology applications in construction

Blockchain technology also known as distributed ledger technology (DLT) is considered to be capable of transforming many global industries, and the construction has no exception. Blockchain was introduced in 2008 as an underpinning technology for the verification tool of world's first cryptocurrency (bitcoin) transactions (Vujičić et al., 2018). The significant features of block chain technology are: (i) immutability (once blocks are chained then cannot be modified); (ii) a peer-to-peer network made up nodes (computers) for decentralized operation; (iii) reliability (all nodes have a same copy of the same blockchain in all nodes which is verified through an algorithm for any anomalies; (iv) authentication (a Proof-of-Work mechanism validate transactions in the Blockchain) (Li et al., 2019). Previous research already been carried out to explore blockchain technology for multiple domains can be classified in seven use-categories: (1) smart homes (2) smart cities and the sharing economy; (3) smart government; (4) smart energy; (5) intelligent transport; (6) business models and organisational Structures; (7) BIM and construction management. The scope of the derived literature in this paper is limited to the previous efforts related to the buildings, energy and construction.

Currently, many researchers are focusing on the applications of Blockchain technology in various construction industry areas such as energy transactions using distributed fields, Integration of IoT technologies with blockchain, BIM and blockchain-based approaches, and resolution of delayed payment to subcontractors' problems through a smart contract. Castellanos investigated the energy transactions generated from wind or solar sources using distributed ledger technology (DLT) (Castellanos et al., 2017). To measure the inside temperature in the building using IoT based smart home devices, a hybrid approach of BIM and blockchain technology is applied for energy management and saving (Dorri et al., 2017). Wang proposed a smart contract-based blockchain method to solve the problem of wage payment to the construction worker (Wang et al., 2017). Previous efforts regarding the blockchain in the construction domain revealed that most of the research was focused on smart contracts to enhance the transactions of payments. However, some web articles have focussed on the conceptual adoption of blockchain in safety compliance and quality conformance in construction.

Blockchain-based quality management system framework

This study intends to develop an innovative system framework that utilizes blockchain technology for effective construction quality management. The main functions and utilization effects of this system includes three main attributes: (1) Implementing text mining, computer vision, internet of things (IoT), and augmented reality (AR) technology to determine the appropriate information generated by quality conformance activities, (2) Leveraging Distributed Ledger Technologies (DLT) in blockchain to ensure security and reliability of information generated during the specific quality-related events, tasks, and activities (3) Based on the report of on-site quality conformance activities being done by worker level, granting the contractor/partner quality conformance level assessment.

The proposed framework enables the categoric generation of construction information related to the quality of work at the bottom worker level that performs the actual work. However, the system instead of the person automatically determines the generated information and controls the reliability of the generated information.The quality management-related stakeholders in a construction project can be grouped into four classes. Quality conformance events and activity information produced during the construction work is mainly generated by contractors and suppliers, and the generated information is stored in the quality management events and activities database (DB). The verification of the quality conformance of the stored information is evaluate d in rules-based or algorithm-based systems.

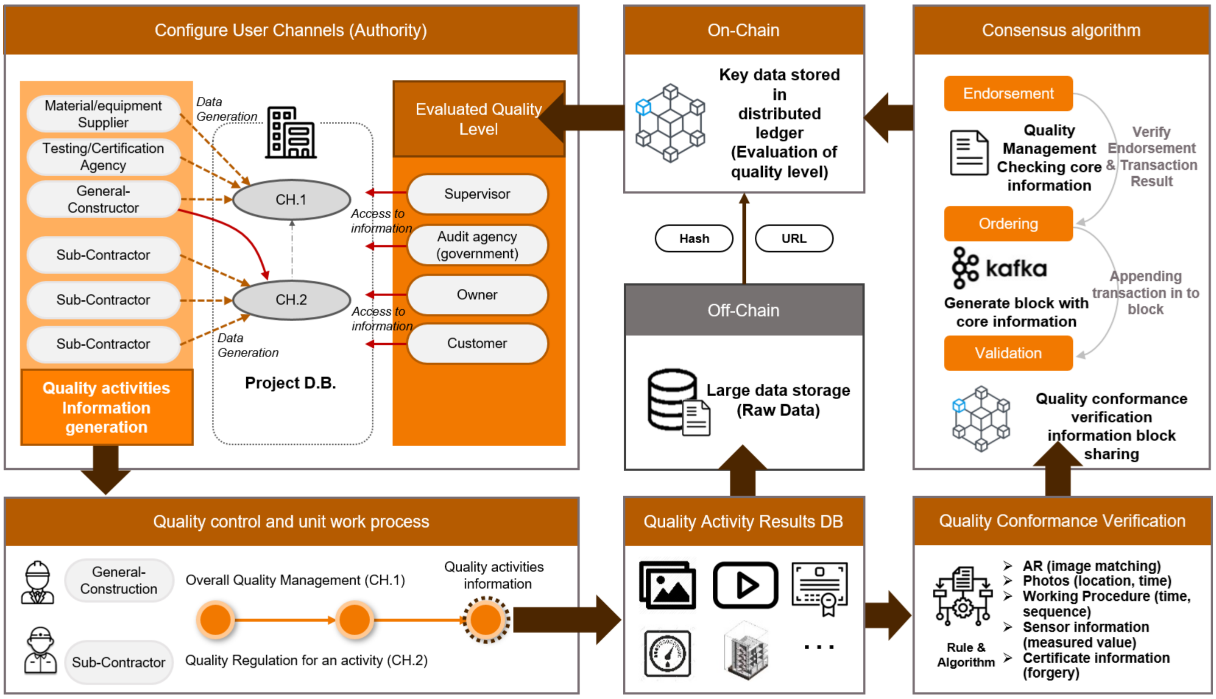

Figure 2: Process of proposed Blockchain-based quality management model.

To allow access of relevant participants to the project's information, the proposed system framework would adopt licensed blockchain protocols to only allow authorized participants to the network. In the process of creating quality conformance events and activities information, checking and verifying the ledger, Hyperledger consensus algorithm can be used to check the author or viewer's authority to ensure the reliability of stored data and prevent unauthorized users from accessing the ledger. Unlike, other specific platforms to a particular business models, Hyperledger can be universally adopted in several fields of industries. The Hyperledger is an open source community of Linux foundation project focused on developing tools and libraries for blockchain deployments. These tools and libraries are open source and can be written or modified based on requirements using common programming languages such as Java, Golang, Node.js, and could be further integrated with construction industry tools for BIM such as Revit, dynamo, grasshopper, as well as to other technologies such as IOT, image recognition, and text-mapping. The configurable module structure allows users to easily select and replace the functions they want to fit the business model of the desired company.

In order to reduce data overload in a Blockchain network, the raw data in large amount with more size such as images, BIM files, sensor data, etc. could be stored in a separate database outside the blockchain, however, the generated hash and URL against each transactions would be recorded in a distributed ledger. Through channel separation and MSP (Membership Service Provider) function in Hyperledger, general contractor can access the ledger of subcontractor’s CH.2, but subcontrator cannot be accessed by general contractor’s CH.1. In addition, the audit agency, and supervisor can grant the participation access to CH.1 and CH.2 for reviewing the quality conformance level of construction companies recorded on the blockchain.

Implementation Scenarios

In order to ensure quality of work, the quality conformance events and activities needs to be checked for each work step, and the generated information during each step is automatically checked by the system, not the person, for compliance with quality-related regulations and procedures. To further elaborate the idea of the study, four case scenarios are selected and detailed as under.

Missing struts when install shoring system: For instance, inspecting the struts when installing the shoring or shielding system in an excavated site, the manger takes images of each job-step during work progress. The augment reality (AR) based image matching techniques check the installation status and accuracy of the struts, any discrepancies could be recorded and sent tot the database. The blockchain system could generate a hash for each generated record and will save on the server.

Checking waterproofing work procedures: In waterproofing work, there are various layers of different materials to be painted and finished on the surface with specific time intervals. The manger captures the images after finishing the primary layer and before starting the second layer, the rule-based engine analyzes the images with corresponding time reference and record the hash against each transaction in the blockchain.

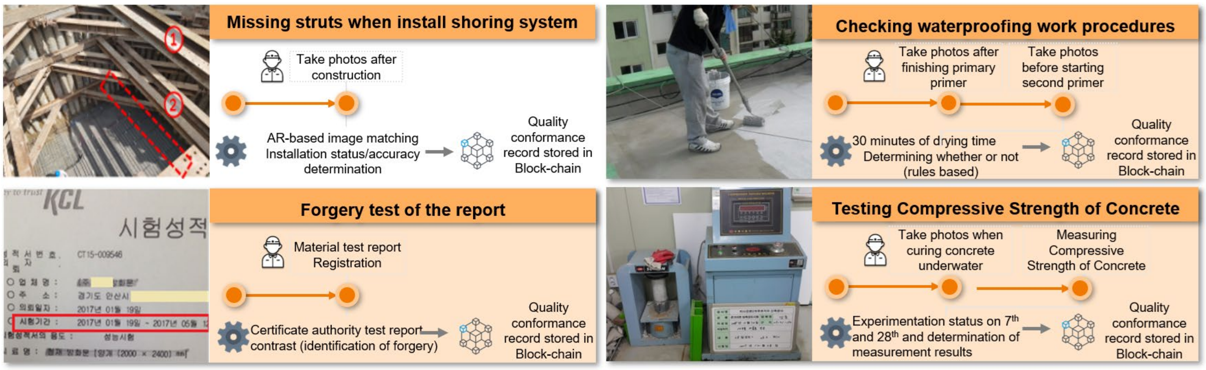

Figure 3: Implementation scenarios for the proposed Quality Management Model.

Testing Compressive Strength of Concrete: Calculating compressive strength of concrete is very critical in construction of structural works. Initially, the quality inspector in the lab take image of concrete molds during curing under water. Then the inspector captures the compressive strength results after 3, 7 and 28 days by doing experiment on universal testing machine (UTM). The system can then generate the hash against both the images and will be saved in the block chain, other data such as images or documents will be stored in the external database.

Material test report Registration: Similarly, equipment or machinery fitness and material quality is also significant to ensure quality of work. In order to have reliable quality and fitness to use information, the document certificate made against each particular inspection for the concerned equipment or materials could be uploaded to the blockchain system. The images of the documents can be converted to the text using optical character recognition technology (OCR) or text mining, then the required relevant important information such as date, time, location and fitness etc. can be extracted, and their corresponding hash along with URL could be stored in the blockchain.

Discussion on Expected Results

The core intention of the study is to develop a framework for a system that automatically evaluate and examine the quality conformance events and activities grading level based on the information generated during the process of performing quality control events, activities and tasks by the manager or workers. The system based on the proposed framework is expected to be beneficial and alternate for Inspection agencies and prospective users or occupants (considering apartments case), as it provides reliable, transparent, and verified information required for quality conformance, without even physically visiting the site.

The rules for quality conformance can be defined from quality management regulations and quality inspection cases. The integration of advance technologies with blockchain such as image recognition, image matching and IoT based sensors could determine the accurate and secure information pertaining to quality conformance. In addition, the determined quality-related information and verification data can be recorded on the blockchain to gain security and reliability, and using channel-specific access rights, users can be provided with reliable quality management activity information at any time.

Additionally, this study proposed a quality management process innovation for shifting the traditional quality management process from top-down approach to bottom-Up approach that can efficiently measure the quality conformance level during the actual work (proactively) before the failure occurs, rather than detecting the defect after the completion of entire work, which is reactive approach.

Conclusion

To ensure the quality of work in construction, the quality control (QC) departments inspect the work compliance with best practices, defined procedures, and specifications. These inspections rely on post-construction evaluation, document-based, and are carried out through a supervisory manner approach from top-down. Apart from that, the traditional quality management system is unable to acquire the job step events/activities information pertaining to the standard and best practices required to produce a qualitative work. To address this issue, this research proposed a conceptual framework for Blockchain-based construction quality management system. This proposed framework utilizes Hyperledger fabric protocols to store key information of quality related events and activities using blockchain technology. It also proposed the application of various technologies, including image recognition, image matching, text mining, and IOT sensors, to verify the suitability of safety activities.It is expected that the Block chained quality management approach will contribute to shift the traditional top-down to passive quality control process to bottom-up and voluntary manner. It might open a new innovative value-chain structure in the construction quality domain which provides securing reliability of activities required for quality assurance procedures and specification implementation.

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Determining Sources of Academic Stress Among Architecture Students

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Abstract

Architectural education brings highly stressful learning environment. By taking into consideration of fluctuating physical and academic backgrounds and resources of universities in Turkey, increased number of architecture departments and architecture students, it is important research subject that determining academic stressors of architecture students. The main purpose of this research is to determine the academic stressors of architecture students. In addition, identifying how the differentiations at university type affect the perception of stressors is another focus of this study. By interviews and literature review 32 academic stressors were determined and with these stressors' questionnaire was designed. Questionnaire applied to 468 architecture students who are educated at two different universities that one is state other is private university. A total of 459 completed questionnaires were returned, representing a response rate of 98.07 percent. Exploratory factor analyze was used to determine most important academic stressors of architecture students. In addition, to reach other aim of study independent sample t-test was used. When the findings of this research analyzed, it is determined that there are seven academic stressors that affect architecture students, and it is found that the differentiation at university type affect the perception of academic stressors.

Keywords: *academic stress, architecture students, architecture education.*

Introduction

Architecture is a multidisciplinary, multi-skilled, multidimensional, and multimedia practice. Architects need to know about many crafts, technologies, and theories and to have the ability to communicate with specialists in many fields. This is also true during the education process for the discipline. Architectural education is not simply vocational education achieved by training. The educational process is not just about teaching how to solve problems but about finding what the problems actually are. In this respect, architectural education has its own specifications, and it is distinct from both the practice of architecture and the education of other disciplines. There are two main classification of architectural courses in the curriculum;

lecture courses that communicate history, technology and legal issues and design studios which ennoble creative exploration and organization of complex problems. The duality between design studios and lectures produce significant workload. Corresponding aforementioned duality, architectural education encompasses highly stressful learning environments. Architecture students state noteworthy stress symptoms during their education. In addition, they are more anxious than the other students who are training at other departments.

The main aim of this study is to identify the main causes of academic stressors experienced by architecture students in Turkey at two different types of universities namely state and private. Moreover, it is also aimed to determine the impact of university type on students' perception of academic stressors.

Architectural Education and Stress

Architecture is a discipline that draws knowledge from the humanities, social and physical sciences, technology, environmental sciences, the creative arts, and liberal arts. Correspondingly, architects need to know about many crafts, technologies and theories and have ability to communicate with stakeholders in various fields. Architecture education should involve the acquisition of design, knowledge (about cultural and artistic, social, environmental, technical, design, professional studies) and skill capabilities (UIA, 2011). In this education environment, several accomplishments are expected from architecture students. This situation puts more stress on students unlike peers at other departments.

Stress often mentioned as "negative emotions" contributing to growing lack of student academic success in university (Ahmed & Julius, 2015; Elias et. al., 2011; Majumdar, 2010; Reifman et al., 2001; Ross et al., 1999). These negative emotions are caused by the existence of sources of stress, or "stressors" in students' lives (Ahmed & Julius, 2015; Reifman et al., 2001; Ross et al., 1999). Several types of stressors exist for university students such as financial obligations, home life, schoolwork, relationships etc. (Elias et. al., 2011; Majumdar, 2010; Reifman et al., 2001; Ross et al., 1999). These stressors incite negative emotions such as stress, depression, anxiety on students causing negative impacts on their academic work.

When the subject has been analyzed from the viewpoint of architecture students, they express a low level of satisfaction with their education experience. Cuff (1991) argues that graduates become frustrated when they first enter architectural practice because of the uncertainty this step entails. Architecture students complain of exhaustion, isolation and stress. Bachman and Bachman's (2006) analysis of students' workload identified that extreme deprivation of sleep, poor diet, reduction of exercise and uncommon family and social activity are all common characteristics of the life of architecture students. The design process also found causing range of anxieties that lead directly to students' feelings of dissatisfaction and depression (Bachman and Bachman 2006). The most remarkable source of stress is juries and exams for many architecture students. Juries and examinations may cause variety of symptoms such as changes in eating and sleeping patterns, nausea and stomach pain in some students due to stress related with exams (Gadzella & Baloglu, 2001).

The leading stressor experienced by undergraduate students are related to academic one (Ahmed & Julius, 2015; Elias et. al., 2011; Majumdar, 2010; Reifman et al., 2001; Ross et al., 1999), thus research aimed to determine academic stressors of architecture students.

Methodology

To reach the research aims, data were obtained from architecture undergraduates at first, second, third and fourth-year architecture students during 2018-2019 academic year and spring semester from two different types of universities of architecture departments in Turkey.

Questionnaire was used as an instrument to collect data. Questionnaire forms were constituted by researchers with literature surveying and interviewing architecture students. Survey form comprised of two sections. First part was designed to obtain data about students' academic stressor items. A review of the extensive literature was done to identify the some of the stressors. Additionally, researchers interviewed 32 students face to face and the question "what is the most important five academic stressors that cause stress for you during your education?" was asked to them. Their responses were categorized according to the type of responses. Finally, 32 academic stressors influencing the architecture students' stress are identified in Table 1. Second section focused on obtaining information about respondents' personal and social-demographical information. Five questions were included in this section as gender, age, type of university, year of education, and grade point average (GPA).

The questionnaire was administrated to all students enrolled in architecture programs in two universities simultaneously. Study participation was voluntary basis. Questionnaires were applied to 468 architecture students and 459 completed questionnaires were returned, representing a response rate of 98.07 percent. Participants were at 18-29 years old and included both males and females. Type of university representations consisted of 262 (57.1%) students educated in private university, 197 (42.9%) students in state university.

The academic stressors of architecture students were investigated by using exploratory factor analyze. In addition, the relationship among academic stressors were determined by correlation analysis. The impact university type was additionally analyzed with t-test. All statistical analysis was evaluated by using SPSS 22.0 for Windows' software program.

Findings

According to several social scientists (Nunnally & Bernstein, 2007), reliability should be measured to identify the internal consistency between questions while using the Likert scale in a questionnaire. To ensure internal consistency reliability analyses were conducted on thirty-two academic stressor items. As a result of reliability analyze, one of the items corrected total correlation value was under 0.3. Therefore, this item was subtracted from the questionnaire and reliability analyze was repeated. Finally, the Cronbach's alpha coefficient was calculated 0.905 that shows range of internal consistency for a study (Cronbach, 1951).

The Perception Difference of Academic Stressor Items According to University Type

To determine the differentiation on perception of academic sources of stressors between architecture students who are educated at different type of architectural school independent sample t-test was conducted (Table 1). According to analysis results, there are statistically significant mean difference at twelve items. Examination/jury anxiety, difficult course contents, unrealistic expectations of lecturers, unrealistic expectations of parents, excessive course overload, excessive teamwork, thought of letting lecturers down when I get poor marks, feeling anxiety when I cannot reach my academic goals, dissatisfying examination grades cause more stress on architecture students who are educated at private university than the others. Whereas limitation to access course materials and inadequate numbers of academic staff causes more stress on state university's architecture students (Table 1).

Table 1. The relationship between university type and academic source of stress items.

	Coded as	**Items**	**Type of University**		**Sig. (p)**
			Private	**State**	
			$\bar{X}$	$\bar{X}$	
SOURCES OF ACADEMIC STRESS	C1	Lack of time for social activities and own interests.	3.40	3.33	0.58
	C2	Overload of architectural design studio studies.	3.27	3.14	0.26
	C3	The increased hours of architectural design studio course at architectural education syllabus.	3.47	3.31	0.17
	C4	Studying long hours for architectural design studio except school hours.	3.60	3.50	0.41
	C5	Examination/jury anxiety	3.99	3.70	**0.01***
	C6	Meeting deadlines for assignments and architectural projects.	3.74	3.71	0.77
	C7	Grade rating system at architectural design studios.	3.46	3.46	0.94
	C8	Difficult course contents	3.30	2.99	**0.00***
	C9	Inappropriate assessment and evaluation techniques for grading courses.	2.94	3.01	0.58
	C10	Insufficient education/teaching techniques.	3.01	3.22	0.08
	C11	Lack of time for studying courses because of overload academic curriculum.	2.79	2.98	0.08
	C12	I cannot ask for help from lecturers about what I do not understand at office hours	2.97	2.73	0.06
	C13	Limitation to access course materials.	2.38	2.62	**0.04***
	C14	Inadequate numbers of academic staff.	2.57	3.45	**0.00***
	C15	Excessive amount of material and subject to study.	2.87	2.91	0.70
	C17	Oral presentations for courses.	2.42	2.44	0.82
	C18	Unrealistic expectations of lecturers.	2.55	2.27	**0.01***
	C19	The unrealistic expectations of my parents.	3.25	2.74	**0.00***
	C20	Excessive course overload	3.42	3.34	**0.00***
	C21	The size of the curriculum (workload) is excessive	3.08	3.25	0.51
	C22	Excessive assignment and homework.	3.53	3.49	0.16
	C23	Difficult examination questions	3.13	3.04	0.74
	C24	Examination time is short to complete the answers	2.77	2.74	0.38
	C25	Excessive in-class assignments.	3.01	2.62	0.74
	C26	Excessive teamwork	2.85	2.50	**0.00***
	C27	Thought of letting lecturers down when I get poor marks.	2.61	2.06	**0.00***
	C28	Thought of course grades affect my future and whole life	2.85	2.51	**0.00***
	C29	Feeling anxiety when I cannot reach my academic goals.	3.27	2.85	**0.00***
	C30	Dissatisfying examination grades	3.34	3.07	**0.01***
	C31	Lack of concentration on course subject	2.80	2.91	0.33
	C32	My academic success is not enough to catch my occupational dreams	2.97	2.84	0.25

Academic Stress Factors of Architecture Students

As part of main aim of this research to determine the factor structure is important. To identify the main categories of academic stressors, exploratory factor analyze was conducted on the responses to thirty-one items with varimax rotation (eigenvalue=1 cut-off). Items with factor loading greater than 0.4 were accepted as principle stressors (Nunnally and Bernstein 2007). Due to factor loadings of all items greater than 0.4, none of the items were extracted from the questionnaire. Coefficient alpha reliabilities, factors and factor loadings were summarized at Table 2.

Table 2. Exploratory factor analysis of academic stressors.

Factors	Coded as	Factor loadings	% of variance	Cronbach Alpha
Factor 1 (DCAE)	C2	0.753	11.81	0.797
	C4	0.732		
	C3	0.731		
	C1	0.646		
Factor 2 (IASUA)	C10	0.777	9.75	0.743
	C14	0.690		
	C9	0.656		
	C12	0.584		
	C13	0.574		
Factor 3 (AROD)	C30	0.718	8.50	0.777
	C32	0.692		
	C29	0.673		
	C31	0.590		
	C28	0.510		
Factor 4 (ECC)	C25	0.768	8.27	0.753
	C26	0.646		
	C24	0.594		
	C23	0.591		
	C8	0.409		
Factor 5 (IAS)	C21	0.743	8.02	0.798
	C11	0.638		
	C15	0.609		
	C20	0.547		
	C22	0.494		
Factor 6 (FD)	C19	0.652	7.72	0.663
	C18	0.618		
	C27	0.525		
Factor 7 (ASTP)	C5	0.665	6.75	0.685
	C6	0.587		
	C17	0.566		
	C7	0.460		
Total Explained Variance			**60.87**	
Kaiser-Meyer-Olkin (KMO) Value			**0.90**	
Barlett's Test of Sphericity	**Approx. Chi-Square**		**5098.39**	
	df:		**465**	
	p:		**0.00**	

KMO values and Barlett tests of sphericity were indicating that the data set is suitable for factor analysis (Pallant, 2005). Principal component analysis and varimax rotation were used as methods of factor extraction and rotation, respectively. The results indicated seven-factor solution, which accounted and explained 60.87% of total variance. Each factor was interpreted and labelled and coded based on the stressors that made up the group as follows:

- Factor 1: Different Characteristics of Architectural Education (DCAE)
- Factor 2: Inadequate Academic Staff and Unusual Assessment and Evaluation Techniques of Courses (IASUA)
- Factor 3: Anxiety about cannot Reach their Occupational Dreams (AROD)
- Factor 4: Examinations and Course Challenges (ECC)
- Factor 5: Intensive Academic Schedule (IAS)
- Factor 6: Fear of Disappointments (FD)
- Factor 7: Academic Success and Time Pressure (ASTP)

Inter-Relationship Among Academic Stress Factors

Using correlation analysis academic stressor interrelationships were analyzed. The inter-correlations within the seven stressors are given at Table 3. There are remarkable positive correlations (significant at $p \leq 0.01$) between

- ECC and DCAE (0.426),
- IAS and DCAE (0.552),
- ASTP and DCAE (0.505),
- ECC and IASUA (0.403),
- IAS and IASUA (0.414),
- ECC and AROD (0.456),
- IAS and AROD (0.407),
- FD and AROD (0.665),
- ASTP and AROD (0.441),
- IAS and ECC (0.579),
- FD and ECC (0.457),
- ASTP and ECC (0.459),
- ASTP and IAS (0.482).

Table 3. Correlation amongst academic stressors.

	DCAE	IASUA	AROD	ECC	IAS	FD	ASTP
DCAE	1						
IASUA	0.289**	1					
AROD	0.299**	0.293**	1				
ECC	0.426**	0.403**	0.456**	1			
IAS	0.552**	0.414**	0.407**	0.579**	1		
FD	0.253**	0.221**	0.665**	0.457**	0.396**	1	
ASTP	0.505**	0.362**	0.441**	0.459**	0.482**	0.318**	1

**. Correlation is significant at the 0.01 level (2-tailed).

Results

In this research academic stressors of architecture students and the correlation among these academic stressors are determined. In addition, the relationship between university type and sources of academic stressors are identified. The results of the research are below:

- There are twelve significant relationships between sources of academic stressors and university type. Two of these sources cause more stress on students who are educated at state university. When the context of two items are analyzed, it is remarkable that both of the items related with Factor 2 “Inadequate Academic Staff and Unusual Assessment and Evaluation Techniques of Courses”.
- Other ten items cause more stress on architecture students who are educated at private architectural schools. Three of items belong to Factor 3 “Anxiety about cannot Reach their Occupational Dreams”; two items take score under Factor 4 “Examinations and Course Challenges”; three sources of academic stress related with Factor 6 “Fear of Disappointments; and item belongs to Factor 5 “Intensive Academic Schedule” and one item related with Factor 7 “Academic Success and Time Pressure”.
- There are seven key academic stressors that cause stress on architecture students.

  - Factor 1: Different Characteristics of Architectural Education
  - Factor 2: Inadequate Academic Staff and Unusual Assessment and Evaluation Techniques of Courses
  - Factor 3: Anxiety about cannot Reach their Occupational Dreams
  - Factor 4: Examinations and Course Challenges
  - Factor 5: Intensive Academic Schedule
  - Factor 6: Fear of Disappointments
  - Factor 7: Academic Success and Time Pressure

are determined significant academic stressors of architecture students. The professional degree plan in architecture is filled with diverse and challenging topics including history, technology, human factors, theory, urban planning, issues of professional practice, and design. Situated at the curriculum’s epicenter is the focal experience of design study, which is typically taken every semester for four or five credits. Architecture students foresee to specialize and overcome architecture at design studios and that the studio curriculum anticipate the learning and assimilating main topic of architecture subjects.

It can be concluded from these findings that there is a significant difference about the perception of sources of academic stressors between the students at private and state architectural schools. In addition, seven key academic stressors may cause burnout, then students may receive treatment for mental health issues, and they decide to leave his/her school. At this point, it is important to decrease the stress level of architecture students. Therefore, having knowledge about the sources of stress and stressors of architecture students’ may provide to take some precautions to minimize their effects. In addition, these efforts contribute to maximize the productivity of learning.

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The Moderating Effect of Team Absorptive Capacity Between Complexity and Quality Performance in Construction Projects

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Abstract

Due to the unique nature of construction projects, complexity has been found to be an inherent characteristic of such projects. Despite this fact, previous studies found a negative effect of complexity on project management performance. Absorptive capacity of the project team has been found to moderate the effect of complexity on time and cost performance. However, project management performance is measured based on time cost and quality. This study adds to the existing literature by assessing the moderating effect of absorptive capacity between complexity and quality performance. A quantitative research approach, through the use of a structured questionnaire was adopted. Perceptual data was elicited from project team members as respondents to the study. A total of 140 questionnaires were distributed amongst the study population using purposive sampling technique. Data was analyzed using both descriptive and inferential statistical methods. Structural equation modelling (SEM) was used to assess the moderating effect of absorptive capacity between complexity and quality performance. The study findings show despite that project complexity has a significant and direct effect on the variance of project management quality performance, the ability of the project management team to acquire, assimilate and transform knowledge and information to be exploited for project use significantly improves project management performance. It is recommended that the absorptive capacity of the project team should be one of the core considerations when setting up a project management team.

Keywords: *absorptive capacity, complexity, construction projects, quality performance.*

Introduction

Project complexity can be understood as the number and heterogeneity of different elements that interrelate (Burke & Morley, 2016). According to Hobday et al. (2000), projects are usually established with the explicit aim of solving complex tasks. As such, complexity is seen as an inherent characteristic of projects with interdisciplinary teams, ambiguous goals, diverse methods and the uncertainty of unique and novel mandates (Geraldi, 2009). Despite the fact that complexity is an inherent and defining feature of projects, studies agree that project complexity has a negative effect on project management performance as complexity is generally assumed to decrease project management performance (Biedenbach & Müller, 2012; Bjorvatn & Wald, 2018).

Over the years, various constructs have been used to moderate the negative effects of complexity on construction project management performance, mostly adopted from other industries such as manufacturing. The concept of absorptive capacity was coined by Cohen and Levinthal (1990) in the business and organizational management literature which presupposes smooth knowledge exchange between individuals. Despite the popularity of absorptive capacity in the wider business literature, the project management literature has applied it only sparingly as noted by Killen et al. (2012) although an established stream of literature views projects as temporary organizations (Fortwengel et al., 2017). Zahra and George (2002) defined the construct as a set of organizational routines and processes by which organizations acquire, assimilate, transform, and exploit knowledge to produce a dynamic organizational capability. Absorptive capacity is path-dependent and develop cumulatively, facilitated by communication between individuals and subunits (Cohen & Levinthal, 1990). Absorptive capacity refers to an organization's ability to recognize the value of new information, assimilate it, and apply it to improve organizational performance (Flatten et al., 2011).

Overall, outcome-focused studies of absorptive capacity at the project management team level are rare. However, as evidenced by several recent contributions, there is an emerging interest among project management and team scholars to apply the construct (Popaitoon & Siengthai, 2014; Leal-rodríguez et al., 2014; Backmann et al., 2015; Sandor et al., 2016; Oluwaseyi et al., 2017; Bjorvatn & Wald, 2018). There is need to identify absorptive capacity as a driver of teams' performance and project management success. The professional and organizational diversity frequently encountered in construction project teams as noted by DeFillipi and Arthur (1998), represent a palette of original and novel perspectives that need to be assessed, assimilated and applied by the project team collectively. Indeed, this fusion of disparate experience and expertise is often the reason why project teams are assembled (Cicmil et al., 2009).

Bjorvatn and Wald (2018) established a positive moderating effect of absorptive capacity on the relationship between complexity and project management performance. However, with a view to maintain model parsimony, the study defined project management performance on the basis of time and cost only. Whereas project management success is typically measured in terms of cost, time and quality as the three measures are not mutually exclusive (Khang & Myint, 1999; Tabish & Jha, 2018). One of the critical measures of project management success is the quality of its performance that may be affected by the attempt to crash the completion time with additional budget (Kerzner, 1995; Badiru & Pulat, 1995). Bjorvatn and Wald (2018) adopted a reduction approach and thus, considered only time and cost performance. This creates a gap in defining the overall effect of absorptive capacity on project management performance.

Methodology

A cross-sectional quantitative method of research was adopted to carry out this work. A questionnaire was designed to elicit the perception of project team members as respondents to the study on the concept of project complexity, quality performance, and also the absorptive capacity level of the project team they were involved in. A total of 140 respondents were sampled using purposive sampling technique. However, only 104 were returned and used for analysis. Data from respondents was analyzed using both descriptive and inferential statistical techniques. Partial Least Square- Structural Equation Model (PLS-SEM) was used to model the causal relationships between the three constructs in the study using the computer software SmartPLS 3. Hypothesis were derived from literature which serves as the basis for the structural model formulation.

1. H1- Project complexity negatively affects project quality performance (Muller et al., 2011; Sheffield et al., 2012; Bjorvatn & Wald, 2018).
2. H2- Project complexity negatively affects team absorptive capacity (Bjorvatn & Wald, 2018; Koops et al., 2016)
3. H3- Absorptive capacity moderates the effect of complexity on project management performance (Bjorvatn & Wald, 2018).

The Partial Least Structural Equation Model

The PLS-SEM being a second-generation multivariate analytical tool as opposed to first generation multiple regression analysis was used to test the causal relationship between the three study constructs; Project Complexity, Absorptive Capacity and Quality Performance. This is majorly due to the ability of PLS-SEM to handle non-normality of data, and also the modelling of latent variables and respective indicators. Perceptual measures were employed for all constructs in the main model. Perceptual measures as noted by Ketokivi and Schroeder (2004), have been found to produce reliable and valid results in management and organizational studies. Each construct was measured using three or more item scales that were assessed on five-point Likert scales (“1” = Strongly disagree, “5” = Strongly agree”). The partial least square structural model was set up with one (1) formative measurement model, two (2) reflective measurement models and the structural model. The three measurement models include project complexity measurement model (reflective) with four (4) indicators, the team absorptive capacity measurement model (formative) with eight (8) indicators, and the project management quality performance measurement model (reflective) with six (6). In all, the model was made up of ten (10) reflective indicators and eight (8) formative indicators making a total of eighteen (18) indicators associated with the three variables. Figure 1 captures the consequent model.

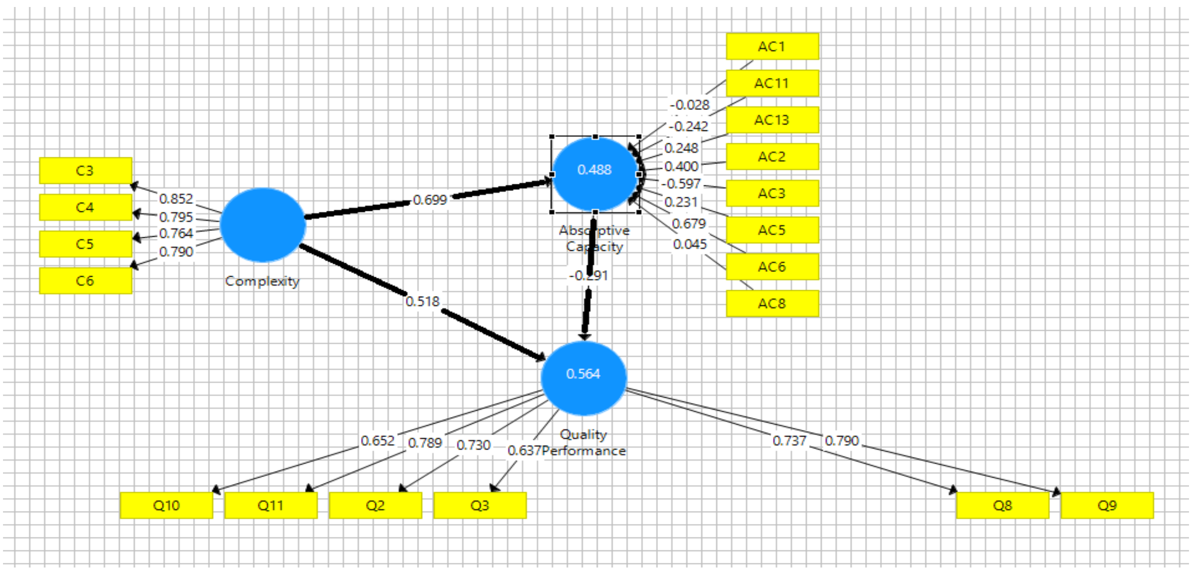

Figure 1: The structural model.

The Model Reliability and Validity

The validity of an instrument has to do with the ability of the instrument to measure what it is designed to measure (Kumar, 2011). In order to ensure face and content validity of the questionnaire-based multi-item scaling used in this study, the items included were derived from a comprehensive review of previous studies that have investigated the study's constructs. The reflective scale for dependent latent variable i.e. quality performance was developed specifically for this study using "negative questions" to reflect low quality performance. Indicators for this measure were tested and refined in a pilot study involving twenty respondents' representative of the main survey. For absorptive capacity and its components, validated absorptive capacity measurement instrument proposed by Molina et al. (2011) was adopted. In consequence, a total of eight (8) indicators were used to assess distinct nuances of team-level absorptive capacity, rendering a rich representation of the construct. The reflective project complexity scale was drawn from Tyssen et al. (2014), who found the instrument to have a reliability of 0.798. This instrument builds on the conceptual discussion of complexity in projects, incorporating complexity related to task, structure and uncertainty by Geraldi et al. (2011). A distinct advantage of this scale is that it is designed specifically to measure complexity in projects. Prior to data collection, the instrument was also subjected to scrutiny from industry professionals and also academics to ensure the instrument is valid for the study.

Table 1 provides the measurement items or indicators for each construct with respective loadings showing how each indicator loads on its construct, which reflects on the Average Variance Extracted (AVE) of the Model. According to Lowry and Gaskin (2014), the AVE is conceptually equivalent to saying that the correlation of a construct with its measurement item or indicator is larger than its correlation with the other construct which signifies model validity. Usually, higher indicator loadings result in higher AVE score. AVE value of 0.64 and 0.53 respectively for project complexity and quality performance were evidence of the model uni-dimensionality or convergent validity as supported by Henseler et al. (2015). Also, The Cronbach's alpha, composite reliability and Dijkstra-Henseler's rho. A as measures of internal consistency reliability were used to assess the reliability of the model. All values were above the threshold of 0.70 which shows model reliability has been achieved.

Table 1. Indicators of constructs.

Code	Absorptive Capacity	Loadings
AC8	Important knowledge was transmitted regularly to all project participants.	0.57
AC2	Different project participants shared informative documents periodically	0.58
AC6	When something important occurred, all project participants were informed within a short time.	0.83
AC11	The organizational cultures of the project participants were compatible.	0.47
AC1	There was close personal interaction between project participants.	0.32
AC5	There was a clear division of responsibilities regarding the use of informative knowledge shared by project participants.	0.56
AC3	Project participants shared their own common professional language.	-0.08
AC13	The operating and management styles of project participants were compatible.	0.42

Code	Complexity	Loadings
C6	It was difficult to communicate information across the project with minimum loss in transmission	0.79
C3	The nature of relationship among the project team members was more adversarial than collaborative	0.85
C4	The number of relationships amongst team members was difficult to manage	0.79
C5	The nature of information for project use was uncertain at most times	0.79

Code	Performance	Loadings
Q2	Construction materials were not specified based on durability properties.	0.69
Q11	There were a lot of onsite alterations during construction.	0.72
Q9	Sub-contractors were not engaged based on requisite expertise	0.75
Q3	Ease of maintenance and repair was not considered during design.	0.61
Q8	There was no provision of a written project quality management plan document	0.73
Q10	Delivering a qualitative product was not a priority during design and construction	0.68

Results and Discussion

Characteristics of Respondents

Demographic nature of the respondents was assessed with a view to have an overview of the sample population. Also, questions regarding the nature of projects respondents were involved in were asked to contextualize the findings of the study. Respondents were requested to a select a past project they were involved in and respond based on their experience on that project. Figure 2 shows the functional roles performed by respondents on their respective projects. A larger percentage of the respondents served as Architects with 35.5% of the sample population. Quantity Surveying roles were performed by 22.1% of the respondents. Project management roles as well as Building roles were performed by 13.5% of the respondents respectively. Structural engineering roles represent 10.6% while service engineering represent the least with 4.8%.

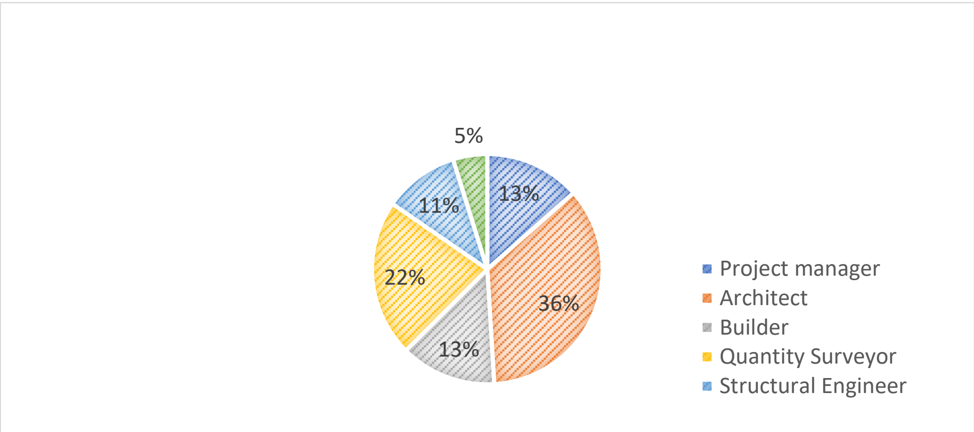

Figure 2: Functional roles performed by respondents.

The project team size in terms of members is an indication of the interdependencies in respective projects the respondents were involved in. Figure 3 shows a larger share of the sample population were involved in project teams with members not more than ten (10). Teams with members ranging from five (5) to ten (10) members represent the largest proportion with 85.6%. Teams with less than five (5) members represent 9.6% whereas teams with members ranging from eleven (11) to fifteen (15) members represent only 4.8% of the sample population. Figure 4 shows the types of project respondents were involved in. Majority of the respondents were involved in public projects with 77.9% while 22.1% represents the proportion of the respondents involved in private projects.

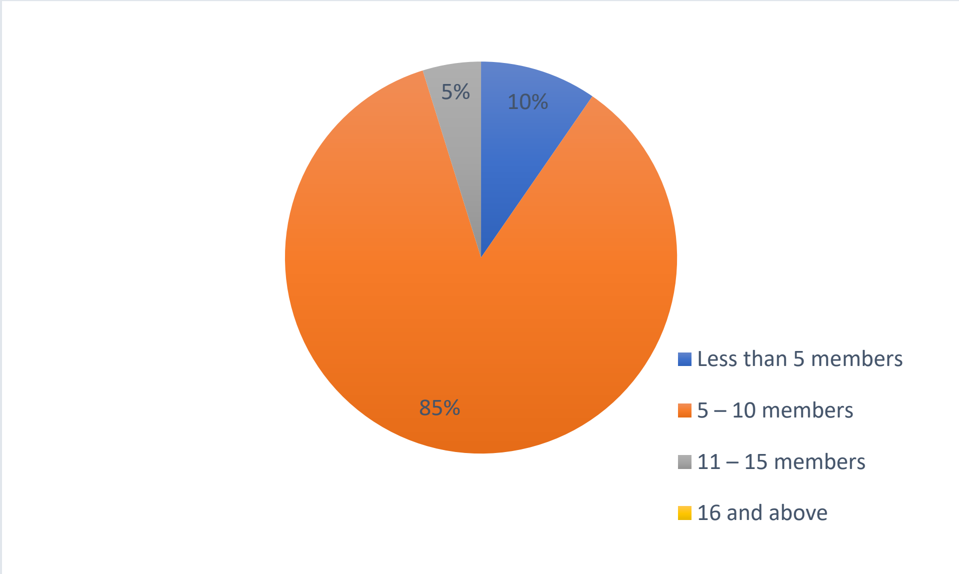

Figure 3: Project team size in terms of members.

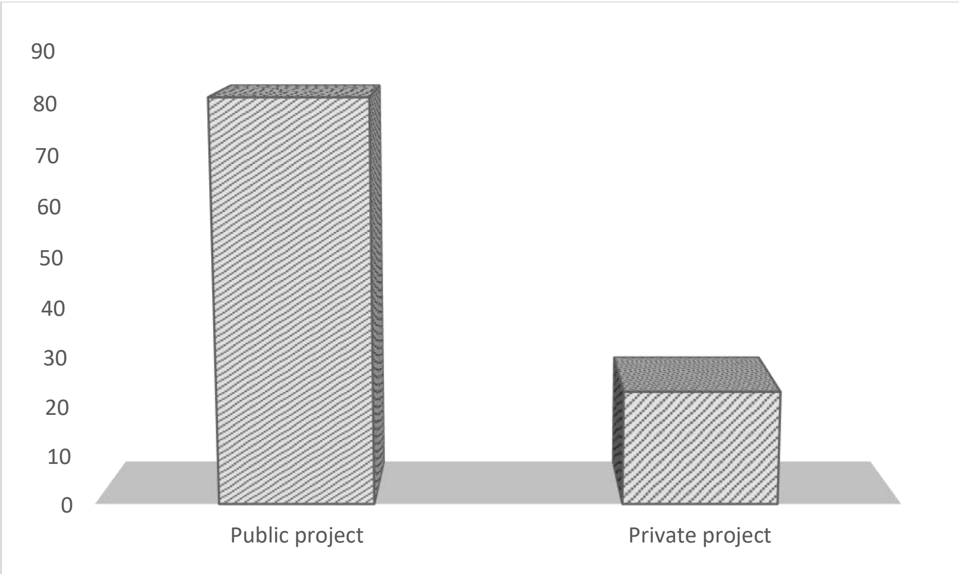

Figure 4: Nature of Projects Respondents were Involved.

Evaluation of the Structural Model

The path coefficients, having standardized values from -1 to +1, represent the hypothesized relationships among the constructs. Estimated path coefficients close to +1 represent strong positive relationships and estimated path coefficients close to -1 represent strong negative or moderating relationships. The variance inflation factor (VIF) scores are all below 5.0, so we conclude that that collinearity does not pose any problem in the structural model. Table 2 shows that the path coefficient between complexity and low-quality performance which translates to a positive relationship with (β=0.518). This means project complexity has a direct linear relationship with low-quality performance of construction project. Whereas complexity has a strong negative effect on team absorptive capacity with a path coefficient of (β= -0.699). However, there is a weak negative relationship between absorptive capacity and low-quality performance with a path coefficient (β= -0.291). To further ascertain the significance of these relationships, bootstrapping was deployed on the SmartPLS software using an alpha protection level of 5% and 5,000 independent subsamples. The conservative no sign change option of the bootstrapping algorithm was used. The standardized confidence interval estimation method was chosen at 95% confidence level.

Table 2. Significance testing for path coefficients.

	Original Sample	**Std. Dev.**	**T values**	**P Values**	**Significance level**
Absorptive Capacity -> Low Quality	-0.291	0.1	2.92	0.00	***
Complexity -> Absorptive Capacity	-0.699	0.05	14.53	0.00	***
Complexity -> Low Quality Performance	0.518	0.09	5.48	0.00	***

***$p<0.01$

The predictive power or accuracy of a partial least square structural equation model is measured by the coefficient of determination (R^2). Table 3 shows the R^2 values of the two endogenous variables in the model- Absorptive capacity and Low-quality performance as 0.488 and 0.564 respectively. The R^2 values are the values in the circles in the structural model in Figure 1.

Table 3. R^2 Values of endogenous variables and significant levels.

	R2 Values	Standard Deviation	T Values	P Values	Significance level
Absorptive Capacity	0.488	0.07	7.14	0.00	***
Quality Performance	0.564	0.06	9.66	0.00	***

***$P<0.01$

Summary of Hypothesis Test

Hypothesis 1: The path coefficient of the Complexity – Low-quality performance path (β=0.518) was found to be significant ($p<0.01$) as shown in Table 3. The empirical t-value is greater than the critical value of 1.96 threshold as specified in Hair et al. (2014). Furthermore, the coefficient of determination (R2) for quality performance is 0.564. The implication of this is that the exogenous variable (Project complexity) explains 56.4% of the variance in project management Low-quality performance. As such, **the findings support the hypothesis that says project complexity negatively affects quality performance.**

Hypothesis 2: The significance of the path coefficient (β= -0.699, $p<0.01$) shows a relatively high negative effect of project complexity on team absorptive capacity with an R^2 value of 0.488. As such, **the findings support the hypothesis on the negative effect of complexity on team absorptive capacity.**

Hypothesis 3: When the moderator (absorptive capacity) was introduced in the model, the relationship between independent variable (project complexity) and dependent variable (quality performance) was reduced from (β = 0.518, $P < 0.01$) as shown in Table 3, to (β = 0.213, $P < 0.01$) as shown in Table 5 meaning that there is a moderation. As such, **the finding supports the hypothesis that absorptive capacity moderates the effect of complexity on project management performance.**

Table 4. Specific indirect path coefficient of the model with moderator.

	Original Sample	**Sample Mean**	**Std. Dev.**	**T Value**	**P Value**
Complexity -> Absorptive Capacity -> Quality	0.213	0.24	0.08	2.7	0.01

Note: n=104; Bootstrap sample size=5000, BC 95% CI= Bootstrap confidence Intervals *p<.05, **p<.01, ***p<.00

As noted by DeFillippi and Arthur (1998), the professional and organizational diversity frequently encountered in construction project teams represent a palette of original and novel perspectives that need to be assessed, assimilated and applied by the project team collectively. Indeed, the need to provide a positive performance within a complex project context is often the reason why project teams are assembled (Cicmil et al., 2009). The findings of this study is consistent with previous works on team absorptive capacity and performance (Bjorvatn & Wald, 2018; Jansen, Van Den Bosch, & Volberda, 2005; Leal-rodríguez et al., 2014; Popaitoon & Siengthai, 2013). It builds on the view that, in as much as the project team have the capacity to acquire knowledge through information assimilation with regards to the project, the ability to transform the acquired knowledge for project use allows the team to improve performance through effective exploitation within a complex context.

Conclusion and Recommendation

Complexity has been defined as an inherent characteristic of construction projects due to the diversity and uniqueness of such projects. As such, complexity can only to be mitigated but not eliminated. Scholars have noted the negative effect of complexity on project management performance. The consistent issues of overspending, project delays and also poor project management quality performance cannot be overemphasized. This led to the need to find ways to limit or mitigate the effect of complexity on projects with a view to improve project management performance. Various constructs and team dynamism have been identified to limit the effect of complexity on performance. This study used the construct of absorptive capacity as a moderator of project complexity on quality performance. In a similar study, absorptive capacity was found to have a positive moderating effect of overspending and delays, which are two of the three dimensions of project management performance. This study also found a significant moderating effect of team absorptive capacity on project complexity and performance. One could then be tempted to say absorptive capacity moderates the effect of complexity on all dimensions of project management performance. However, this might not be the reality of the moderation if a case study was conducted where all dimensions of project performance were assed together. The findings might significantly differ if the moderation is observed without scope and delimitations on the dimensions of project management. Regardless of this limitation, the study findings show despite that project complexity has a significant and direct effect on the variance of project management quality performance, the ability of the project management team to acquire, assimilate and transform knowledge and information to be exploited for project use significantly improves project management performance. It is recommended that Absorptive capacity and the ability of individual team members to acquire, assimilate and transform knowledge and information for project use should be one of the core considerations when setting up a project management team.

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Designing out Errors: Application of Lean TRIZ Method to Safety Related Problems in the Construction Industry

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Abstract

The construction industry needs safer practices due to its complex and fragmented nature. Therefore, making errors visible is essential for the error-proofing process. It becomes possible with the Lean concept of designing out errors and developing ways to prevent errors before they turn out into defects. Also, going Lean creates a more productive and effective process when implementing innovative methods such as TRIZ, a problem-solving, analysis, and forecasting tool. Lean TRIZ is a new approach to improve construction processes while reducing the likelihood of errors. It strongly coincides with eliminating or possibly preventing errors stemming from unsafe acts and conditions. This study proposes a new method of designing out errors with the implementation of the Lean TRIZ method to minimize construction safety related problems. Then, real construction problems arising from unsafe practices and conditions are analyzed with the Lean TRIZ method. The main contribution of the study is to introduce the Lean TRIZ concept and to analyze the feasibility of using this method to solve safety problems. Moreover, the study provides a guideline and encourages the construction practitioners to benefit from solutions provided as part of this research in the context of the Lean TRIZ method.

Keywords: *construction, lean, safety, TRIZ.*

Introduction

The dynamic nature of the construction industry brings the need for more efficient methods to manage construction projects. As of today, many companies are struggling with uncertainty, complexity, low performance, and efficiency in construction projects. Hence, it is of paramount importance to find efficient solutions for areas needing improvement. Moreover, there need to be strategies bringing up an innovative way of improving performance and promoting practices on sites. At this point, Lean management offers a unique solution to the problems that have arisen from the increasing complexity of projects because Lean aims to maximize value while minimizing waste. Although Lean has found its roots in the manufacturing industry, it has lately been adopted as an excellent way of improving construction processes. With the adoption of Lean principles, it is possible to deliver construction projects with higher success. The use of Lean tools and techniques also help design out errors. Considering the error prone nature of construction projects, the use of Lean methods becomes even more important to eliminate waste and increase value. The benefits of utilizing Lean tools and techniques in the construction projects have already been mentioned in several studies (Ballard & Howell, 1998; Sacks et al., 2010; Aziz & Hafez, 2013). This led the construction industry to practice Lean to a great extent and seek similar strategies to improve performance.

It is apparent that the industry is in need of inventive solutions to problems arising in construction projects. Hence, the industry is adapting to an environment where mistakes are either avoided or detected. This is possible through adopting innovative strategies and the use of outstanding techniques. At this point, the Theory of Inventive Problem Solving (TRIZ) is an excellent method to provide inventive solutions to problems thanks to fostering innovative ideas. TRIZ has already been applied in various construction related research highlighting its power on fostering innovation and promoting construction technology (Mohamed & Abourizk, 2005; Ding et al., 2014; Reneva & Chechurin, 2016). TRIZ is a more powerful technique when integrated with other problem solving tools such as SWOT, brainstorming, and 6σ (Hua et al., 2006). Especially when designing out errors, sound techniques need to be put in place in order to improve performance. Hence, this study investigates Lean TRIZ, which is a methodology structured with the Lean and TRIZ principles for the process improvement. In this respect, the study first presents the roots of Lean construction along with TRIZ. Then, the Lean TRIZ method is introduced. To illustrate the method, examples of safety related problems in the construction industry are analyzed with the Lean TRIZ method.

Lean Construction

Lean was first introduced by John Krafcik in 1998 as 'Lean production'. It had its roots in the manufacturing industry. Krafcik (1988) described a "Lean" plant as a production system, where inventory levels are minimum for the fact that downtime occurrences and quality problems are easily detected and handled. Even though Lean was first offered as a term in the manufacturing industry, it later gained a wide area of application in other industries such as healthcare, technology, and construction. The introduction of Lean to the construction industry started in the 1990s. Gregory Howell and Glenn Ballard, two researchers from Lean Construction Institute, have collected a broader experience in the construction sites. They discovered that a major portion of the construction projects generates similar problems such as inefficient planning, over budget completion, and low workforce efficiency and productivity. Detecting these common problems, they came up with the Last Planner System (LPS), which is a collaborative planning process for Lean project execution with the objective of increasing worker productivity (Ballard & Howell, 1998). Then, Koskela (1992) also mentioned that a new production philosophy needs to be put in place for the construction industry, which will act as a fundamental paradigm shift. This way, the construction industry might better benefit from the production principles of manufacturing in the context of Lean.

Going Lean is needed for the defective processes in mass production and craft production. Hence, Lean is an effective approach for both customer satisfaction and enhanced project performance as previously implied by several studies (Horman & Kenley, 1996; Khadem et al., 2008). Several studies have investigated the use of Lean in construction, emphasizing its benefits for the construction projects. For example, Sacks and Goldin (2007) developed a Lean management model for high-rise apartment buildings by adopting Lean principles (i.e., pull scheduling, reduced batch sizes, and a degree of multiskilling). The model intended to provide customized apartments, improved cash flow, and reduced apartment delivery cycle times. Aziz and Hafez (2013) concluded that Lean projects are safer, easier to manage, completed sooner, cost effective, and are of better quality by referring to the impact of Lean in minimizing waste in construction. Boyce et al. (2012) investigated the aspects of Lean thinking and concluded that it helps improve the design phase of complex projects by emphasizing the essential function of the collaborative planning process in highway design. Similarly, El-Reifi (2013) implied the positive impact of Lean thinking adopted by the design team in achieving higher customer satisfaction. Khan and Kim (2014) emphasized the importance of identifying waste types in mid/high-rise building construction. However, the literature still lacks a comprehensive description of approaches or models to reveal the relation between Lean components. Notably, the integration of Lean with other error proofing methods are worth investigating in terms of revealing its benefits.

This study discusses TRIZ in the context of Lean construction. In this respect, the Lean TRIZ approach is introduced to foster its application in the construction industry for experiencing less waste and higher value. Examples are provided and analyzed using TRIZ principles and Lean aspects.

TRIZ

TRIZ is the Russian acronym for the "Theory of Inventive Problem Solving" (Barry et al., 2017). TRIZ was first invented by the Soviet inventor and science-fiction author Genrich Altshuller and his colleagues, beginning in 1946. TRIZ is the "theory of the resolution of invention-related tasks" and it is "a problem solving, analysis and forecasting tool derived from the study of patterns of invention in the global patent literature" (Altshuller, 1988; Altshuller, 2004).

The theory reveals the patterns of evolution, and TRIZ practitioners developed an algorithmic approach for the invention of new systems and the refinement of the existing ones. TRIZ provides repeatability, predictability, and reliability with its structure and algorithmic approach. It is an international science of creativity that is developed based on the patterns of problems and solutions, and it does not rely on the spontaneous and intuitive creativity of individuals and groups. TRIZ is the result of the evaluation of more than three million patents to discover the patterns predicting breakthrough solutions to problems. Figure 1 illustrates the TRIZ method, which aims to develop innovative solutions to problems removing the barriers brought by the traditional methods. The problems are solved thanks to the 40 inventive principles relying on a complete technical evaluation.

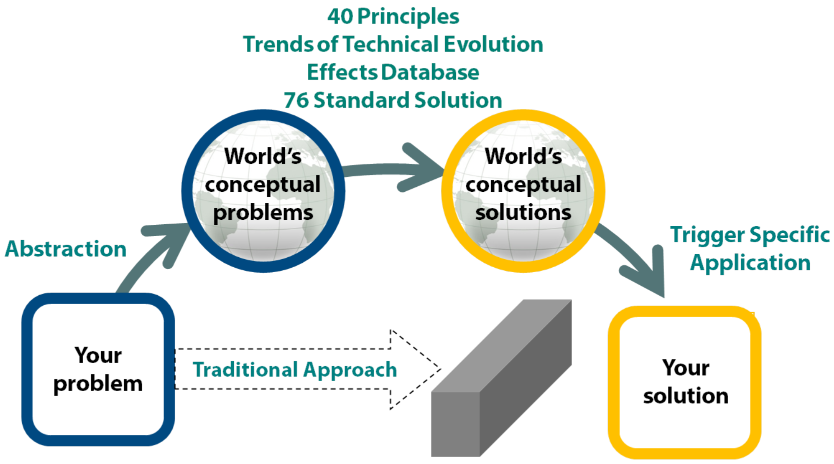

Figure 1: TRIZ Essentials (https://www.wikiwand.com/en/TRIZ).

TRIZ is composed of a practical methodology, tools sets, and model-based technology for generating innovative solutions for problem solving. The previous research on TRIZ has brought that problems, solutions, and patterns of technical evolution are repeated across industries and sciences. The previous research also indicated that the innovations used scientific effects outside the field in which they were developed. TRIZ practitioners apply these findings to create and improve products, services, and systems (Barry et al., 2017).

TRIZ is more powerful when integrated with other methods (Hua et al., 2006) The methods are strengthened by the integration with TRIZ, and the integrated methods are applied to the design phases of the new product development process. Hence, TRIZ has a proven benefit in improving the processes when integrated with other problem solving techniques. To improve the processes and find solutions to problems, especially in the engineering applications, TRIZ utilizes the 40 inventive principles, which were discovered by Genrich Altshuller. These 40 principles were provided for creating inventive solutions by a careful investigation of technical patents. The 40 principles might be applied not only in technical fields such as architecture, computer software, microelectronics, food production but also for non-technical spheres of biology, agriculture, business, management, marketing, social relations, pedagogy etc. The inventive 40 principles present fundamental, universal, and powerful instruments of human creativity.

TRIZ interferes with the scope of quality management. Hence, it is common to find several examples in the quality management area such as quality standards, control, assurance, reliability, customer focus, supplier selection, project management and improvement teams where TRIZ is used (Redseptor, 2003). Mistake proofing, a useful Lean tool, is, therefore, in close relation with TRIZ by setting an example to several principles of TRIZ. For example, asymmetry, a TRIZ principle, is explained in two ways;

"A: Change the shape of an object or system from symmetrical to asymmetrical.
B: If an object or system is asymmetrical, change its degree of asymmetry" (Redseptor, 2003).

Similarly, the "mutual exclusivity" principle is also used for mismatching at mistake proofing. Another TRIZ principle is "preliminary anti-action", which is explained as;

"A. If it will be necessary to do an action with both harmful and useful effects, this action should be replaced with anti-actions to control harmful effects." (Redseptor, 2003). This principle is used for mistake proofing in the design for foreseeable unintended use. Below is an example of how mistake proofing was applied in the inventing solutions by adopting principles of "prelimary action" and "self service". TRIZ brings new insight into problem solving by using resources to reach the ideal solution. For having good solutions, contradictions are solved, idle resources are used, and solving contradictions by using resources makes the system more ideal (Rantanen & Domb, 2008).

Lean TRIZ

Lean TRIZ method (LTM) is a modified and simplified version of TRIZ, which is enriched with the aspects of Lean for problem solving. This method is also generated through a broader modification of the TRIZ contraction matrix, which aims to reveal principles of solving product related problems depending on its features. The main objective of implementing LTM is to experience a reduction in cost, cycle time, and error rates in a process up to 15% in a 30-day period. Its implementation has already proven its benefits in various applications. For example, when it is applied to a product or service, it has the capacity to improve product design thanks to a two-day LTM workshop for design improvement LTM is more a simple form of traditional TRIZ method in that it provides short term improvement initiatives. It also allows for a quicker process redesign, process reengineering, benchmarking, and Six Sigma (Harrington, 2017).

LTM includes five phases, namely identifying improvement opportunities, preparing for the workshop, conducting the workshop, implementing the change, and measuring results and rewards or recognition. Figure 2 presents the LTM cycle based on these phases.

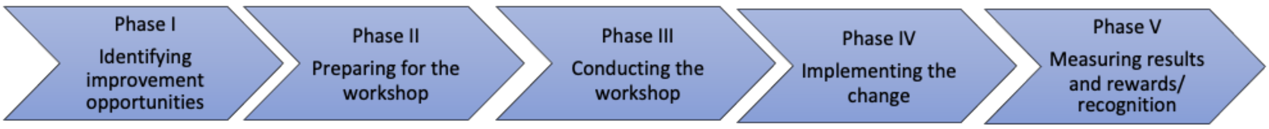

Figure 2: Lean TRIZ method cycle (Adapted from Harrington, 2017).

As it is presented in Figure 2, LTM is an effective means of providing improvement opportunities for product and process design. Considering the critical nature of process efficiency in construction projects, one might assert that LTM can be successfully applied to construction processes to improve process efficiency. Moreover, the method also allows for creating a safer work environment by revealing the areas needing improvement. Hence, this study discussed the method and its potential in reducing or preventing errors for safety related examples in the construction industry.

Safety Specific Examples from the Industry

The examples of safety related problems, which interfere with TRIZ principles, are presented below. The examples are analyzed discussed in the context of LTM.

Example 1- Mechanical Overload Switch

Problem: The load a hoist or crane can carry depends on its rigging as well as the lift radius and thus boom length. The crane capacity is lower when the lever arm is greater.

Reducing: An overload switch indicates the load carried by a hoisting device or crane.

Figure 3: Mechanical Overload Switch (https://vetec.dk/product/overload-switch/).

TRIZ Principle: This example presents the “Feedback” principle. Introducing feedback (referring back, cross-checking) is essential to improve a process or action.

Example 2-Prestressed Rebar before Concrete Pouring

Problem: Undesirable working stresses in concrete pouring

Reducing: Concrete beams are typically prestressed, which means that the steel rebar within the concrete is put into tension before the concrete is poured into the fixture. This strengthens the concrete’s ability to resist tension through the rebar, which in turn decreases construction costs.

Figure 4: Prestressed rebar before concrete pouring (http://www.southampton.ac.uk/~jps7/Lecture%20notes/TRIZ%2040%20Principles.pdf).

TRIZ Principle: This example addresses the "preliminary anti-action" principle of TRIZ, which means creating beforehand stresses in an object that will oppose known undesirable working stresses later on.

Example 3-Drilling into Rebar

Problem: Prevent errors before they turn into defects
Reducing: Drilling can damage metal pipes, conduit, reinforcement steel. PROTEK drill interrupters offer protection against drilling into grounded metal pipes, conduit, post-tension cabling, and rebar while drilling concrete walls and slabs.

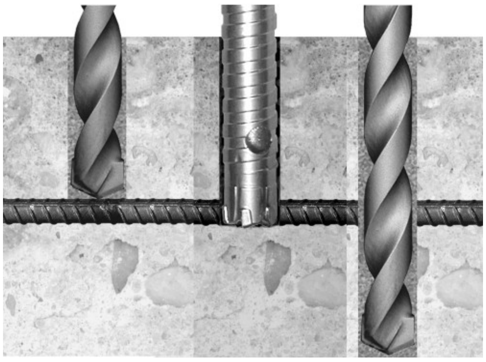

Figure 5: Drilled into rebar (http://championcuttingtool.com/cm79-sds-rebar-cutter.html).

TRIZ Principle: This example addressed the principle of "beforehand cushioning" of TRIZ, which means that preparing emergency means beforehand to compensate for the relatively low reliability of an object or system. The use of mistake proofing tools, devices, and practices in the processes increase the reliability of the system.

Example 4-Worker Fall Protection

Problem: Workers can fall from heights.
Reducing: The g-link dual retractable system allows 100% tie-off where one can move from one anchor point to the next without disconnecting the retractable. The bulk of the unit is attached to the back of a person's harness, and the system is constructed of lightweight aluminum components, which reduces worker fatigue.

Figure 6: G-link Dual Retractrable System (https://www.guardianfall.com/performance-safety-products/self-retracting-lifelines/product/g-link-dual-retractable-srl).

TRIZ Principle: This example refers to the "Beforehand Cushioning" principle of TRIZ, which directs preparing emergency means beforehand to compensate for the relatively low reliability of an object.

Example 5- Andon Display

Problem: To remove errors by visual aids.
Reducing: Andon is a visual aid that alerts and highlights where the action is required. For example, it may be a flashing light in a manufacturing plant that indicates the line has been stopped by one of the operators due to some irregularity.

"Andon" is a principle and is also a typical tool to apply the *Jidoka* principle in Lean Manufacturing – Jidoka is also referred to as 'autonomation', which means the highlighting of a problem, as it occurs, in order to immediately introduce countermeasures to prevent re-occurrence." (http://www.shmula.com/about-peter-abilla/what-is-andon-in-the-toyota-production-system/ visited 03/12/2017)

Figure 7: Andon Display (http://toa-se.com/wp-content/uploads/andon-screenshot-web.png).

TRIZ principle: This example addresses the principle of "feedback" of TRIZ, which means introducing feedback (referring back, cross-checking) to improve a process or action.

Conclusions

Safety is a major concern for construction projects. Hence, companies are seeking for innovative tools and techniques to best manage projects and experience a higher safety performance. To eliminate or possibly to prevent errors in the processes, it is essential to design out errors and re-engineer the processes. Hence, this study discusses the LTM, which is an error proofing methodology for bringing up a better product design and built-in-quality. The method also applies to construction processes in terms of improving the performance, mainly in the safety context. In this respect, examples associated with safety in construction are provided accordingly. The study aims to reveal awareness for safety and promotes safety performance with the use of inventive techniques such as LTM. The study is also expected to guide construction practitioners in terms of utilizing effective tools and techniques to deliver projects succesfully.

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A Framework for Automatic Tolerance Analysis of Removable Flood Wall Anchor Plates With 3D Laser Scanning and BIM

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Abstract

Integrating and storing digital data through Building Information Modeling (BIM) and 3D Laser Scanning is of most importance in terms of visualizing project information. In this respect, this study presents a systematic and practical approach for detecting the assembly quality of anchor plates for a removable floodwall through the integration of BIM and 3D laser scanning. The current methods for analyzing the assembly quality of anchor plates heavily rely on manual inspection and contact-type measurements, which are time-consuming and costly. Therefore, this paper examines a semi-automated method integrating the use of BIM and 3D laser scanning technology for rapid analysis of the assembly quality of anchor plates. In this context, the paper introduces the framework of an automatic dimensional and surface quality assessment method. The following sections describe the project flowchart, data collection, and quality inspection methodology. The study employs the data of a real project located in Heihe, China, to validate the level of technical feasibility and accuracy of the presented methods. The results indicated that the proposed integration of BIM and 3D laser scanning has the potential to produce a semi-automated and reliable method to control the assembly quality of anchor plates.

Keywords: *removable flood wall, laser scanning, BIM, assembly quality analysis.*

Introduction

A floodwall is a primarily vertical artificial barrier that is erected along the banks of a stream or path of floodwaters to prevent floodwaters from reaching the area behind the structure during seasonal or extreme weather events. Traditional floodwalls are mainly constructed from prefabricated concrete elements. This system requires considerable land area, which may restrict access to the structure, and can be very expensive on construction and maintenance. Hence, a removable floodwall system is designed and introduced to overcome those challenges brought by the traditional floodwalls. Unlike traditional ones, these structures are movable and can be deployed or erected only in times of flooding. They are typically lower in cost than levees or traditional floodwalls. Removable floodwall systems can be applied to individual buildings, smaller areas, or a large scale of the infrastructure such as dams, large-size port piers, railway tunnel portals, culvert openings of expressways, openings of civil air defense structures, and urban large-scale communities to prevent flood disasters (Chen et al., 2018). Compared with traditional flood protection methods, the removable floodwall takes advantage of the low labor intensity, high work efficiency, and small seepage (Kádár, 2015). Also, a removable floodwall gives protection in case of flooding and open access to the floodplain over the remaining time. It can also be used as an emergency tool against flooding in unprotected low-lying areas in addition to the heightening of permanent flood protection structures in extreme events.

One of the critical procedures during the installation process is the accuracy tolerance control of anchor plates, which are embedded in reinforced concrete plinths for connecting fixed columns. Ensuring the installation precision of anchor plates without deviation during concrete pouring is crucial because the control precision of concrete pouring is in millimeter accuracy. The current methods for analyzing the tolerance accuracy of anchor plates, however, rely primarily on manual inspections and contact type measurements such as rulers and measurement tapes, which are time consuming and costly. Also, there is a lack of systematic storage and management of the information obtained. A major portion of the researchers and practitioners adopt non-contact sensing techniques to monitor the dimensional properties of the precast structures. Laser scanners have recently been one of the most popular recent measurement tools in the construction industry (Kim et al., 2015). Laser scanning directly acquires 3D point cloud data at a high accuracy level with 2mm to 6mm at 50 meters (Muszyński & Rybak, 2017; Olsen et al., 2010). According to the existing studies (Dai & Lu, 2010; Dai et al., 2013; Golparvar-Fard et al., 2011), which conducted comparisons between laser scanning methods and vision based approaches, the laser scanning approaches offer better accuracy than vision based methods.

This paper introduces a semi-automated method that integrates the use of BIM and 3D laser scanning technology to enable rapid analysis of the assemble quality of anchor plates for a removable floodwall. The researchers first propose a framework of an automatic dimensional and surface quality assessment method. The following sections describe the data capture, quality inspection procedure, and the data storage and delivery methods accordingly. The study utilizes the data of a real project located in Heihe, China for validating the level of technical feasibility and accuracy of the presented methods. The results indicate that the proposed integration of BIM and 3D laser scanning has the potential to produce a semi-automated and reliable method to proactively control the assemble quality of anchor plates for removable floodwall during field installations.

Literature Review

BIM for Construction Quality Control

BIM is an effective tool in terms of collaborative planning and team working. It has several modules such as cost, time, quality, and safety, which enable a construction project to be executed with higher performance. It is also a beneficiary tool for quality control. BIM is a rich and formal model that provides an ample number of possibilities for automated quality inspections; it can interpret and execute a variety of criteria ranging from client requirements to health codes, safety codes, and building design and construction regulations (Park & Kim, 2015). There are three types of BIM-based quality control methods (Choi, 2012), namely the physical quality control, logical quality control, and data quality control. Physical quality control includes elements checking, and clash checking between physical elements on different construction sections such as MEP and structure. Logical quality control relies on rule-based checking using formulas, architecture acts, guidelines, specifications, and so on. Data quality control refers to data reliability checking and it checks whether a specific component has its proper attributes or not (Park & Kim, 2015). Kim et al. (2013) developed a BIM evacuation simulation module, called InSightBIM™, for BIM-based quality checking in supertall buildings. Zhang et al. (2013) developed an automated error detection module and an installation system (i.e., fall protection installations such as staircases, slab edges, slab openings, and protective equipment) operated through Tekla™.

Laser Scanning for Construction Quality Control

Laser Scanning is a novel surveying technology. A laser scanner sweeps the surrounding space with laser light to acquire 3D data points with reasonable accuracy, great speed, and high density. Point clouds provided by laser scanners can be used directly for measurement and visualization (Bosché & Guenet, 2014). One of the important applications of laser scanning is construction quality control (Akinci et al., 2006; Boukamp & Akinci, 2007; Tang et al., 2011). Akinci et al. (2006) proposed a first formalization for integrating project 3D models and sensor systems to defect detection and characterization for construction quality control. Bosché and Guenet (2014) then presented the implementation of such a system, called the Scan-vs-BIM principle. According to the different types of geometry quality, research efforts on geometry quality inspection can be divided into three categories, namely (1) dimensional quality inspection, (2) surface quality inspection, and (3) displacement inspection (Wang & Kim, 2019). The dimensional quality inspection has covered dimensions of prefabricated elements and dimensions of building façade elements, such as size (Kim et al., 2014; Wang et al., 2016), shape (Kim et al., 2016), position (Bosché, 2010), and orientation (Bosché, 2010). For surface quality inspection, most research works are focused on surface crack, spalling, flatness, and deformation/distortion. Displacement inspection is focused on the change of relative position of a structure or elements.

Integrated BIM and Laser Scanning for Construction Quality Control

The integration of 3D laser scanning and BIM offers an opportunity for construction quality control (Wang et al., 2017). During the construction phase, the change orders always occur. Therefore, construction works on site need to be assessed to make sure the as-built construction outcomes are consistent with the as-designed BIM model. Moreover, the discrepancy should be checked if it is less than the tolerance value (Wang & Kim, 2019). Tang and Akinci (2012) utilized laser scanners to collect dense 3D point clouds for bridge inspectors. Akinci et al. (2006) utilized sensing technologies and project modeling capabilities to develop an active quality control system, which included a process of acquiring and updating detailed design information, identifying inspection goals, inspection planning, as-built data acquisition and analysis, and defect detection and management. Bosché (2010) introduced an approach for automated recognition of project 3D BIM objects in large laser scans to automatically control the compliance of projects with respect to corresponding dimensional tolerances.

Methodology

This study analyzed anchor plates for removable floodwall using 3D laser scanning and BIM technology for quality controls. A research framework was developed, as shown in Figure 1. The research was conducted in eight steps.

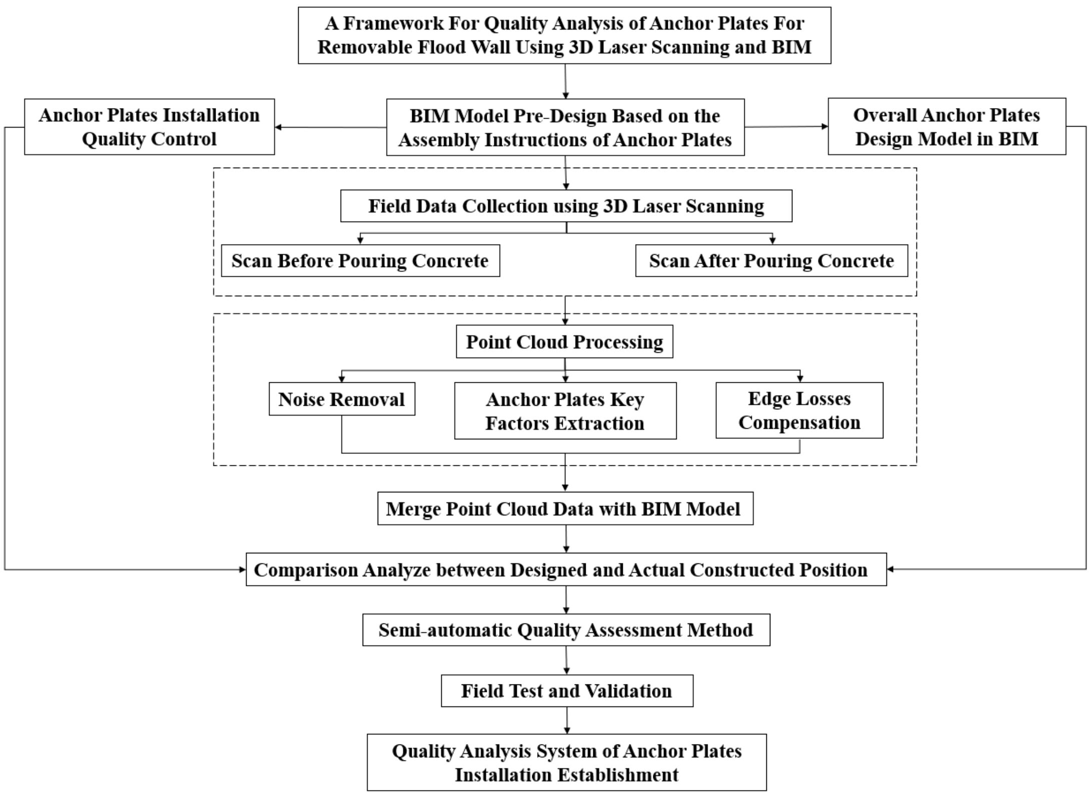

Figure 1: Research framework.

Step 1: Literature review. A thorough literature review and background study were conducted to evaluate the feasibility of using 3D laser scanning and BIM for tolerance analysis.

Step 2: A BIM model was created based on the design and the assembly instructions of the anchor plates.

Step 3: Laser scanning and noise removal. This work included the selection of a suitable laser scanner, optimization of scanning methods, parameters, and locations, and removing point cloud noise.

Step 4: Scan to BIM. The point cloud data was converted into 3D BIM in Revit.

Step 5: Semi-automated method development. Integration of the use of BIM and 3D laser scanning technology to enable rapid analysis of the assemble quality of anchor plates for removable floodwall.

Step 6: Laboratory validation. An indoor test was conducted to validate the laser scanner accuracy and optimize the selections of the laser scanning parameters. The field test will continue after passing the indoor testing.

Step 7: Field implementation. The author performed quality control and quality assurance for installing the anchor plates and then compares it with the manual installation quality test report.

Step 8: Semi-automatic optimization. Field data was analyzed to find out the deficiencies in the program and to summarize and improve the integrated installation quality assessment for the anchor plate.

Case Study

This study implemented the methodology in a real-life project. The project is along with Heilongjiang river, within the city limits of Heihe, China. The length of the removable floodwall is 3,135 meters, with a total of 1,056 prefabricated anchor plates. The purpose of installing a removable floodwall is to meet the new flood control standard without blocking the view of the skyline. Anchor plates are identical to each other with the same installation procedure of each anchor plate. The authors decide to use two sample anchor plates to describe how the quality analysis was performed in this study.

Developing a BIM Model

The floodwall anchor plates used in this study were produced by the IBS company of Germany. A 3D model of the anchor plate was developed, as shown in Figure 2a. The individual component of the anchor plate is shown in Figure 2b.

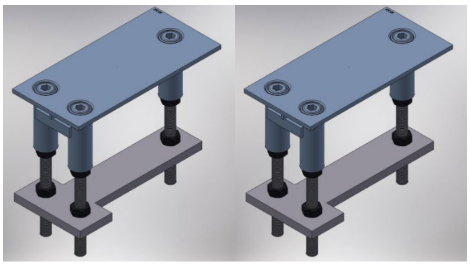

Figure 2a: Anchor plate – BIM Model.

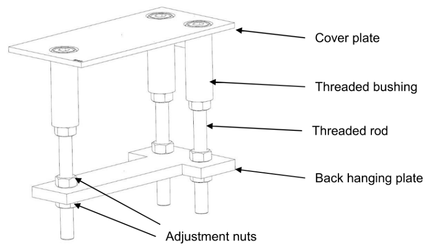

Figure 2b: Anchor plate – Components.

Based on the design and construction drawing, the research team developed three-dimensional BIM models in Revit and georeferenced it to the coordination system used by the project. BIM technology has the potentials to manage the life cycle of removable floodwall projects and improve project quality and efficiency, reduce project cost, reworks, and wastes. Figure 3a and Figure 3b present the BIM model of the reinforcement structure and the overall structure after pouring concrete, respectively.

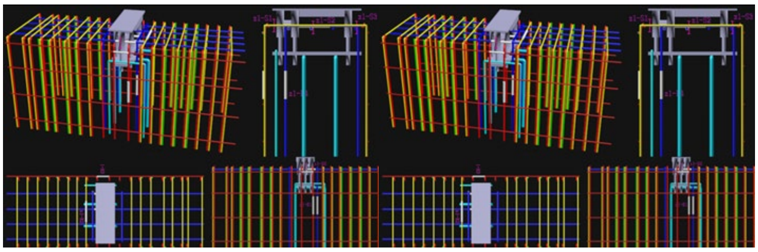

Figure 3a: Installation BIM model before pouring concrete.

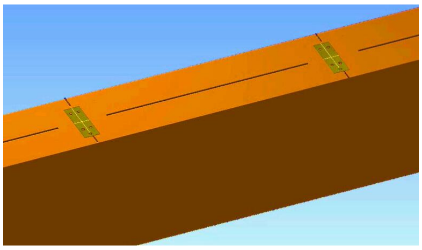

Figure 3b: Installation BIM model after pouring concrete.

Capture of Point Cloud Data

The laser scanner used in the project was determined by factors such as the range and accuracy specifications of the scanner, the accuracy requirements of the project, the cost of the scanner, as well as the budget of the entire project. The location and the scanning parameters of the scan were crucial to maintain a high level of accuracy. There are three key impact factors of the scanning accuracy: (1) distance to the object; (2) incident angle between the 3D laser scan and the installed anchor plates; (3) angular resolution of the 3D laser scanner. After all those factors are studied, the Leica P30 laser scanner was selected to capture the data. Multiple scans were then performed to minimize the occlusion effect.

Laser scans the anchor plates before pouring concrete: The anchor plates were installed in a reinforced concrete foundation and embedded flush with the ground. The plate accepted the center posts. In non-operative mode, the anchor plates' internal threaded bushings are closed with dummy bolts. They protect the bushings from debris. In case of a flood, the dummy bolts are removed, and service bolts are utilized to connect the center posts with the anchor plates.

Figure 4 shows the anchor plates, which were installed every 30 meters according to the plan and specification.

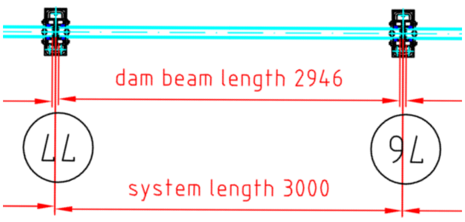

Figure 4: Anchor plate positions.

After an anchor plate was placed and levelled, it was permanently welded to the reinforcement to protect any movement during the cast-in-place process, as shown in Figure 5a. Multiple scans were performed to capture the point cloud data. Control targets were placed at the recommended optimal distance from the scanner and evenly throughout the scan at different elevations. Then, point clouds were tied into a single coordinate system, as shown in Figure 5b.

Figure 5a: Anchor plate in the jobsite.

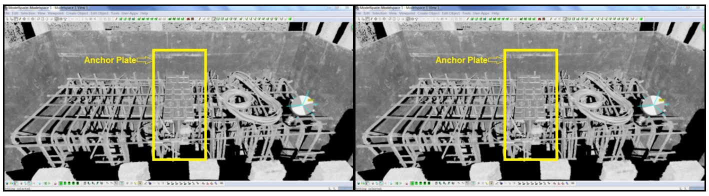

Figure 5b: Anchor plate point cloud.

Laser scans the anchor plates after pouring concrete: When the correct positions of anchor plates were checked and documented, concrete work was then performed. After the concrete was cured, scans were conducted to capture the as-built position of the anchor plate, as shown in Figure 6a and Figure 6b. The data were compared to the point cloud before pouring concrete to check if the position was changed due to the concrete work.

Data Analysis and Result

After performing a 3D laser scan, the raw point cloud data need to be processed. Cyclone was selected as the software to process point cloud data because it is a software developed by Leica, the manufacturer of 3D laser scanner used in the study, hence avoiding compatibility problems in between the software and the equipment, and avoiding the cost of purchasing a new software since Cyclone comes with the Leica 3D laser scanner.

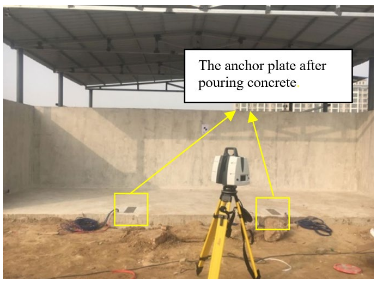

Figure 6a: Scan anchor plate after pouring concrete.

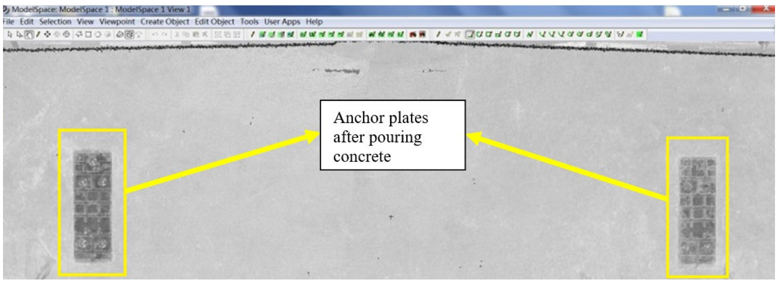

Figure 6b: Anchor plate point cloud after pouring concrete.

The project used China Geodetic Coordinate System 2000 (CGCS2000) as its main georeference system. Each control point was surveyed by the Lecia Total Station under the CGCS2000 system. When the point clouds were tied into the control points, the entire point cloud is georeferenced in the CGCS2000 system. Thus, the BIM model and point cloud data were in the same coordinate system and could be compared. Due to the high density of the original point cloud data, it was necessary to eliminate the point cloud noise and use the feature extraction algorithm to reduce the number of point clouds and the reading time of the computer. Then, the point cloud data were extracted and saved in IFC format for storage, to facilitate comparison with BIM data.

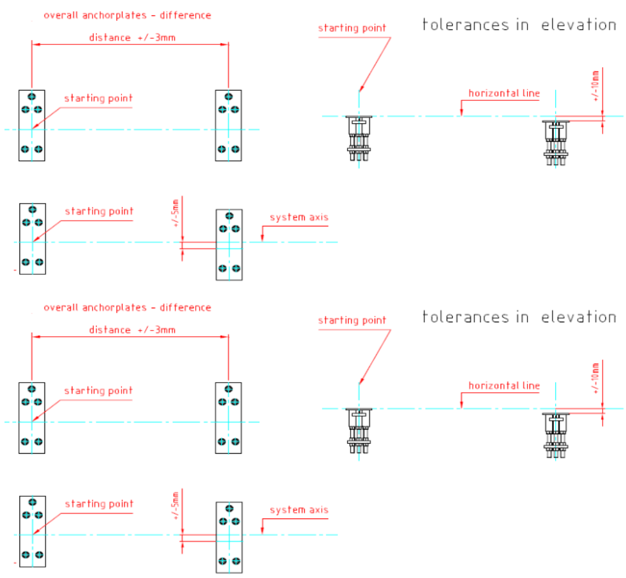

Figure 8: Design tolerance.

Based on the design tolerance provided by the manufacturer, the offset on the X-axis (+/- 5mm), Y-axis (+/- 3mm), and Z-axis (+/- 10mm) need to be evaluated and measured, as shown in Figure 8. In order to measure the torsion deviation, each anchor plate was controlled by four checkpoints, which are the four corners. By comparing the created BIM model and the scanned point cloud data, the errors were calculated automatically, as shown in Figure 9.

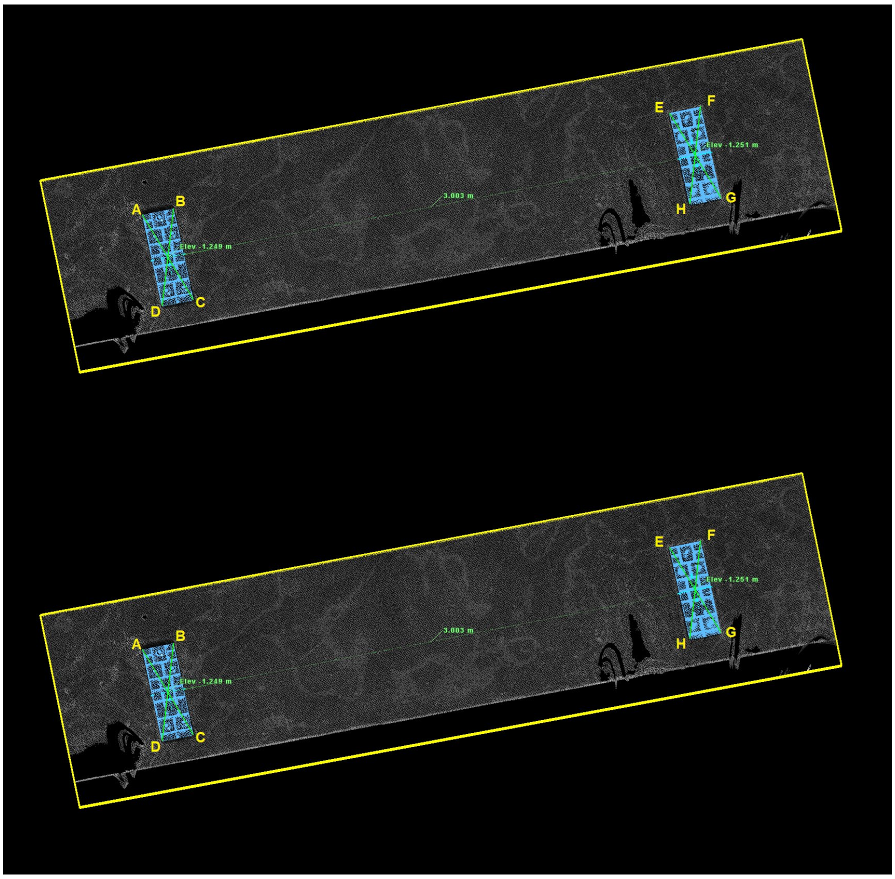

Figure 9. Comparison between BIM and point cloud data.

Researchers examined the distance and the offset of the three axes between the center point of the anchor plate. The required center to center distance is 3000mm. The actual distance is 3003 mm with -3mm on X-axis, 3mm on Y-axis, and 2mm on Z-axis. All of them met the quality requirement, as shown in Table 1. Table 2 shows the deviation of the control points to determine the torsion quality. The most significant deviation is 5mm on Z-axis, and it is within the requirement of +/- 10 mm.

Table 1. Deviation from center point to center point.

	Distance	Meet the quality requirement
Point-Point	3003 mm	Yes
X distance	-3 mm	Yes
Y distance	3 mm	Yes
Z distance	2 mm	Yes

Table 2. Deviation of the control points.

Anchor Plat	Control Point	Error(mm)		
		△X	△Y	△Z
Left	A	2	1	3
	B	3	3	5
	C	2	3	2
	D	2	3	3
Right	E	2	3	4
	F	1	2	3
	G	2	2	2
	H	3	1	5

Conclusion

This study built a framework of integration of BIM and 3D laser scanning technology to control the construction quality of removable floodwall anchor plates. BIM technology was used to establish an accurate three-dimensional model according to the design. Meanwhile, 3D laser scanning technology was used to scan anchor plates before pouring concrete and after. Based on the tolerance requirements, a comparison was performed between the point cloud and BIM model to determine whether the tolerance was within the allowable range. A series of rectifying measures were carried out for the components beyond the allowable range of tolerance to ensure the quality of the construction and installation. It did not only improved the efficiency of construction quality control but also established a preliminary foundation for semi-automation of quality control for built-in fitting in the concrete structure. It also provided a reference for the combined application of BIM and 3D Laser in future scientific research.

As a future work, a robust system will be developed to automatically extract the key points such as the center point, corners, and alignment of the embedded parts for further comparative analysis. The combination of BIM and 3D laser scanning in the whole process will significantly reduce the time consumption of manual measurement and avoid the error of manual measurement. It can sufficiently improve efficiency while ensuring the precision of quality control, and finally achieve comprehensive automatic quality control. How to build an automated algorithm to get more accurate dimensions of anchor plates is the further research direction.

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BIM Execution Plan based on BS EN ISO 19650-1 and BS EN ISO 19650-2 Standards

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Abstract

The major requirement of architecture, engineering, and construction (AEC) industry is to effectively manage information gathered from different project stakeholders. A structured guideline requires for managing the process and information productively. The first global Building Information Modeling (BIM) standards, BS ISO 19650-1 and BS ISO 19650-2, are recently published for managing information over the whole life cycle of a built asset using BIM. The research objective of this study is to develop and implement a BIM execution plan (BEP) based on BS EN ISO 19650-1 and BS EN ISO 19650-2, and identify the benefits of using BS EN ISO 19650 standards in the BIM-based construction projects. The results of this study indicate that using ISO 19650 standards in the BIM projects allows stakeholders to (1) demonstrate a significant value proposition for purpose-driven, structured, verified and validated information models, (2) support data exchange in a collaborative information management system efficiently, and (3) minimize data over processing. This study makes a significant contribution to the AEC literature and industry by presenting the development and implementation process of a BIM Execution Plan based on BS EN ISO 19650-1 and BS EN ISO 19650-2 standards, and benefits of BS ISO 19650-based BIM projects. This study will promote the use of ISO 19650 standards in the BIM-based construction projects.

Keywords: *ISO 19650, BIM, building information modeling, BIM execution plan*

Introduction

Implementing standards and performing data management in the construction projects streamline processes that in turn increase the value in the architecture, engineering, and construction (AEC) industry. System and software standardization help professionals minimize the project cost, reduce the need for specialized expertise, consolidate the vendor management, reduce incompatibility, and simplify the infrastructure and the ecosystem (Global Industry Council, 2018). Construction projects may include a number of stages, or gateways, at which information is collated or produced. In such projects, consultants, clients, contractors and subcontractors generate huge amounts of data. Hence, information management becomes more significant for the construction project stakeholders. Information management ensures the parties to manage the resources in the most effective way with the aim of achieving the employer's project requirements (EPRs) (Designingbuildings, 2020). Especially, information management is highly significant in the large-scale construction projects including multiple stakeholders from different disciplines due to numerous data. Such a problem can be solved by applying a standardized methodology throughout the project delivery process. For this purpose, the International Organization for Standardization (ISO) published the first global Building Information Modeling (BIM) standards which are BS EN ISO 19650-1 and BS EN ISO 19650-2. These standards represent a significant step for systematizing the information management requirements in the BIM-based construction projects with an internationally agreed set of concepts and principles (Bimplus.co.uk. 2020). BS EN ISO 19650-1 and BS EN ISO 19650-2 can be applied any sort of construction projects regardless of the project size and complexity. The ISO 19650 series describe the latest industry standards and best practices for managing information in the construction projects. Furthermore, BS EN ISO 19650-1 and BS EN ISO 19650-2 can be used for standardizing the project life cycle that in turn provides a transparent information flow, a good structure for data capture and a clear view for operational process in the construction projects (Global Industry Council, 2018). Currently, any BIM standard or any converted standard does not exist in Turkey. The research objective of this study is to develop and implement a BIM execution plan (BEP) based on BS EN ISO 19650-1 and BS EN ISO 19650-2, and identify the benefits of using BS EN ISO 19650 standards in the BIM-based construction projects. It is expected that this study promotes the use of ISO 19650 standards in the BIM-based construction projects. Using a BS EN ISO 19650 standards based BEP in the construction projects allows parties to demonstrate a significant value proposition for developing structured, purpose-driven, verified and validated information models which supports data exchange in a collaborative information management system efficiently, minimizes data over processing and satisfies employer’s information requirements.

Research Methodology

The research methodology of this study consists of three steps which are semi-structures interviews with subject matter experts (SMEs), literature review and case study, respectively. These methods were selected in order to integrate different perspectives on the subject domain. The information gathered by these research methods was triangulated for the purpose of determining the benefits and requirements of ISO 19650-1,2 standards in the BIM-based construction projects.

In the first step of this study, face-to-face semi structured interviews were performed with two SMEs in order to determine the benefits and requirements of the BIM standards. These interviews were conducted to gather the details of the published standards and the necessity of them in the BIM-based construction projects. In these interviews, the requirements and deficiency of standardization, possible solution recommendations and applications of ISO 19650 standards including the relevant procedures and processes throughout the project design, construction and operation were discussed. Two interviewees are Civil Engineer. One of these interviewees has 25 years of experience in the AEC industry, the other has 10 years of experience. The first interviewee had PhD degree, and works as a Director of Engineering & Design in an international company. The second interviewee has MSc degree, and works as a Senior Information Management Lead in an international company.

In the second step, a literature review was performed. This technique was selected as one of the data collection method in this study because reviewing literature allows researchers to determine the major requirements of the AEC industry, and obtain detailed information on the subject domain. BS EN ISO 19650-1 entitled “*Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM)-*

Information management using building information modelling - Part 1: Concepts and principles" and BS EN ISO 19650-2 entitled "*Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) - Information management using building information modelling - Part 2: Delivery phase of the assets, and Transition guidance to BS EN ISO 19650"* were examined and used in this study for developing the BIM execution plan. In the literature review, keywords were used for reducing subjectivity and obtaining detailed information on the subject matter. Publications with any of the following keywords were identified: 'ISO 19650', 'BIM Standards' and 'BIM and ISO 19650'. Studies published between 2018 and 2020 were analyzed using databases such as Elsevier, IOP Science and Google Scholar in the literature review. The reason of short timeframe is that ISO 19650 standards were published in 2018. A total of five conference papers, one book and 3 journal articles were reviewed manually. The reason of the limited publications considered within the scope of this study is that a few studies based on ISO 19650 standards exist in the literature.

In the third step, a case-study was executed using 2D plans of a construction project. In the case study, a BIM Execution Plan (BEP) was developed according the ISO 19650-1,2 standards. Considering the BEP, 3D BIM model of the project including structural, architectural, and mechanical plans, 4D model of the project including the clash detections, scheduling were performed, respectively.

Development of BIM Execution Plan

BIM Execution Plan is a guideline that explains how the information management aspects of the appointment will be carried out by the project team throughout the project delivery process (International Organization for Standardization, 2018a). This comprehensive document helps project teams identify and execute BIM in the various phases of construction management process (Assemblesystems.com, 2020). Developing a detailed BIM execution plan and effectively integrating BIM into the project delivery process are highly important in terms of project success.

To develop a BEP based on ISO 19650 standard frameworks and requirements, first, the BEP must be provided by a prospective lead appointed party in their tender response. According to ISO 19650-2, the BEP is one of the several resources developed by the lead appointed party (i.e. contractor) on behalf of the delivery team to convey the information management approach (International Organization for Standardization 2018b). [1] BIM Execution Plan is a succinct resource which is supplemented by additional resources to be used by the prospective delivery team if appointed (UK BIM Framework, 2020).

BIM Execution Plan has two different purposes in supporting the tender process that are appointment[1] and information delivery activities. These activities provide evidence to the appointing party[1] that in turn allows the prospective delivery team to manage project information toward any information requirements supported to them (pre-appointment BEP) and present a delivery tool (UK BIM Framework 2020). The appointed delivery team[1] will use the delivery tool for producing, managing, and exchanging project information during the appointment alongside other resources (International Organization for Standardization, 2018b).

[1] Appointments is agreed instruction for the provision of works, goods or services. Appointed party is provider of works, goods or services. Appointing party is receiver of works, goods or services from a lead appointed party. Delivery team is lead appointed and their appointed parties (International Organization for Standardization 2018a)

Although only one BEP exists for each delivery team, there may be two early versions of it; because, BEP is an alive document, and expected from the project participants to keep the document updated in case of any change in information or workflow. The first version is for the (pre-appointment) BEP, and the second version offers an update in case of alteration; thereby, the revised BEP can fulfil the project goals as an appointment resource.

According to ISO 19650-2, a simplified process leading up to the (pre-appointment) BIM execution plan composed of three steps (International Organization for Standardization 2018b). In the first step, ISO 19650-2 Clause 5.1, the appointing party identifies the project wide information requirements and other resources. In the second step, ISO 19650-2 Clause 5.2, the appointing party defines the appointment specific Exchange Information Requirements (EIR) and issues tender information to prospective lead appointed parties. The last step, ISO 19650-2 Clause 5.3, the prospective lead appointed party develops a (pre-appointment) BEP that is returned alongside other tender response resources (International Organization for Standardization, 2018b). Further, the (pre-appointment) BEP should covers seven different key information management assessments as recommended in ISO 19650-2 clause 5.3.2. These assessments provide (1) the details of individuals undertaking the information management function, (2) proposed information delivery strategy, (3) proposed federation strategy to be adopted by the delivery team, (4) the delivery team's high-level responsibility matrix, (5) proposed adds/amends to project's information production methods and procedures (if there are any), (6) proposed adds/amends to project's information standard (if there are any), and (7) proposed schedule of software, hardware and IT infrastructure (International Organization for Standardization, 2018b). As the BEP is a formal appointment resource, it will need to be subject to a change management process throughout the appointment process. Additionally, this document serves as a series of defined project level instructions including guidelines on the method of integrated BIM processes that are followed throughout the project delivery process.

Within the scope of the research a BIM execution plan was developed and implemented in a case study. Development and implementation of BEP was illustrated by IDEF0 diagram (Fig 1). In the first step, a BIM execution plan was developed in accordance with the ISO 19650 standard's frameworks and requirements, and its mechanism was provided with BEP cycle. Then, BIM implementation was performed in a construction project according to the BEP document prepared in the first step.

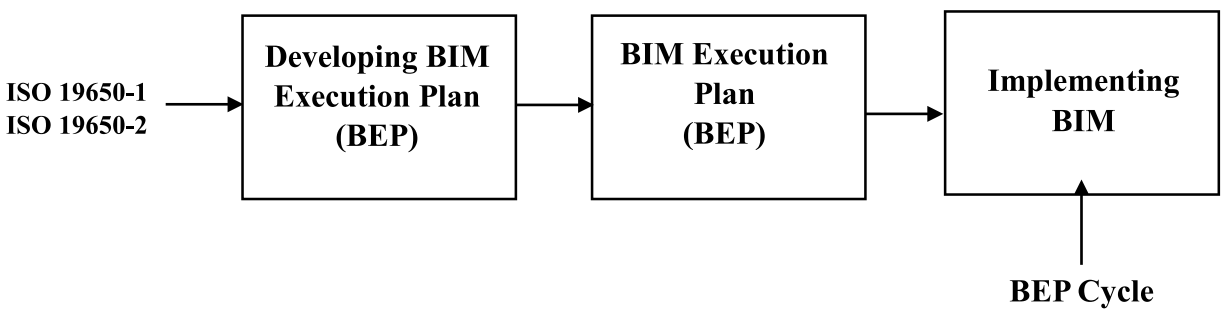

Figure 1: Methodology of BEP.

For this study, a BIM execution plan was generated with the aim of applying BIM process throughout the design process of a project based on ISO 19650-1, 2 standards' frameworks and requirements. During the BIM implementation process, A BEP cycle was applied that consists of eleven steps (Fig. 2).

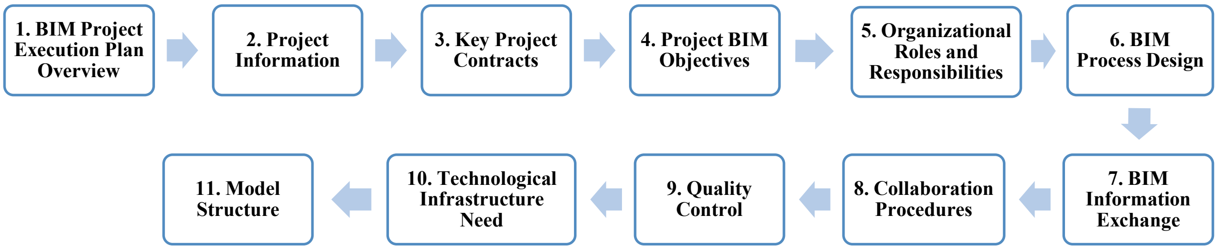

Figure 2: BEP cycle.

Case Study

In the case study, a residential 4-floor building was modeled via Autodesk Revit 2020. The main model of the building, which is the completed version of the project, is demonstrated in Figure 3.

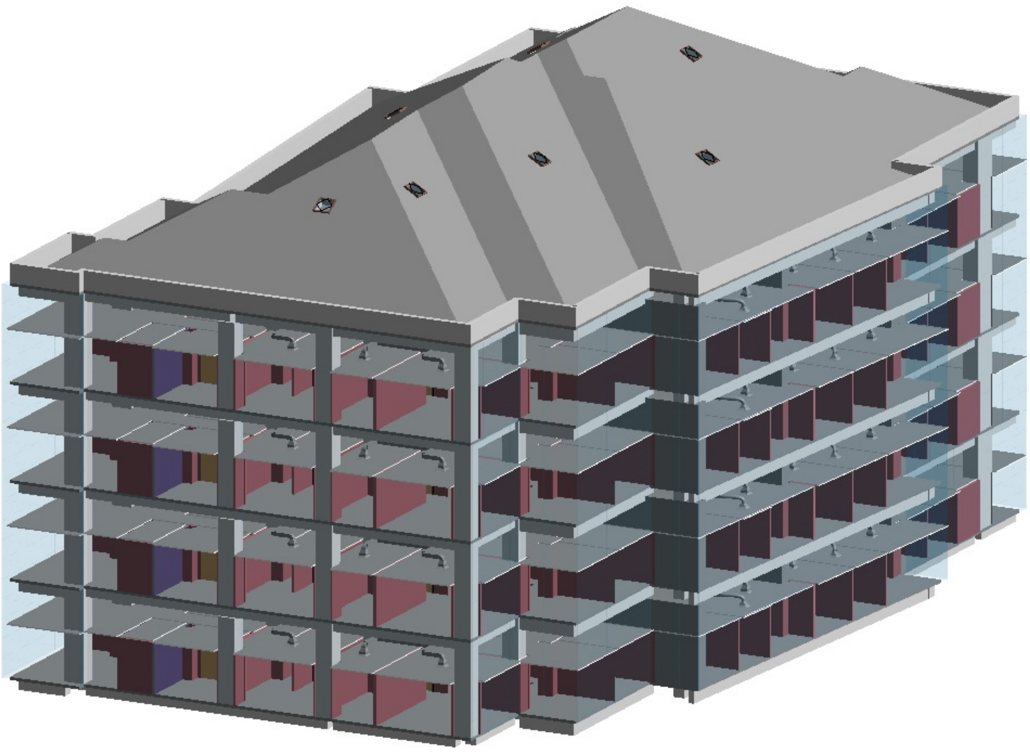

Figure 3: Main model of the building.

BIM process implemented using the BEP which was developed according to ISO 19650-1, 2 standards. In the scope of BIM implementation, the architectural, structural and mechanical 3D BIM model designed using the determined LOD specification via Revit 2020. The structural 3D BIM model was sketched which includes structural elements such as column, beams with respect to 2D model of plan. During drawing process, the models, files, families, views and clashes were entitled, and the quality was controlled correctly according to the constituted BEP, respectively. In the next step, with the use of these models the clash test was launched, detected, and resolved consummately. First clash test was performed between structural and mechanical models. The second test was executed between architectural and mechanical models. Then, the results of clash tests were reported. The clash test conducted by rules such as tolerance was 0.000 m. After performing the clash tests, totally 28 clashes between structural and mechanical, and 508 clashes between architectural and mechanical were detected. The project schedule was created via MS Project 2018 in detail. Totally, the project workflow includes 126 activities. In the last step, the 4D modelling of the project was conducted by linked the imported 3D view of elements with respect to relevant activity from the imported schedule by using Navisworks 2020. Simulation was made after linking all activities with the 3D view in Revit.

Results

According to the triangulation of literature review and face-to-face semi structured interviews with SMEs, eight benefits of using ISO 19650 standards in the BIM-based construction projects were identified. These benefits are represented in Table 1 with their related source of data.

Table 1. Benefits of using ISO 19650 standards.

ID	Benefits of using ISO 19650 standards	Related source of data
A#1	Enable teams to minimize non-value added activities, and increase predictability for cost and time	SMEs (semi structured interviews)
A#2	Identify employers' project requirements in the tender process (i.e., state exchange information requirements (EIR))	SMEs (semi structured interviews)
A#3	Digitalize the process, and prevent paperwork by using common data environment (CDE)	SMEs (semi structured interviews)
A#4	Enable teams to manage the information management process effectively	SMEs (semi structured interviews)
A#5	Provide a data standardization framework by assigning the responsibilities for information delivery	SMEs (semi structured interviews)
A#6	Allow employers/operators or clients to meet particular requirements or respond to their national contexts	ISO 19650-1
A#7	Able to apply to whole life cycle of a built asset and construction projects of all level of complexity	ISO 19650-1
A#8	Reduce the time and cost in producing coordinated information with the use of shared information containers by adopting CDE	ISO 19650-1

According to the SMEs' comments, A#2 is the prominent benefit of using ISO 19650 standards in the BIM-based construction projects. In case of the employer's information requirements (EIRs) may not specify at the beginning of the project, and could cause major problems in terms of cost and time. By the virtue of ISO 19650 standards, employer's information requirements will be identified in tender process, and involved in the contracts that in turn assist project teams to prevent possible non-value added activities such as delays, defects. Further, A#6 and A#2 have a cause-effect relation. If the EIRs are identified in the tender process, these requirements can be met efficiently with the limited non-value added activities. Similarly, A#1, A#3, A#4, A#5 and A#7 have a cause and effect relation. Applying ISO 19650 standards in the BIM-based construction projects ensures the use of common data environment (CDE) that in turn digitalizes the processes, enables project teams to manage the information management process and prevents non-value added activities. Generally, except A#7, the other benefits are interrelated issues. A#6 shows that even intricate BIM-based construction projects can be efficiently managed throughout project life cycle by using ISO 19650 standards.

Discussion & Conclusions

This paper presents the development and implementation process of a BIM Execution Plan based on BS EN ISO 19650-1 and BS EN ISO 19650-2 standards, and identifies eight benefits of using ISO 19650 standards in the BIM-based construction projects by conducting, semi-structured interviews with SMEs, literature review and case study. This study makes a significant contribution to the AEC literature and industry by presenting the development and implementation process of a BIM Execution Plan based on BS EN ISO 19650-1 and BS EN ISO 19650-2 standards, and benefits of BS ISO 19650-based BIM projects. This research will promote the use of ISO 19650 standards in the in the construction projects. Accordingly, this study will increase the awareness of importance for the usage of ISO 19650 standards in the BIM-based construction projects. Results of this study can be used by all stakeholders involved in the BIM-based construction projects.

According to the experts' comments, A#1, A#2, A#3, A#4, A#5, A#6 and A#8 are interrelated benefits and have a cause-effect relation among them. Experts also highlighted that A#2 is the most prominent benefit because if the employer' project requirements are identified at the beginning of the tender process in detail, the project success can be reached in terms of time and cost. A#6 presents that ISO 19650 standards can be adopted in any size and complexity of the construction project throughout the whole project life cycle. All these benefits prove that the use of ISO 19650 standards in the BIM-based construction projects streamline the processes by minimizing non-value-added activities such as delays, paperwork and defects.

Findings of the study indicate that considering ISO 19650 standards framework and requirements in the BIM-based projects allows project stakeholders to demonstrate a significant value proposition which are structured, purpose-driven, verified, and validated information models. The value proposition supports data exchange throughout a collaborative information management system efficiently, minimizes data over processing, and satisfies employer's information requirements. According to the SMEs' comments, using a BEP based on the ISO 19650 allows project teams to conduct the data management system by standardizing the information throughout the project delivery process.

A future direction of this study could be developing a BEP in accordance with ISO 19650 standards for various types of buildings such as hospital, industrial building, and shopping center. Another future direction could be analyzing and developing a BEP considering the ISO 19650-3, ISO 19650-4 and ISO 19650-5.

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Current Practice of Lean Leadership in Construction – An Empirical Study

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Abstract

Lean has been widely applied in construction in the last decade. Aiming to maximize value while minimizing waste, Lean tools are of utmost importance in promoting construction project performance. However, tools represent a small portion of Lean. Using tools without organizational and cultural change does not ensure the lasting success. At this point, Lean leadership plays a crucial role. Lean leadership is a system that develops leaders as well as employees in line with Lean principles to sustain continuous improvement. In construction industry, Lean leadership studies are quite limited. Therefore, in this study, a comprehensive literature review was conducted to understand and interpret the core components of successful Lean leadership revealing the impact of good leadership on the effectiveness of Lean practices. In this respect, Lean leadership attributes are questioned along with providing current practice of Lean leadership in construction projects. Lean leadership is investigated within leader, employees and team, process, and organizational levels. This study contributes to construction management body of knowledge by bringing leadership into question and putting Lean practices forefront of successful project management. The study is expected to guide construction practitioners to educate Lean leaders and potentially diffuse Lean thinking from leaders to employees and organizations.

Keywords: *construction, leadership, lean, project management.*

Introduction

The construction industry relies on on-site production and projects are unique. Complex, dynamic, and fragmented nature of the industry leads to uncertainty (Salem et al., 2006). The construction industry also suffers from high variability, inefficient use of resources and poor productivity. As a result, majority of construction projects are completed with serious deviations from time, budget, and quality (Forbes & Ahmed, 2010; Madanayake, 2015). To overcome these challenges, various efforts are in place. One powerful way to improve construction performance is the adoption of Lean principles. Lean as a term was first emerged in manufacturing industry and it has later been adopted in the construction industry. Lean aims to maximize value for the customer while minimizing all forms of non-value adding activities. Lean construction efforts started with the detection of problems on construction sites. Howell and Ballard (1994) were among the first researchers who detected problems in construction sites related to uncertain schedules and variation in the workflow making an inference to Lean. Theoretical foundations of Lean construction were also developed by Koskela (1992), a Lean pioneer. He proposed Transformation-Flow-Value (TFV) theory of production implying that only conversions add value. Thus, he pioneered the studies investigating the application of Lean philosophy to construction. Then, Lean efforts have gained a considerable popularity in the construction industry.

Howell and Ballard (1998) describe Lean as a change in the process but rather a change in the way of thinking. Lean thinking aims to bring the perfection redefined continuously. Womack and Jones (1996) defined main principles of Lean thinking as customer value, value stream, flow, pull and perfection. With an inference to these principles, Lean construction principles were indicated as customer focus, culture and people, workplace organization, standardization, waste elimination, continuous improvement and built-in quality (Construction Industry Institute, 2005). Previous studies in Lean construction have already proven that various benefits such as time and cost savings, increased productivity, coordination, and commitment are achieved thanks to utilizing Lean tools and methods. Besides, it provides higher quality with higher customer satisfaction and improved worksite safety (Forbes & Ahmed, 2010). Lean practices have successfully been implemented in various construction projects over the years. However, some bad experiences were in place due to misperception or incorrect implementation of Lean ideals. Liker and Convis (2011) highlighted that point improvements from practicing Lean are mostly achieved in the silo of the company but companies failed to transmit those to all organization or maintain in a successful way. The underlying causes of unsuccessful Lean implementation are stated as lack of adequate Lean awareness and understanding, misperception and mis-implementation of Lean practices, lack of top management commitment and support (Bayhan et al., 2019; Demirkesen et al., 2019; Madanayake, 2015). Besides, poor leadership is revealed as one of the main causes of failure in Lean construction implementation (Bettler & Lightner, 2013).

Lean construction research relies both on hard (process-related) and soft (people-related) elements. However, the main research area in Lean construction rather focuses on process-related elements (Gao & Low, 2014). Lean construction is simply perceived as the application of Lean tools to processes, also called as 'Lean Toolbox'. The focus on these tools might result in significant improvements in short term (Dombrowski & Mielke, 2013). However, tools only represent a small portion of Lean applications. The use of tools without a change in culture and system of the organization does not ensure the lasting change (Alves et al., 2012). Therefore, creating awareness towards Lean thinking plays a crucial role in fostering Lean implementation. The missing link between the Lean toolbox and the successful implementation of real Lean is the Lean leadership, which is the complementary part of Lean thinking (Liker & Convis, 2011; Orr, 2005). Hence, this study focuses on Lean leadership and its current practice in the construction industry. The study intends to promote leadership in the construction projects by revealing the underlying components of leadership. In this respect, a detailed literature review was conducted to provide a complete synthesis of leadership studies in the construction industry.

Research Background

Lean Leadership

Successful implementation of Lean requires a different way of thinking. Leadership is of paramount importance for employing this change (Orr, 2005). Leadership is simply defined as "the ability to motivate, influence, and enable individuals to contribute to the objectives of organizations of which they are members" by House et al. (2004). There are various leadership definitions as well as several leadership styles defined in previous studies. However, Lean leadership literature needs to be considered independently from leadership theories (Poksinska et al., 2013; Seidel et al., 2019). An in-depth literature review provided that a considerable amount of studies found that Lean leadership has common fundamental principles with servant, transformational, situational leadership styles and leadership in self-managed teams (Gao & Low, 2014, p. 106; Poksinska et al., 2013; Seidel et al., 2019). In addition, Seidel et al. (2019) proposed that Lean leadership embodies all general leadership theories rather than being an entirely separate style.

Lean leadership has its origins in the Toyota Way leadership. Liker and Convis, (2011) indicated that the efforts of Lean practices would not give the expected results without Lean leadership. In Toyota, leaders are chosen from employees who conceives the work done by going to gemba and who embraces the culture of Toyota Way throughout the years. This way, leaders come into this position as a result of hard work and effort over the years. Rather than outsourced leaders for short periods, Toyota leaders support and improve the culture in line with common long-term vision and objectives. In Toyota leadership, bottom-up approach is used to embrace people for improvement (Liker, 2004).

Lean leadership is defined as a system aiming to develop and empower the leaders as well as employees to sustain continuous improvement. It also intends to seek perfection by implementing the principles of Lean and focusing on the customer satisfaction (Dombrowski & Mielke, 2013). It can also be defined as "a social process, carried out by leaders with personal attributes aligned with lean principles in order to sustain continuous improvement" (Seidel et al., 2019). Moreover, in construction context it is defined as "essential behavior for producing satisfactory outcomes in the process of change" by Bettler and Lightner (2013).

Lean Leadership Models and Attributes

The major portion of the Lean leadership studies in the literature focused on developing leadership models. The in-depth literature conducted in this study came up with a broad analysis of different Lean leadership models proposed in the literature. Liker and Convis (2011) developed a diamond model by adopting the Toyota way Leadership composing of several cyclic steps. These steps are (1) self-development of Lean leaders by following the True North values, (2) coaching and developing others by helping them to self-develop, (3) supporting daily kaizen and encouraging employees to support improvement culture, and (4) creating long term vision and goals in line with True North values. At the core of the diamond model, True North values take place, which is the vision for a Lean organization to achieve perfection through teamwork, continuous improvement, challenge, and respect for humanity.

In another model developed by Dombrowski and Mielke (2013), basic elements of Lean leadership were presented on a conceptual model based on literature review and subsequent survey. This study presented a comprehensive Lean leadership system including five main Lean principles (1) "improvement culture" which aims perfection (2) "self-development" of the leaders, (3) "qualification" of employees, (4) "going to gemba" (real work place), and (5) "hoshin kanri" (policy deployment). On the other hand, Mann (2005, p. 21) proposed that the main elements of Lean management are "leader standard work" (helps to perform productively), "visual controls" (helps to visualize actual work, detect underperformance and take action), "daily accountability process" (helps to control improvements) and "discipline" (helps to sustain other principles).

A considerable portion of the Lean leadership studies focused on describing behaviors and attributes of Lean leaders. Mann, (2005, p. 102) described the Lean leadership behaviors that are essential to become a successful Lean leader such as being "passionate about the potential of Lean", "disciplined adherence to process", understanding and applying "lean thinking", "ownership" that is being responsible for setting direction for change and empowering others, and "effective relations with support groups". Aij et al. (2015) defined Lean leadership attributes including "communication skills", and "motivational skills" along with the model of Dombrowski and Mielke (2013).

In addition, Gelei et al. (2015) proposed a conceptual model regarding ideal Lean leadership based on an extensive literature review and a survey study. According to this study, "communicative", "motive arouser", "improvement oriented", "consultative" and "inspirational" attributes of Lean leaders were found to have a positive impact on leanness. In the empirical study of van Dun et al. (2016), values of effective Lean middle managers were specified as "honesty", "participation and teamwork", "responsibility", "candor" and "continuous improvement". Furthermore, behaviors of effective Lean middle managers were mostly found as relations-oriented (active listening, agreeing, encouraging, giving positive feedback, socializing), and followed by task-oriented (structuring the conversation, informing, task monitoring, delegating) and change oriented behaviors (visioning, asking for ideas).

Lean Leadership in the Construction Industry

Lean leadership is an effective means of promoting the impact of Lean thinking. Some studies showed that Lean leadership has a crucial role in the construction industry and acts as a foundation for successful and sustainable implementation of Lean construction (Achanga, et al., 2006; Ahmad & Ismail, 2017). There are some Lean leadership studies in the construction industry (Bettler & Lightner, 2013; Gao & Low, 2014; Keiser, 2012; Orr, 2005), but the variety of resources is scarce. Hence, this study aims to fill this gap by providing a broad analysis of Lean leadership in the construction industry context. Previous studies in Lean leadership have either focused on defining Leadership behaviors or defining its attributes.

Orr (2005) investigated Lean leadership behaviors on construction sites based on observations and experience. The study implied that Lean leaders must take the initiative to encourage employees for adopting and implementing Lean principles. Further, Lean leaders must teach and engage workgroups enabling challenge, encouragement, and motivation of workers. To ensure this, the essential aspect is creating mutual trust and respect for people. The focus should also be given on process. To maximize value, abnormalities should be eliminated in the process before delivered to next process. Direct observation at the real workplace and frequent site visits enable the quick handling of problems. Further, deploying policy and setting objectives are essential to ensure that employees follow the objectives aligned with the common and clear long-term vision. Lean Leadership in construction like other industries necessitates the change of individuals' behavior. Hence, leaders should understand and guide the change, further, should support and encourage others (Orr, 2005).

Bettler and Lightner (2013) emphasized the significance of Lean leadership in the Lean construction context highlighting the need for a clear and systematic approach. They proposed a Lean leadership application model. While some leadership characteristics such as “honesty” and “respect” are required in any case, some of them shall be adaptable ranging from “directive” to “participative” leadership styles depending on the situation. They indicated that as time, resources, skills and competencies are higher, more participative leader characteristics are needed (Bettler & Lightner, 2013).

Gao and Low (2014, p. 107) described the attributes of Lean leadership depending on servant leadership style. They conducted a comprehensive study about Lean construction management adopting Liker's (2004) Toyata Way model “4P” (Philosophy, Process, People and Partners, Problem-solving). The study implied that Leaders exhibit some Lean leadership characteristics which are “in-depth job knowledge”, “support to the employees”, “understand problems and root cause”, and “encourage employees to develop a kaizen mindset”.

Methodology

In this study, a comprehensive literature review was conducted to understand and interpret the core components of successful Lean leadership scheme. For this purpose, the search term "Lean leadership" was used to search for relevant studies. A qualitative analysis of the identified literature and studies was assessed through and in-depth literature review. The broad assessment of past studies resulted in a complete synthesis of core Leadership behaviors, attributes, and values.

Results and Discussion

Given the research background, it was indicated that Lean leadership models developed by Dombrowski and Mielke (2013) and Liker and Convis (2011) are dominating the Lean Leadership studies. For the construction industry, the number of studies is quite limited. This shows that there is a growing potential for assessing Lean leadership in the construction. Considering the leaders' impact on project success and employee motivation, it is essential to investigate the Leadership attributes and elements for the construction industry.

Lean leadership in construction projects is evaluated as separate levels as leaders, employees, the real workplace, and the organization in the context of this study. Because Lean leadership is not about the leaders only; employees also play a critical role in developing a successful Lean leadership. Besides, the real workplace in other terms the construction site is significant since the value is created at the real workplaces. It is hard to achieve success in the lack of adopting the Lean philosophy at the real workplace. Hence, it is the organization itself considering all these elements essential to create a Lean environment, spread Lean culture, and achieve long-term goals. For a successful Lean leadership, all these levels play a crucial role. Hence, the levels are discussed separately in terms of Lean leadership.

Leader Level

In the context of Lean leadership, leaders do not represent the top or senior management only. Leaders are all employees who influence the work regardless of their positions (Orr, 2005). Lean leaders should develop and improve themselves which is the main characteristic distinguishing them. Self-development is one of the mostly mentioned fundamental attributes in Lean leadership (Aij et al., 2015; Dombrowski & Mielke, 2013). However, self-development is not mentioned in general leadership theories (Seidel et al., 2019). In the very core of self-development, learning by doing, practicing and challenging take place (Liker & Convis, 2011). Lean leaders should learn the core values of Lean. In addition, enthusiasm and passion for lean are desired attributes of Lean leaders (Aij et al., 2015; Aij & Teunissen, 2017; Liker, 2004; Mann, 2005). These promote leading by example and being a role model (Aij et al., 2015; Dombrowski & Mielke, 2013; Goodridge et al., 2015; Orr, 2005; Seidel et al., 2019) that helps to influence others. Hence, they can develop and inspire others (Mann, 2005, p. 104).

In-depth technical knowledge and experience is a must for successful Lean leaders (Gao & Low, 2014; Liker, 2004; Liker & Convis, 2011). Because training employees, supervising, and auditing the process and eliminating wastes without having adequate technical knowledge is unreasonable. Likewise, project management skills are also necessary as a main task of leaders (Mann, 2005, p. 107). Personal skills of Lean leaders have been discussed in many studies. Some of the essential skills of Lean leaders are systems thinking, critical thinking, responsibility, self-discipline, adapting to situations, openness, honesty and humility (Bettler & Lightner, 2013; Gao & Low, 2014; Liker & Convis, 2011; Orr, 2005; Seidel et al., 2019).

Employees and Team Level

Traditional management is likely to see the organizations as machines and people as functions. However, the lean philosophy perceives the organization as a complicated, dynamic and alive system that places the people in the center (Liker & Convis, 2011). In traditional management, the employees are located at the bottom while management is at the top of the organizational hierarchy pyramid. However, in Lean thinking the hierarchy pyramid is inverted upside down, hence, employees are at the top which highlights the importance of employees (Orr, 2005). Employees add direct value to the customer, while leaders do not add value directly, but indirectly by supporting, coaching the employees, and leading them to the True North. As an essential resource, people should be qualified, empowered and delegated (Aij & Teunissen, 2017; Gao & Low, 2014; Liker & Convis, 2011; Seidel et al., 2019; van Dun et al., 2017). Empowerment provides involvement and responsibility of employees which leads to perform independently even in the absence of the leader (Aij et al., 2015).

The essential part of the successful Lean implementation is devoting a long time to develop people deeply (Liker & Convis, 2011). Developing people is the main mission of every leader in the company (Ahmad & Ismail, 2017; Keiser, 2012; Liker & Ballé, 2013; Liker & Convis, 2011; Seidel et al., 2019; van Dun et al., 2017). Development of people includes not only education in classes but essentially training in the real workplace by challenging employees and encouraging them to solve problems (Dombrowski & Mielke, 2013). Leaders should teach standards of work, recognizing abnormalities, solving problems, and making suggestions (Liker & Ballé, 2013). Lean leaders should also teach employees to be teachers and coaches (Keiser, 2012). Because employees are the possible future leaders who should develop and challenge themselves. A famous saying by Toyota leaders “Before we build cars, we build people.” emphasizes the focus on people development and empowerment (Liker, 2004). Moreover, one of the core principles of Lean thinking is respect for people which is also a required characteristic of Lean leaders (Ahmad & Ismail, 2017; Aij et al., 2015; Aij & Teunissen, 2017; Bettler & Lightner, 2013; Emiliani, 1998; Gao & Low, 2014; Orr, 2005; van Dun et al., 2017). It facilitates effective relations between leaders and employees.

In Lean leadership, team has a central role (Dombrowski & Mielke, 2013) and teamwork is considered important for value added activities (Ahmad & Ismail, 2017; Liker and Convis, 2011; van Dun et al., 2017). Teamwork enhances collaboration and coordination rather than bringing individual work into the forefront (Gao & Low, 2014, p. 76). Construction industry is project specific, hence, the teams are changing as well as other dynamic parameters which leads to less time for soft skills. To overcome this challenge, teams should be stabilized with the help of Lean leader to help new members embracing Lean culture. The other point in construction industry is interdisciplinary team members which requires communicational and interpersonal skills (Keiser, 2012).

An essential competency of Lean leaders is communicational skills. Communication between leaders and employees should be informative, clear, transparent, frequent, face to face, and bidirectional for effective relations (Aij et al., 2015). Establishing working relations, mutual trust, active listening, teamwork, and cooperation are some of the enablers of healthy communication. Intrinsic motivation of employees might be achieved by developing commitment, feedback and encouragement, support and recognition, challenging followers, persuasion and appreciation of employees (Ahmad & Ismail, 2017; Aij et al., 2015; Aij & Teunissen, 2017; Gao & Low, 2014; Gelei et al., 2015; van Dun et al., 2017). In addition, Lean leaders should be motivated for developing the potential for Lean and act as a source of motivation for the employees (Aij et al., 2015).

Process Level

Process focus is fundamental for success of Lean. Focusing on process helps to combine technical elements and Lean management together which are highly interconnected (Mann, 2005, p. 95). Process focus emphasizes the need to make improvements on the process and system rather than blaming people and relating problems to employees (Orr, 2005). Going to gemba is one of the mostly mentioned Lean leadership attributes which is a fundamental principle in Lean thinking (Ahmad & Ismail, 2017; Aij et al., 2015; Dombrowski & Mielke, 2013; Gao & Low, 2014; Goodridge et al., 2015; Seidel et al., 2019; van Dun et al., 2017). The gemba principle means being in the real workplace where the real value is created, in construction it is the construction site. Going to gemba includes being in the place where the problem occurred, observation and analysis of processes to identify problems, taking countermeasures, defining root causes and standardizing the processes (Dombrowski & Mielke, 2013). This provides collection of data and realization of the current actual situation.

Standardized work is also mentioned as an important component (Aij et al., 2015; Liker & Ballé, 2013; Mann, 2005; Orr, 2005; Seidel et al., 2019) in the process level. Standardized work maintains a baseline which helps to measure improvement (Liker & Convis, 2011). Standard work specifies an understandable, clear and precise work definition and expectations from the responsible person (Mann, 2005, p. 25). Stating clear expectations helps employees to keep track of their progress and self-evaluation. Daily accountability also ensures following up given assignments (Mann, 2005, p. 69). After standardization of work, leaders should audit to control the process. If necessary, the standards should be improved through kaizen (Liker & Ballé, 2013). Another essential principle focusing on process is visual controls (Liker & Ballé, 2013; Liker & Convis, 2011; Mann, 2005; Orr, 2005; Seidel et al., 2019). Visual controls provide understandable, transparent and clear communications to everyone that enhances information sharing. The main contributions of visual controls are comparing expected and current performance, enabling improvement, enhancing discipline (Mann, 2005, p. 41).

Problem solving is another attribute that is not mentioned in general leadership theories but emphasized specifically as an essential component in Lean leadership (Seidel et al., 2019). One of the responsibilities of Lean leaders is teaching and coaching employees for root cause analysis and problem solving (Seidel et al., 2019). In Lean leadership, problems are seen as opportunities because problem solving reinforces learning from mistakes, which results in continuous improvement (Goodridge et al., 2015). Other than these, implementation of successful Lean leadership in process level requires effective communication, no-blame culture, sharing knowledge, keeping track of improvement and daily kaizen (Aij et al., 2015).

Organizational Level

Keiser (2012) reported that Lean proved to have benefits according to several interviews with construction companies. Although these companies reaped short term benefits, lacking institutionalization of Lean into company culture results in failure in the long term. In construction industry, Lean is mostly embraced through individual efforts of project manager. However, the change should continue even in the absence of the leader (Keiser, 2012). Besides, temporary and changeable relations in construction industry makes cultural change quite challenging (Orr, 2005). Lean leaders play an essential role in establishing the change in culture. Real change could be achieved at the core of the company which targets employees and especially the leaders (Liker & Convis, 2011). The components implied for the leader, employees and team levels could also be applied at the organizational level (Keiser, 2012).

In a Lean organization, vision and goals are aligned with “True North” values and leadership is focused on these core values. Lean core values are defined as the spirit of challenge, kaizen, gemba, teamwork, and respect (Liker & Convis, 2011). In this regard, long term focus in line with the core values is mentioned in a major portion of the studies in Lean leadership (Gao & Low, 2014; Liker & Convis, 2011; Seidel et al., 2019; van Dun et al., 2017). Hoshin kanri (policy deployment) is an important principle to align daily work and actions with vision. It is the specific and consistent plan for aligning the direction of single decentralized activities with the vision of the organization to ensure that they are in the same direction (Dombrowski & Mielke, 2013; Goodridge et al., 2015; Liker & Convis, 2011). In construction, it can be implemented with the use of visual aids, visible, clear and accessible schedules (Orr, 2005).

Continuous improvement is a cornerstone in the Lean leadership, and it is listed in various studies as an essential component of Lean leadership (Ahmad & Ismail, 2017; Aij et al., 2015; Aij & Teunissen, 2017; Gao & Low, 2014; Gelei et al., 2015). Liker and Convis (2011) stated that "Kaizen is an integral part of leadership". Maintenance kaizen ensures eliminating inevitable daily out of standards failures. After the control of the problem, root cause analysis helps taking countermeasures to prevent further problems. On the other hand, improvement kaizen is a never-ending process for perfection. Because there is always waste to eliminate and a room for improvement (Liker & Convis, 2011). Further, like other Lean principles, customer value is also important in Lean leadership (Aij & Teunissen, 2017; Dombrowski & Mielke, 2013; Goodridge et al., 2015; Seidel et al., 2019; van Dun et al., 2017).

Conclusions

Lean leadership plays a critical role in the successful delivery of construction projects. Hence, an empirical assessment needs to be put in place in order to identify core values and attributes of Lean leadership. In this respect, this study investigates Lean leadership in the construction industry context. To discuss the underlying components of leadership, this study provides a detailed synthesis of previous studies and analyzes leadership in terms of different levels as leader, employees and team, process, and organizational level. The results of the study indicated that self-development, motivation and passion for lean thinking, leading by example, technical knowledge and skills of responsibility, self-discipline, honesty, and openness are among the most important attributes of leader level. Coaching and developing employees, empowerment of employees, effective communication, mutual trust and respect, teamwork, motivation, commitment, support and recognition were found to be the important drivers of employee and team level leadership components. Moreover, going to gemba, standardization of work, visual standards, and problem solving were listed as the essential process level attributes of leadership. Finally, organizational culture, continuous improvement, long term focus, hoshin kanri and customer value were identified as the critical parameters of organization level leadership. The study is expected to guide construction practitioners in terms of developing systematic ways to improve their leadership approach and train Lean leaders who are beware of personal values, ethics, and organizational culture. The identified attributes in the four levels support the successful transformation of construction sites towards Lean construction sites and with this the overall performance. In further studies, the influence of the underlying Lean leadership structure presented in this paper can be validated on the project performance.

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Selection of the Most Proper Progress Payment and Approximate Cost Package Program by DEMATEL Method

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Abstract

In construction, a progress payment is a partial payment that covers the amount of work completed by a contractor who has undertaken to carry out construction work. Since construction projects are time-consuming and completed in high budgets, Step by step payment of the works undertaken by the Contractor keeps the owner on the safe side. In the construction sector, progress payments and approximate cost calculations can be prepared faster by package programs. The choice of package programs which perform similar calculations in the market is a multi-criteria decision-making problem. In this study, the most appropriate package selection problem is solved by using DEMATEL method, which determines the interaction between the variables that affect the decision in the multi criteria decision making environment.

Keywords: *DEMATEL, multi-criteria decision making, construction management.*

Introduction

For construction sector, payment is very significant in the construction process of the construction activities owing to the cost of the resources as materials, machines, and manpower’s. One of the construction contract administration function is progress payment valuations and certifications (Demachkieh et al., 2019). Progress payments are made after satisfactory completion of contract requirements and specifications. Basically, progress payments are made when the owner is willing to allow design products to be released for construction, and when constructed products are inspected and found to comply with the approved design. The main objective of this study is to select the most appropriate progress payment and cost approximate package program that is a kind of multi-criteria decision-making problem by using “Decision-Making Trial and Evaluation Laboratory (DEMATEL)” method. This method has been applied in various problems in different sectors such as construction, finance, logistic, health, textiles, social service. Ji et al. (2019) used DEMATEL method to identify the main factors that affect the three-stage construction cost of the fabricated building production, transportation, and installation. Biao et al. (2009) analyzed quantitatively of the relations between contributing factors by the DEMATEL model on the basis of analyzing the inter-relations between each pair of indices with the Delphi method. Song et al. (2015)

established a structural model of risk cause system by using the integration of DEMATEL and the interpretive structure model. Heravi and Charkhakan (2014) presented a framework for predicting and tracing change-formation components in construction projects using the DEMATEL technique.

DEMATEL Method

One of the decision-making methods is DEMATEL (Decision-Making Trial and Evaluation Laboratory) was developed by Fontela and Gabus in 1976 for the solution of problems in economic, political and scientific (Gabus & Fontela, 1972). DEMATEL method is useful to visualize the structure of complicated causal relationships with matrices or digraphs. It can convert the relationship between the causes and effects of criteria into an intelligible structural model of the system (Falatoonitoosi et al., 2013). The steps of the DEMATEL method are as follows (Fontela & Gabus, 1976):

Step 1: Establishing the direct-relation matrix:

Evaluation of the relationship between the criteria is done at this step. The decision maker scores the criteria in pairs based on a four-level scale consisting of scores from 0 to 3. The definition of the scoring scale is shown in Table 1.

Table 1. Scoring scale.

Linguistic Expression	**Numeric Values**
no influence	0
low influence	1
high influence	2
very high influence	3

As a result of the decision of the decision maker, A direct relationship matrix in dimension nxn is obtained to represent the number of n criteria / factors. a_{ij}, which constitutes the elements of matrix A, shows the degree to which criterion i affects criterion j.

Step 2: Obtaining the normalized direct-relation matrix:

Based on the direct relationship matrix A, the normalized direct relationship matrix denoted by X is obtained with the help of the following equations, respectively.

$$X = k.A \quad (1)$$

$$k = \frac{1}{maks \sum_{j=1}^{n} a_{ij}}, \quad (2)$$

$$i, j = 1,2, \dots, n \quad (3)$$

With the equations (1), (2), (3) below, the sum of the direct relation matrix's rows and columns are calculated. The maximum value is selected from the row and column totals. The elements of matrix A are divided by this value. Thus, X normalized direct correlation matrix is obtained, each element of which is normalized between 0-1.

Step 3: Calculate the total-relation matrix:

By using the equation (4) shown below by the unit matrix I, the total relationship matrix T is obtained.

$$T = X(1 - X)^{-1} \tag{4}$$

Step 4: Determination of affecting and affected criterion groups

Row total are taken from the T total relationship matrix, thus obtaining the D_i matrix in dimension $nx1$. Column totals of the total relationship matrix and then transposed of these total values are taken. Thus, $1xn$ column totals and then transposition of these total values will get R matrix in size $nx1$.

$$T = \left[t_{ij}\right]_{nxn}, i, j = 1,2, \dots, n \tag{5}$$

$$D_i = \left[\sum_{j=1}^{n} t_{ij}\right]_{nx1} = [t_i]_{nx1}, i = 1,2, \dots, n \tag{6}$$

$$R_i = \left[\sum_{i=1}^{n} t_{ij}\right]_{1xn}^{t} = \left[t_j\right]_{nx1}, j = 1,2, \dots, n \tag{7}$$

Step 5: Determination of threshold values

The sum of rows and sum of columns of the total relation matrix T in Equation (5) are computed as an D and R $nx1$ vectors.

As a result, while i = j the sum $(D_i + R_i)$ that is called "Prominence'' proves the degree of importance role of criterion i in system and also gives an index that shows the total effects both given and received by criterion i. Likewise, the (D_i, R_i) that in called "Relation" shows the net effect that criterion i donates to the system. When (D_i, R_i) is positive, criterion i will be to the cause group and when (D_i, R_i) is negative, criterion i is a net receiver (Falatoonitoosi et al., 2013).

Case Study

A construction company decided to purchase a computer program to make progress payments and approximate cost calculations. As a result of market research, it was determined that 3 criteria were important: *price*, *user-friendly* and *compatibility with CAD software*. In addition, the company owners thought that there was an interaction between the selection criteria.

Firstly, by taking the opinions of a group of experts consisting of technical office manager, technical office chief and technical office engineers totally 6 people who are experts in their fields, by means of the scale in Table 1. As a result of the pairwise comparisons, A direct relation matrix shown in Table 2 was obtained.

In Table 2, as an example of binary comparisons, a_{12}= 2.00 means that the price criterion highly affects the user-friendly criterion.

With the help of equations in the 2nd step, the X normalized direct relationship matrix presented in Table 3 was obtained.

Table 2. Relationship matrix between criteria.

	Criteria			
	Price (C1)	User-Friendly (C2)	Compatibility with Cad Software (C3)	**Total**
C1	0	2	3	5
C2	2	0	2	4
C3	3	1	0	4
Total	5	3	5	

Table 3. Normalized direct relationship matrix.

	Criteria		
	Price (C1)	User-Friendly (C2)	Compatibility with Cad Software (C3)
C1	0	0,4	0,6
C2	0,4	0	0,4
C3	0,6	0,2	0

As seen in Table 3, all values in the normalized direct relationship matrix are in the range of 0-1. After the normalized direct relationship matrix, the T total relationship matrix shown in Table 4 was obtained using the equation in the 3rd step. Depending on the number of evaluation criteria, 3x3 dimension unit matrix was used in this equation. The values shown in Table 4 were obtained by applying equations in the 4th step to the T total relationship matrix.

Table 4. Effect / Relationship values of the criteria.

	Criteria			Effects / Relationships			
	Price (C1)	User-Friendly (C2)	Compatibility with CAD Software (C3)	D	R	D+R	D-R
C1	0,52	0,28	0,44	1,24	1,2	2,44	0,04
C2	0,16	0,24	0,16	0,56	0,56	1,12	0
C3	0,52	0,04	0,44	1	1,04	2,04	-0,04

When the degree of affecting the criteria is examined, it can be said that the price criterion has the highest degree of affecting other criteria with $D_2 = 1{,}24$, on the other hand, the price criterion with the value of $R_2 = 1{,}2$ has the highest degree of effect from other criteria. When we look at $D_i - R_i$ the impact values of the criteria, the degree of impact with positive values is "net effecting" the price and user-friendly criteria respectively. The compatibility with CAD software criterion, which has a negative impact rating, is "net affected".

Finally, an effect-relationship diagram was drawn by determining the threshold value. The threshold value for this problem was accepted as 0,2. The effects above this threshold are presented in Figure 1 in the effect-relationship diagram, drawn by using $D_i + R_i$ and $D_i - R_i$ values.

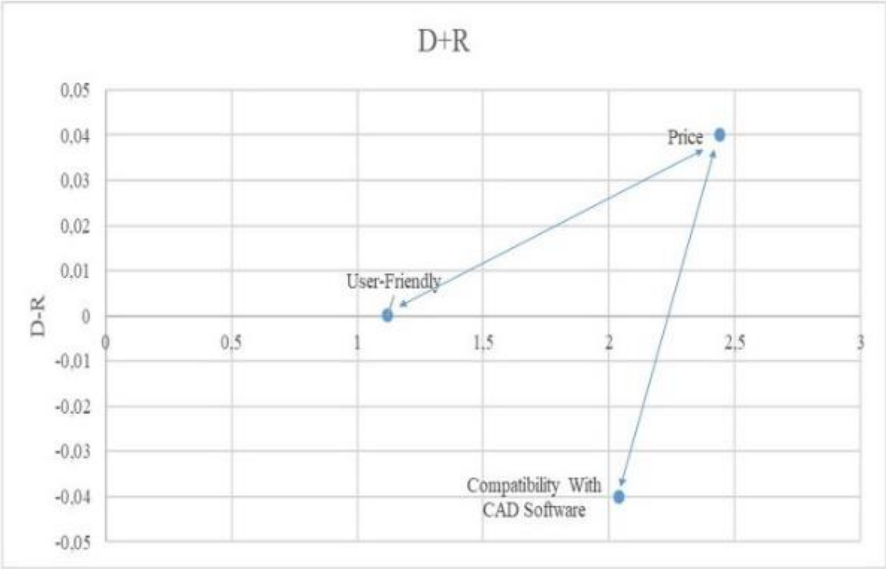

Figure 1: Effect / Relationship diagram.

Results

Progress payment and cost approximation is significant for construction companies. Every activity that takes place in executing a construction contract revolves around the contractor satisfactorily completing some requirement so that it can get paid, or the owner determining that a given requirement or specification has satisfactorily been completed so that the contractor get paid. In this study, by using DEMATEL (decision making trial and evaluation laboratory) method to analyze the structure of the influencing factors of purchasing a package program for progress payment and approximate cost to a construction company, it is getting the structure of the effect relation among these factors. The result indicate that criterion of price has a highest effect degree. Results of DEMATEL applied the case study showed the potential of this method in MCDM, so it can help decision makers for acquiring more strong decisions.

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Investigation of Organizational Perception on Contract Types and Shop Drawings Practices on Construction projects in Turkey

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Abstract

Many variables affect construction projects. The type and model of the contract stand out as the main administrative feature of construction projects. Depending on the terms of the contract, construction projects proceed with the drawings approved on the construction site. Shop drawings practices are needed since it is impossible for plans and drawings to reveal every detail works. Shop drawings practices may increase the price and duration of the project and may lead to conflict between the project parties as it facilitates the construction practices and improves the quality of the works. This study aims to investigate the perceptions of construction organizations on the risks of contract models and shop drawings practices according to the different variables and work items in construction projects. In this context, it is aimed to identify top risky technical and administrative variables of construction projects based on a survey of construction professionals in Turkey in terms of the severity of shop drawing practices. According to the characteristics of organizations, it has been seen that the organizations showed different approaches to the top risky technical and administrative variations regarding the effect of the shop drawings practices.

Keywords: *project variables, construction drawings, shop drawings.*

Introduction

Pietroforte (1997) stated that "a shop drawing is a set of drawings are produced by contractors and suppliers under their contract with the owner". Fisk and Reynolds (1997) noted that shop drawing is a link between design and construction and such drawings are submitted to the owner's architect/engineer by a contractor or subcontractor.

Shop drawings practices are needed since it is impossible for plans and drawings to reveal every detail of every aspect of the work (Fisk & Reynolds, 1997). While plans and specifications often define the overall nature of the project, construction methods are expected to be determined by the contractor. Owners and architects / engineers expect this expertise from the contractors. Shop drawings also provide a way for contractors to propose and architect/engineers to approve a particular method of accomplishing a special requirement (Fisk & Reynolds, 1997).

Shop drawings practices may be mandatory due to the condition of the project contract and procurement model. Shop drawing practices can lead to an increase in the project's budget and duration, and as a result, can have a significant influence on project parameters.

Due to the variability of location and time of the projects to be implemented, construction projects are never the same. Besides this, construction projects consist of different technical and administrative variations. The type and model of the contract stand out as the main administrative feature of construction projects. The tendency of the construction projects to the design changes was examined on the basis of the various technical and administrative variables of the construction projects.

This study aims to investigate the severity of shop drawings practices on construction projects according to the different technical and administrative variations in construction projects based on a survey of construction organizations in Turkey. The research findings were compared to emphasize the differences and consensus of the opinions of the organizations with respect to the status of shop drawings practices.

Existing Knowledge

Marzouk and El-Rasas (2014) and Abd El-Razek et al. (2008) indicated that, in Egypt, delay in preparation and waiting for approval of shop drawings has become one of the top significant contractors and consultant originated delay factor, respectively. Delay in the approval of shop drawings is one of the most critical owners originated attributes affecting delay in residential construction projects in India (Doloi et al., 2012; Meghai & Rajiv, 2013), and in the United States of America (Baldwin & Manthei, 1971).

Research by Bramble and Callahan (2011) declared that the delay in reviewing the shop drawings was one of the most important design-related delay in the US construction projects.

Cox et al. (1999) conducted a case study on construction projects of four different characteristics to investigate the effects of the change order request (COR) process on construction projects. Authors were emphasized that the projects were exposed to 5% to 8% changes in the drawing and specifications after the contract process due to the shop drawings and design deficiencies in the tender documents.

Inadequate or improper checking of shop drawings has been cited as one of the common causes of construction failures in Europe (Petroski, 1985; Yates & Lockley, 2002). In addition, in Europe, before approving shop drawings, improving of the structural connection design details, reviewing all shop drawings by design engineers including bar list and bending details, and checking the field specification appropriately are recommended as common methods to reduce failure in construction (Petroski, 1985; Yates & Lockley, 2002).

Research Method

A questionnaire was designed to examine the severity of shop drawing practices on the basis of various technical and administrative variables on the construction projects in Turkey.

The survey was conducted with civil engineers and architects on behalf of their organizations. A respondent from each organization was included in the survey to make an organizational based assessment. Respondents were asked to evaluate the questionnaire on the basis of reinforced concrete building projects up to 5000 m2. Also, respondents were asked to carry out the survey based on the organization's experience, as they participated in the name of the organization. A total of 91 organizations participated in the survey (See in Table 1).

Table 1. Distribution of respondents' organizations.

Type of Organization	**Number of Respondents**
Contractor	47
Consultant	25
Owner	19
Total	91

The research results were classified according to two types of organizational characteristics. While the contractors were considered as a separate organizational feature, the consultant-project owners were handled together. In this way, the negativity caused by the low number of owners surveyed was compensated.

The factor weighting method was used to collect data in the questionnaire. In the questionnaire, a five-point Likert scale was used to collect data. Respondents weighed the importance of the factors according to the assessment parameters.

At first, participants were asked to scale the frequency of design changes in construction projects according to different contract types.

The frequency Index of contract types were calculated by equation (1) presented in the following:

$$F.I.(\%) = \frac{\sum W_i \times X_i}{A \times N} \tag{1}$$

Where,

F.I. (%): Frequency Index of Contract Types

Wi: The weight assigned on Likert scale given to contract types by the respondents and ranges from 0 to 4, where; 0: Never, 1: Less, 2: Moderate, 3: Frequent, 4: Very Frequent

Xi: Number of choice of the (i) th weight in the Likert scale for the contract types.

A: is the highest weight (i.e. 4 in this case) and;

N: is the total number of respondents

Next, participants were asked to scale the frequency and severity of shop drawing practices according to various work items in the construction projects.

Top significant factors regarding the shop drawing practices were specified by calculating the Relative Importance Index (R.I.I.) scores with respect to different assessment parameters.

The factors level of significance was measured by calculating relative Importance Index scores (R.I.I.). Factors Importance Index scores were calculated using equation (2):

$$R.I.I.(\%) = \frac{\sum W_i \times X_i}{A \times N} \tag{2}$$

Where,

R.I.I. (%): Relative Importance Index

Wi: The weight assigned on Likert scale given to each factor by the respondents and ranges from 0 to 4, where; 0: Never, 1: Less, 2: Moderate, 3: High, 4: Very High

Xi: Number of choice of the (i) th weight in the Likert scale for the factor.

A: is the highest weight (i.e. 4 in this case) and;

N: is the total number of respondents

The Risk Significance Index (R.S.I.) of the work items are calculated by equation (3) presented in the following:

$$R.S.I.(\%) = \frac{F.I. \times AV.S.I.}{100} \tag{3}$$

Where;

R.S.I. = Risk Significance Index of Work Items; F.I. = Frequency Index; AV.S.I. = Average Severity Index in Equation (4):

$$AV.S.I.(\%) = \frac{C.I. \times T.I}{2} \tag{4}$$

Where;

AV.S.I. = Average Severity Index of (i) th factor

C.I. = Severity of Cost Overrun Index; T.I. = Severity of Time Overrun Index

The highest risk significance index refers to the top risky work item, while the lowest refers the minimum risky work items in terms of shop drawings implementations.

The frequency of shop drawings practices may vary depending on the factors encountered in the construction project as the construction projects are in uncertain circumstances and exposed too many variables.

In this context, the rate of frequency of shop drawing practices was estimated according to the factors causing shop drawing practices by equation 1. The higher the frequency index refers to the more frequent cause, while the lower refers to the less frequent factor causing the implementation of shop drawing practices.

Results

At first, the frequency of design changes in the construction projects was assessed according to the contract type. Relative Importance index scores for the frequency of design changes were shown in table 2. The highest number refers to the most design changes, while the lowest number represents the least design changes in construction projects. Contractors and Consultant-Owner were stated that the highest design changes were realized in unit price contract type. The incentive for cost/time overruns in projects in lump sum contracts is more pronounced than cost plus contracts. Cost and time overruns are more prone to occur in the lump sum projects (İlter & Çelik, 2018).

Likewise, all respondents were stated that the least design changes were realized in the fixed price contract type. The highest relative importance index average was realized in the contractor's assessments. This finding interpreted that; construction projects are more prone to design changes according to the contractors.

Table 2. Frequency of design changes according to the contract types.

	Frequency Index (F.I.)	
Contract Types	**Contractors**	**Consultant-Owner**
Fix Price	0.41	0.19
Lump Sum	0.50	0.42
Unit Price	0.62	0.69
Cost + Fee	0.45	0.29
Average	0,5	0,4

The Risk Index of work items is presented in Table 3. According to the contractors, the top risky work items are those undertaken for the "Frame Construction (superstructure)" construction. While, according to the consultants and owners, construction works undertaken in “post frame construction (post superstructure)” process were indicated to be top risky work items. However, the risk index realized in "Consultant-Owner" assessment was relatively low compared to the contractors. This reveals that, according to the contractors, shop drawing practices constitutes higher risk in construction projects.

The Frequency index of factors causing shop drawings practices in construction projects were presented in table 4. All organizations emphasized that, the most common cause of shop drawing practices is due to design errors and deficiencies. Apart from this, the highest frequency index was realized in the contractor’s assessment (See in Table 4). This has revealed that, according to contractors, construction projects in Turkey are more demanding for shop drawings practices.

Table 3. Risk significance of work items according to the organizations.

	Risk Significance Index (R.S.I.)		
Work Items	**Contractors**	**Consultant-Owner**	**Overall**
Excavation and Foundation	0,44	0,41	0,43
Structural Frame	0,51	0,40	0,45
Electrical	0,32	0,26	0,29
Wastewater	0,24	0,17	0,21
Domestic Water	0,24	0,18	0,21
Construction works after structural frame	0,47	0,43	0,45
Doors, Windows, and other fine works	0,42	0,39	0,41
Average	0,38	0,32	0,35

Table 4. Frequency index of causes of shop drawings according to the organizations.

	Frequency Index (F.I.)		
Causes of Shop Drawings	**Contractors**	**Consultants-Owner**	**Overall**
Errors/ Insufficiencies in Design	0,80	0,73	0,76
Inconsistencies between different design disciplines	0,79	0,68	0,74
Inconsistencies between drawings-specifications	0,71	0,59	0,65
Errors / Insufficiencies in Specifications	0,63	0,58	0,60
Low Constructability Design	0,61	0,54	0,58
Health and Safety Precautions	0,51	0,36	0,43
Insufficient ground investigation	0,52	0,36	0,44
Errors in Construction Methods	0,50	0,47	0,49
Lack of Contractor’s experience	0,56	0,48	0,52
Supervisor characteristics	0,48	0,38	0,43
Changes in Technology	0,44	0,43	0,43
Shortage of Materials	0,48	0,49	0,49
Average	0,59	0,51	0,55

Conclusion

The main purpose of this study is to examine the risk status of shop drawings practices, according to various technical and administrative features of construction projects. In this study, it is aimed to raise awareness about the measures to be taken in construction projects in order to reduce the risks of shop drawings practices in construction projects. The main implications of this study are presented in the following.

According to the opinions of both contractors and consultant-owner, it is observed that the most common shop drawing practices in construction projects are realized with unit price contracts.

In general, it has been observed that contractors are more concerned and more complaining about the risk perception of shop drawing practices, as higher indexes resulted in contractors' evaluation. Project performances may be negatively affected due to shop drawing practices. Any organization involved in the project may have to cover additional costs arising due to the shop drawings practices. In general, consultants and project owners take a more effective role in the formation of the technical and administrative structure of the project in a comprehensive manner than contractors. It has been observed that organizations exhibited different approaches with respect to shop drawing effects according to their organizational characteristics. As general, organizations were observed to show a stance in accordance with their interests.

Shop drawings may have a beneficial influence on improving the quality and consistency of the works, as well as cause an increase in the project price. Construction projects may face difficulties in completing the project within the contract price and duration, when the shop drawings are the conditions of the contract. The bid price of the works may vary due to the extreme detail content of the shop drawings. It will be beneficial for contractors to prepare bids during the tender process, as taking into account the impact of shop drawings practices on increasing the cost of the project.

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A Lean Implementation Framework for the Turkish Construction Industry

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Abstract

Lean has been widely adopted in the construction industry since the last decade. However, benefits of practicing Lean has not yet been well understood by the construction practitioners. The reason behind is that implementing Lean is either though to be costly and requires special expertise for hands-on practice. To overcome this challenge, this paper presents a Lean implementation framework for the construction practitioners. In this respect, a questionnaire was conducted with professionals in Turkish Construction Industry to identify need, assessment, and implementation scheme. The framework indicates the importance of planning and management in the implementation process of Lean Construction (LC). Moreover, it provides a roadmap for the organizations to implement LC successfully. The framework encourages organizations to analyse and identify their current state and create their own value stream mapping along with developing a new policy and strategy for the lean culture. The results of this study are expected to guide construction practitioners with the implementation of LC and practice the components of the framework developed in this context of this study.

Keywords: *Lean Construction, Turkish Construction Industry, Lean Tools, Implementation Framework*

Introduction

The construction industry in Turkey has an importance role on the economy. However, since 2015, it is observed that its share in GDP has decreased in parallel with the shrank in the growth momentum of the industry (KPMG, 2020).This also proves that the construction industry is facing problems arising from the internal dynamics. Since construction projects are uncertain and complex in nature (Ansah et al., 2016), managing them with conventional approaches result with delays, cost, and time overruns (Sorooshian, 2014). Moreover, construction industry suffers from lack of investments in terms of innovating the industry, lack of well-trained workers, productivity losses, lack of recovery plan and lack of collaboration (Koutsogiannis, 2017). Given this fluctuation in the industry, construction companies need to change in order to remain competitive. Many countries in the word, especially United Kingdom, respond to this need by transforming their industry from conventional approach to Lean construction (LC).

Lean construction is considered as a new philosophy to manage construction processes (Dinesh et al., 2017). However, LC is not just a change in procedure, it is rather a radical change of the entire business model, construction, and way of thinking (Howell & Ballard, 1998). Hence, it is difficult to expand the philosophy within the industry due to resistance for change. To expand adoption of LC, it is necessary to provide a complete guide for industry practitioners in terms of encouraging them utilizing Lean practices and make them benefit from the practices in the best manner. Considering these barriers behind Lean adoption and industry needs, this paper provides a Lean implementation framework for the Turkish Construction Industry. In the first step, the study presents the research background based on an in-depth literature review. Following the research background, the study explores the current situation of LC practices in the Turkish construction industry. Then, the study sets out an implementation framework for LC in Turkish construction industry.

The Concept of LC

Lean was first articulated as a term in the manufacturing industry by Taiichi Ohno in 1988. Taiichi Ohno, a production engineer from Toyota, developed Toyota Production System after he witnessed the manufacturing industry is producing a lot of waste. LP is based on optimization of production performance to a standard of perfection for fulfilling the unique requirements of customers (Howell, 1999). It predominantly aims to define value from costumer perspective and reduce the waste from the production process while improving the quality of product (Erol et al., 2017). With the book *The Machine That Changed the World,* published by Womack et al (1990), Lean production became a widely known concept and adopted by several industries. The proven success of Lean production in the manufacturing industry thrilled the construction industry for implementing Lean principles in the construction projects. Hence, the significant improvement of Lean production was researched also in the construction industry (Salem et al., 2005)

LC is derived from lean production (LP) principles (Salem & Zimmer, 2005), based on the Toyota Production System developed under the leadership of Taiichi Ohno (Ghosh & Burghart, 2019). The Lean construction efforts started with the development of the Last Planner System (LPS) discovered by Glenn Ballard and Gregory Howell in 1990s. The two researchers witnessed inefficiencies and deficiencies in either planning and execution of construction projects due to low productivity and high waste. Hence, they proposed the LPS to design out construction processes. LPS is a tool for production planning and control based on LC principles (Rotimi et al., 2016). It allows planning on weekly basis according to promises, while at the same time providing a master plan, enabling full planning and program development. (Rotimi et al., 2016). Moreover, it provides continuous improvement by analysing the main causes of failure with metrics along with the learning component (Forbes & Ahmed, 2010). LPS improves the predictability and reliability of construction production by providing collaborative framework (Mossman, 2015) that provides coordination, commitment, and transparency between all stakeholders of the project (Pellicer et al., 2015).

While the Last Planner has evolved in 1990s, Lauri Koskela, a Lean mastermind, also studied the adoption of Lean in the construction industry and became one of the leading researchers who contributed to the expansion of the concept in the (Sarhan & Fox, 2013). Koskela (1992) introduced the TFV(Transformation-flow-value) theory to the construction industry, demonstrating an understanding of creating better value for the customer, thereby forming the basis of the LC (Abdelhamid, 2004). However, LC was first coined as an expression in August 1993 in the first meeting of International Group of Lean Construction (IGLC) (Forbes & Ahmed, 2010). Followingly, Lean Construction Institute (LCI) was co-founded by Ballard and Howell in 1997 (Forbes & Ahmed, 2010) to promote adoption of Lean principles in the construction industry (Common et al., 2000). Later, with the Egan report published in the UK, LC was promoted for the industry, and since then it has spread all over the world (Pekuri et al., 2012).

LC is a system, which relies on planning and control that enhances project performance (Strickland & Kirkendall, 2010). It aims to improve the performance by eliminating waste from the construction process, increasing productivity, enhancing health & safety, and fulfilling the client's requirements (Ansah et al., 2016). Eliminating wasteful activities which does not add value to the process enables the smooth flow of the process (Radhika & Sukumar, 2017). This makes the workflow more predictable, the project time is reduced and the project performance increases as a result (Emuze & Ungerer, 2014). Ballard (2000) contributed to the LC efforts by proposing LPS. LPS is one of the oldest Lean techniques and it allows effective planning and collaboration for the organizations seeking perfection and aiming to eliminate waste. Apart from LPS, there are other LC tools that organizations gain considerable benefits with implementing LC, which in turn results in reduced waste and enhanced value (Arif et al., 2019). Some of these tools and techniques are 5S, JIT (Just-in-Time) delivery, Kanban cards, Kaizen (continuous improvement), concurrent engineering (CE), visual management, Andon, and VSM (Value Stream Mapping). These tools and techniques are either used to eliminate waste or prevent error in the construction processes. The benefits of using such tools and techniques have already proven in various studies (Bajjou et al., 2019; Demirkesen, 2020; Demirkesen & Bayhan, 2020).

LC in the Turkish Construction Industry

Lean construction studies in the Turkish construction industry are scarce. There is limited research, which investigated LC in the context of Turkish construction. For example, Polat and Ballard (2004) researched the main causes of waste in Turkish construction industry and they proposed an initial framework based on LC and Lean Project Delivery System to remove waste. Moreover, Polat et al. (2017) investigated the root causes of construction and demolition waste in Turkey. In their study, they promoted the utilization of LC tools such as CE, LPS, Kanban, off-site production, and JIT. In another study, Tezel & Nielsen (2013) studied the Lean conformance among Turkish contractors. According to their research, there is a lack of awareness of Lean construction among Turkish contractors. However, they concluded that the strong base of the industry is promising for adopting LC principles.

Previous studies highlighted that lack of awareness, lack of training, lack of knowledge among workers, and lack of information sharing are the main barriers hindering the adoption of Lean construction and its implementation in the construction industry (Alarcon et al., 2002; Forbes & Ahmed, 2011; Sarhan & Fox, 2013). Same barriers also apply to the Turkish construction industry. However, the reasons behind such barriers may vary. For example, Turkish construction industry is advancing rather with conventional methods and it has a conservative nature in practice, which eventually leads to resistance for change. The construction industry is considered as the leading sector in Turkey and profit margins are quite high. This results in unwillingness for adopting the change. However, there has been a considerable shrinkage recently, which is an alarming situation for the future of the industry. Hence, the industry must change the direction towards adopting the chance and developing ways for innovating. Thus, this study presents a framework, which will lead industry practitioners to adopt Lean principles and implement Lean construction in their projects for promoting the change and experiencing higher success rates.

The scarcity of resources in the Lean adoption among Turkish contractors formed the basis for this study. Since there is much evidence that Turkish contractors have low awareness towards Lean applications, the study aims to reveal such awareness and present the Lean applications that contractors might benefit and utilize in their projects.

Methodology

To observe the awareness for Lean construction in the Turkish construction industry, a questionnaire was designed and administered to construction professionals operating in Turkey. The questionnaire attempted to measure the general awareness of LC in the Turkish construction industry. The questionnaire was circulated over social networks with professionals operating in the Turkish construction industry. A total of 52 participants responded to the questionnaire. The questionnaire was composed of more than two sections. However, only two sections with 4 queries are included in this research due to space limitations. The first part of the questionnaire intended to collect data about respondent profile. Queries in this part are related to the background of respondents. The second part of the questionnaire aimed at measuring the current awareness of LC in the Turkish construction industry. The questions in these both sections were closed-ended questions with multiple-choice nature.

Analysis of Findings

Figure 1 represents the distribution of respondent's profession. By profession, 52% of the respondents were architects, 2% were interior architects, 34 % were civil engineers, 4% were mechanical engineers, 2% were geological engineers and 6% were project managers. Figure 2 presents the main business activity of organizations. According to this figure, 17 % of the respondents work for a client company. 2 % is a client representative. 33% of the respondents are on the contractor side. The 38% participants work for an architecture and/or technical design company and 2% of them were supplier. There are also participants as consultants or who work for a building audit company, which has a percentage of 8 in total.

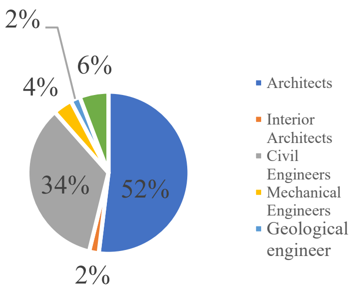

Figure 1: Respondents by profession.

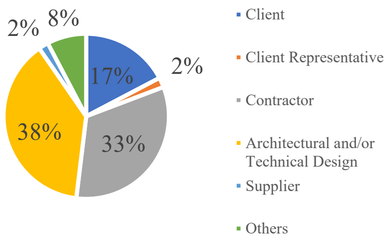

Figure 2: Organizations' main business activity.

In the second part of the questionnaire, the participants were asked to define the levels of understanding and / or use of LC practices in their organizations. Since the questionnaire consists of closed-ended questions, the answers were classified by numbering from the highest frequency to the lowest. Table 1 shows this classification.

Table 1. Level of lean understanding/usage frequency.

	Number	Frequency
No knowledge about LC and there is no evidence that proves the usage of LC principles, tools, and techniques	35	70.00%
Although there is awareness about LC, it is not implemented in the organisation.	14	28.00%
Implementation of LC is systemically evidenced in action.	1	2.00%
LC is interrelated as a whole and happens automatically.	0	0.00%
LC is status quo which is challenged to improve further.	0	0.00%

The analysis of the questionnaire data indicated that the majority of the participants (70%) either stated that they do not have an up-to-date information about LC or their organizations do not implement it. 28% of the participants reported that they have a general idea about LC and its applications, but they indicated that they have had no chance to implement it yet in their organizations. The remaining 2% indicated that their organizations do implement LC in a systemic way.

Lean thinking first appeared in the manufacturing industry. It is now being implemented in the Turkish manufacturing industry with success. However, the analysis of questionnaire data showed that the Lean construction awareness is pretty low in the Turkish construction industry. According to the questionnaire data, 70% of the participants stated that they do not have awareness for LC. On the other hand, Tezel and Nielsen (2013) mentioned that even though LC is foreign to the companies in Turkey, there is a high level of conformance to the LC practices.

This requires the development of either an implementation guide or roadmap so that the awareness is created for a broader community. To fill this gap, this study developed a Lean construction implementation framework to guide industry practitioners with the best Lean tools and techniques and make them benefit from them at maximum.

LC Implementation Framework for the Turkish Construction Industry

LC frameworks, also known as LC models, are guidelines for implementing LC strategies and control the performance levels of construction projects (Sarhan et al., 2019). Hence, a generic framework is needed to promote the implementation of LC and eventually improve performance levels in the construction projects. This study proposes such framework to provide a road map for the Turkish contractors aiming to utilize LC tools and techniques.

The proposed framework is based on the Lean Enterprise Institute (LEI)'s action plan (https://www.lean.org/whatslean/gettingstarted.cfm) that aims to guide the construction industry for LC implementation efforts. The framework comprises of four stages (See Figure 3). Stage 1 identifies the need for change. It sets out the actions necessary for the implementation of the set goals. Stage 2 directs the development of strategies and policies needed to implement LC. Stage 3 presents the phase, where the process begins for the strategies and plans determined. Last stage presents the selection of tools and techniques necessary to implement Lean.

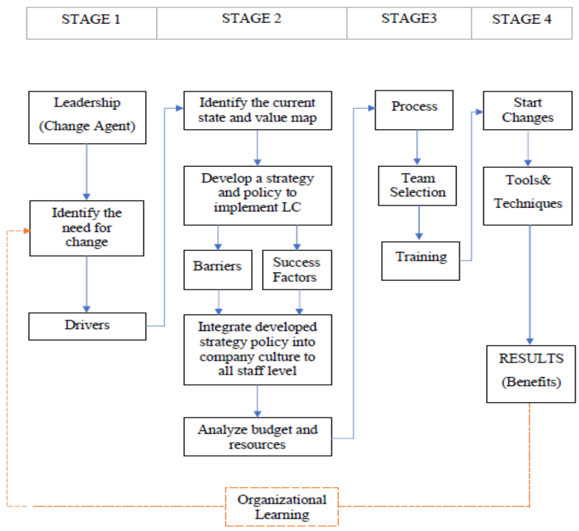

Figure 3: Proposed LC framework.

According to the presented framework, Stage 1 should start with identification of the need for change. In LC transformation, the organization should identify its need for change and the driving factors that push it to change (Ogunbiyi, 2014). Then it should be continued with the recruitment of a change agent to lead the LC transformation successfully. Because transformation to Lean organizations is a radical process since there is a significant need of organizational change. Therefore, the change agent system is mostly used for Lean transformation to assist the change processes (Nordin & Belal, 2017). The Lean or the change leader should create the environment necessary to adapt the organization to the Lean approach and be part of the strategy (Womack & Jones, 2003). Moreover, the change agent must lead employees resisting to change and provide the vision necessary to make the change happen (Donovan, 2005).

Stage 2 starts with defining the current state of the organization and mapping the value stream. Consequently, policy and strategy formulation to implement LC is developed. This formulation includes processes and decisions to shape the path, which is to take by the organizations to achieve their goal (Foster & Browne, 1996). The pace and scope of improvement, the expected goals, and the plan to balance and relate the activities should be defined in the context of these strategies and policies (Ogunbiyi, 2014). Then, barriers and success factors in the implementation of LC should be identified.

The culture adopted by the organization and employee behaviour can affect the Lean implementation efforts as barriers. These barriers can also affect the performance of the project when it is not managed well (Sarhan & Fox, 2013). Previous research conducted in Lean for other countries indicated that the main barriers in front of Lean implementation are lack of Lean construction awareness, contracting & subcontracting problems, financial issues, lack of top management commitment, lack of technology, and lack of client commitment (Sarhan et al., 2018; Sarhan & Fox, 2013). On the other hand, a considerable portion of the studies investigated the success factors in the Lean implementation. When success factors are determined properly, they smoothen and make the Lean implementation process easier (Ogunbiyi, 2014). According to Demirkesen and Bayhan (2019), management commitment, Lean training, and customer satisfaction were listed as the main success factors for a successful Lean implementation process.

Stage 3 is the preparational part of the framework. It begins with improving the processes. As part of this process, Lean team should be selected based on their skills, capabilities, and openness to change. Moreover, an effectively working team to implement LC should be well chosen. According to Grant and Hallam (2015), an effective team should be collaborative, cross-trained, multi-skilled, and open to change as well as helping others in case of conflict. Moreover, trainings should be provided to the team to promote the change, involvement in the process and eliminate the barriers to the Lean implementation process (Salem et al., 2005). Besides training the team, periodic coordination meetings (i.e. huddle meetings) should be conducted between stakeholder teams. Plenary sessions should also be coordinated to exchange experiences, failures, and successes (Alarcón et al., 2002).

Stage 4 is the last step of the whole process. Successful Lean implementation requires a successful combination of Lean tools and techniques to complete the system so that it cannot operate independently (Drew et al., 2004). When appropriate tools and techniques are integrated into the process, the organization becomes able to create a stable process.

Conclusion

The construction industry has several challenges faced out requiring the need for change. Hence, the industry is need of proper tools and techniques to promote innovation and change the culture. In this respect, LC is an effective means of changing the organizational culture and lead employees to produce effective work. The current trend of the construction industry in Turkey indicates that the industry is in need of more efficient processes and working strategies. To make this possible, the organizations seek for different approaches and develop ways to improve the organizational performance. This, this study investigated the current awareness for LC in the Turkish construction industry, in this context, a questionnaire was designed and administered to construction professionals operating in Turkey. The results of the data analyses revealed that there is a considerable lack of awareness in terms of Lean and its applications in Turkish construction industry. This also indicated that the industry practitioners are not quite familiar with the Lean tools and techniques. This led to the development of a framework, which acts as a roadmap of guideline for the Turkish construction industry illustrating the best Lean implementation scheme. The framework presents the steps required to implement LC in a construction project. The framework consists of the elements of leadership and management, driving forces, policies and strategies, barriers and success factors, team selection, training, initial changes, and tools and techniques. The framework is expected to guide industry practitioners in terms of getting familiar with the Lean and its implementation along with developing an understanding of efficient Lean tools and techniques. As a future work, similar frameworks might be developed for other countries and the results might be compared accordingly.

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Construction Schedule Management and BIM: A Bibliometric Literature Review

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Abstract

Construction Schedule management based on BIM technology is one of the prominent concepts challenging the traditional practices in the construction sector. Due to the characteristics of the construction industry, planning is subject to unpredictable changes and variability. At that point, BIM integration to the planning processes is critical to overcome the problems and to obtain regular workflow in site activities. This study aims to conduct an extensive literature study that focuses on the relationship between Construction Schedule management and Building Information Modeling. For the comprehensive literature study, articles between 2005-2020 are examined by using Scopus to determine the gap between schedule management and BIM. It was found that despite the importance of the construction sector, the current BIM and schedule integration literature falls short in terms of both the number of publications and content of papers.

Keywords: *Building Information Modeling (BIM), construction, planning, schedule, 4D planning, construction sites.*

Introduction

The construction project schedule is one of the requirements for successful construction project management. It plays a significant role in determining the flexibility of the available resources and complex precedence relationships, which becomes a substantial challenge worldwide. Even though a lot of academic researchers and industry practitioners paid attention to it in the last few decades, still a large number of project failures exist related to project scheduling (Derbe et al., 2020). Researchers have been investigating the problems regarding the schedule's reliability, methods, causing factors and risks, resource assignment, and emerging technologies (Allen et al., 2008).

Thanks to technological developments and 3D modeling in the architectural era, engineering, and construction (AEC) industries have new opportunities to improve scheduling processes. However, scheduling still has been mostly made manually, which can be an extensive and very tedious process. Since it is challenging to interact between scheduling software and BIM, many benefits of the BIM technology remain unexploited. Being able to use information stored in BIM to assist in generating schedules could help to achieve significant time reductions in scheduling compared to traditional manual methods. Previous research has demonstrated the feasibility of creating construction schedules for the construction process by using the state-of-the-art technologies, including BIM (Lia et al., 2017). However, to date, only a few works -directly focused on this topic- have been able to complete the automation of this process successfully.

This paper aims to conduct an extensive literature study that focuses on the relationship between Construction Schedule Management and Building Information Modeling.

Background

The construction project schedule is one of the essential tools for project managers in the Architecture, Engineering, and Construction (AEC) industry that makes them able to track and manage the time, cost, and quality of projects. In other words, to deal with the competitive environment, "planning and scheduling" are vital to understand project performance (DeSnoo et al., 2011). Also, these processes are fundamental for the lifecycle of construction projects because they involve the selection of the most appropriate technique and tools, estimation, and allocation of the resources; therefore, they have to be addressed correctly and efficiently.

Developing a reliable construction project schedule is one of the significant factors in construction projects' success. However, while meeting the project schedule, several parameters should be considered: Project schedule reliability (Gannon et al., 2012), choice of schedule methods (Abou-Ibrahim et al., 2019; Al Nasseri et al., 2016; Xu et al., 2018), the complexity of projects (Abou-Ibrahim et al., 2019), the potential existence of schedule risks and risk prediction capability (Choudhry et al., 2014; Liu et al., 2015; Luu et al., 2009; Shen et al., 2017; Soto Ramirez et al., 2018), project finance (Larsen et al., 2016), the extent of project team collaboration (Sinesilassie et al., 2017) determining sequence logic and other factors are some of the known daunting tasks.

Increased emphasis on planning effort by practitioners contributes to developing a reliable schedule (Lekshmi & Unnikrishnan, 2018; Lines et al., 2015). BIM is being evolved to cope with the requirement of the consideration of the time and space relationships of construction activities (Kropp at al., 2018). Recently, researchers have been focusing on emerging technologies such as four-dimensional building information modeling (4D-BIM), which links 3D geometrical design with the project schedule (Chan et al., 2015).

There is much work has been undertaken to demonstrate that creating a 3D model overtime assists in the planning process. 4D Planning is produced when a schedule is linked to a 3D-model to enable visualization of the time and space relationships of construction activities (Buchmann- Slorup & Andersson, 2010; Liston et al., 2001). 4D Planning facilitates a more significant analysis of the construction schedule to assess its implementation (Koo & Fischer, 2000; Mahalingam et al., 2010; Trebbe et al., 2015), and help reduce scheduling errors through plan inquiry and validation. 4D BIM aims to amplify the understanding of the construction plan through 4D visualizations, which are "simpler representations of the development of the project and can be used by a wider variety of project participants at varying levels of skills and experience" (Mahalingam et al., 2010). Other Planning related benefits of 4D BIM include more effective coordination and review practices (Hartmann & Fischer, 2007; Olde Scholtenhuis et al., 2016), better planning and management of on-site space and resources (Kassem et al., 2015; Wang et al., 2004), and use of automated construction progress tracking capabilities (Kim et al., 2013; Kim et al., 2013).

The most important aspect of using 4D is that it adds value to the process and saves time and money. The most significant constraints still seen as a cost and a lack of understanding of how the technology will be applied. However, Standish Group 2015 Chaos Report pointed out that any successful project which met the planned time, budget and increase productivity use 4D tool in their process. Also, the Centre for Integrated Facility Engineering confirmed that 4D modeling at the appropriate stages in the construction process results in significant building efficiencies and cost savings (Silver, 2015).

Methodology

A bibliometric analysis was used to evaluate studies in the area of Construction Schedule Management and BIM. A bibliometric search provides sufficient information on the necessary records (Bankar & Lihitkar, 2019). It has been used to trace relationships amongst abstract, article, title citations. Citation analysis, which involves examining an item's referring documents, is used in searching for materials and analyzing their merit. In addition, this study used the bibliometric search of the Scopus search engine, which is one of the largest sources of peer-reviewed literature comprising of the most significant number of citations and abstracts (Bakkalbasi et al., 2006; Martin-Martin et al., 2018). The study only focused on journal articles written in the English language.

While setting the review boundaries the studies related with 4D BIM but falls into the scope of construction performance, monitoring and controlling site activities, construction safety and waste management are excluded.

Study was divided into the following steps:

- Stage 1:

1. "Construction Schedule Management" keyword search in the abstracts, titles, and (or) keywords of publications indexed in the Scopus
2. Selection of only peer reviewed articles published in academic journals.
3. Exporting the bibliographical descriptions.
4. Developing a map of links and analysis of clusters.
5. Analysing the results.

- Stage 2:

6. Searching the Scopus database based on "Construction Schedule Management" and "BIM."
7. Exclusion of duplicates and articles that do not directly discuss BIM and Construction Schedule Management
8. Analysing the results.

- Stage 3:

9. Analysing the articles focused on BIM and Construction Schedule Management

Findings

The primary research was done by the abstract and citation database Scopus. Initially, the "Construction Schedule Management" keyword is searched with restriction for the year 2005. The results are selected to be exported with CVS file format for bibliometric analysis. There exist many computer programs for bibliometric analysis, of which VOSviewer (van Eck & Waltman, 2011) was utilized in this study. VOSViewer, a scientometric analysis software tool, was chosen to construct and analyze the bibliometric network of science due to its unique mining and visualization feature for large amounts of textual data (Van Eck & Waltman, 2011). Furthermore, some extant studies have used VOSViewer in the field of construction management, i.e., construction waste management (Jin et al., 2019a), construction safety (Jin et al., 2019b) and building information modeling (He et al., 2017).

The keywords found in VOSviewer are limited to 10 times of repetition.

Stage 1

Below Figure 1 shows the database results based on construction schedule management. In Figure 1, different concepts are represented by nodes and connected by lines, which indicates mutual citations of articles with schedule management. It is shown that construction management and productivity have larger node size and front size compared to other terms due to is high mutual citations with schedule management.

According to Figure 1, Planning methods and techniques, resource allocation and optimization are the most preferred research areas with schedule management. In terms of planning methods and techniques, Line of balance, CPM and PERT seem like main research topics. However, linear programming and constraint programming have the weak links with construction schedule.

From Figure 1, it should be noted that there is not a strong relation between Construction Scheduling and BIM. Although BIM has been serving as one of the most innovative revitalization technologies in the construction project schedule (Hardin & McCool, 2015). BIM has been still used to reduce project duration through collaboration and communication among stakeholders. In addition, visualization also has weak link with scheduling. This also shows the lack of digitalization for scheduling. May et al. (2018) indicated that construction projects have been significantly affected by loss of productivity, which resulted an average of 20% schedule slippage due to lack of digitalization. The application of full digitalization in construction projects can be effectively reduce schedule overruns by 10–15% (May et al., 2018). With that in mind, adopting digital technologies and other artificial intelligence in construction projects is vital to enhance schedule performance.

Furthermore, studies on schedule management with risk assessment seem scarce. With that in mind, quantifying and forecasting schedule risks and uncertainties, mapping scheduling risks with activity durations can be shown as research gap areas.

Although cloud computing and sustainability are the outstanding terms for the researchers, there is research gap between schedule management and both terms.

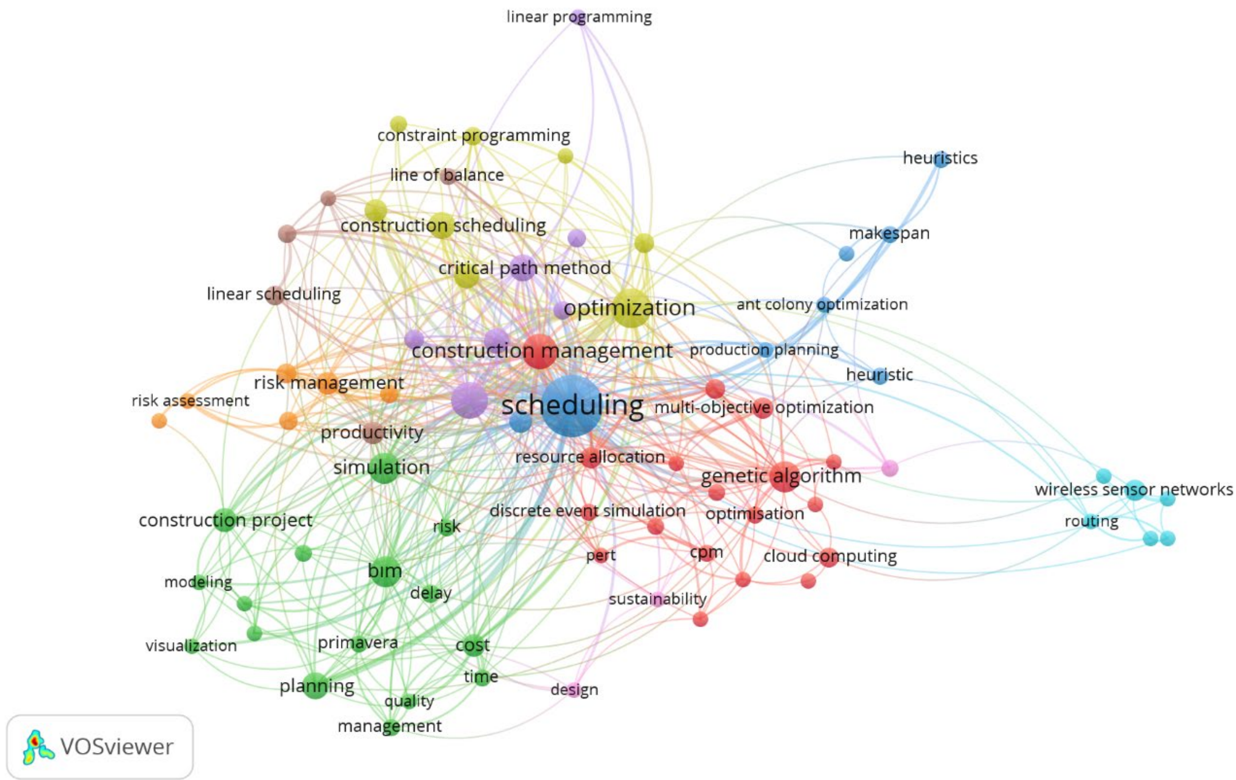

Figure 1: Bibliometric analysis results.

Stage 2

The next research was done for “Construction Schedule Management” and “Building Information Modeling” keywords in Scopus database by selecting just only articles. The concept of these two keywords relations through these years is shown in Figure 2. It is seen that the two concepts have been working since 2011 and number of the documents have reached the highest number in year 2018. In addition, as per Figure 3, %44. 6 of the regarding documents belong to engineering.

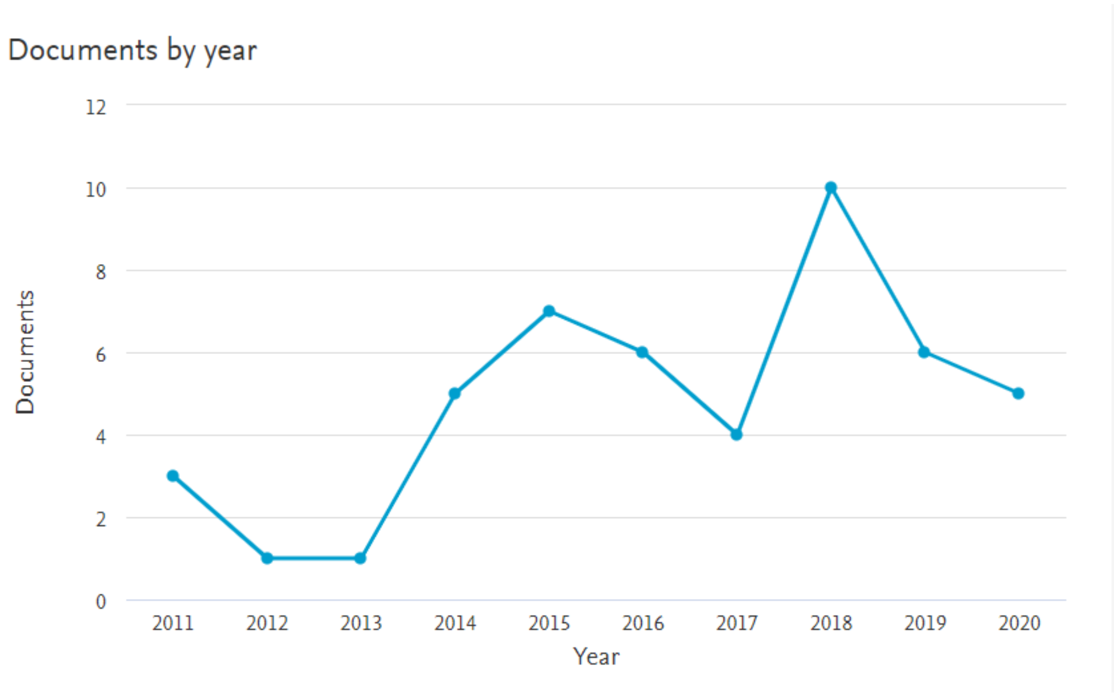

Figure 2: Documents related to “Construction Schedule Management” and “Building Information Modeling” sorted by year.

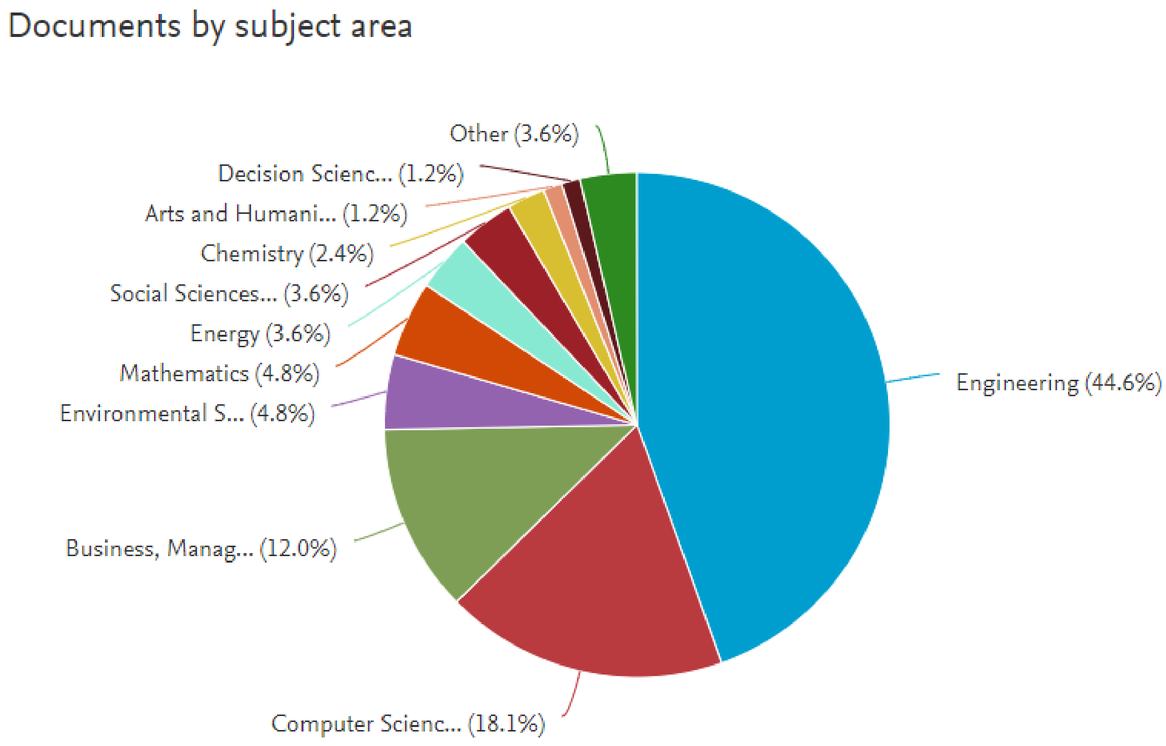

Figure 3: Documents related to “Construction Schedule Management” and “Building Information Modeling” sorted by subject area.

By the countries of origin of the first authors of the publications (Fig. 4), the United States based academic institutions have produced the highest number of publications, followed by the China, South Korea, and Canada institutions.

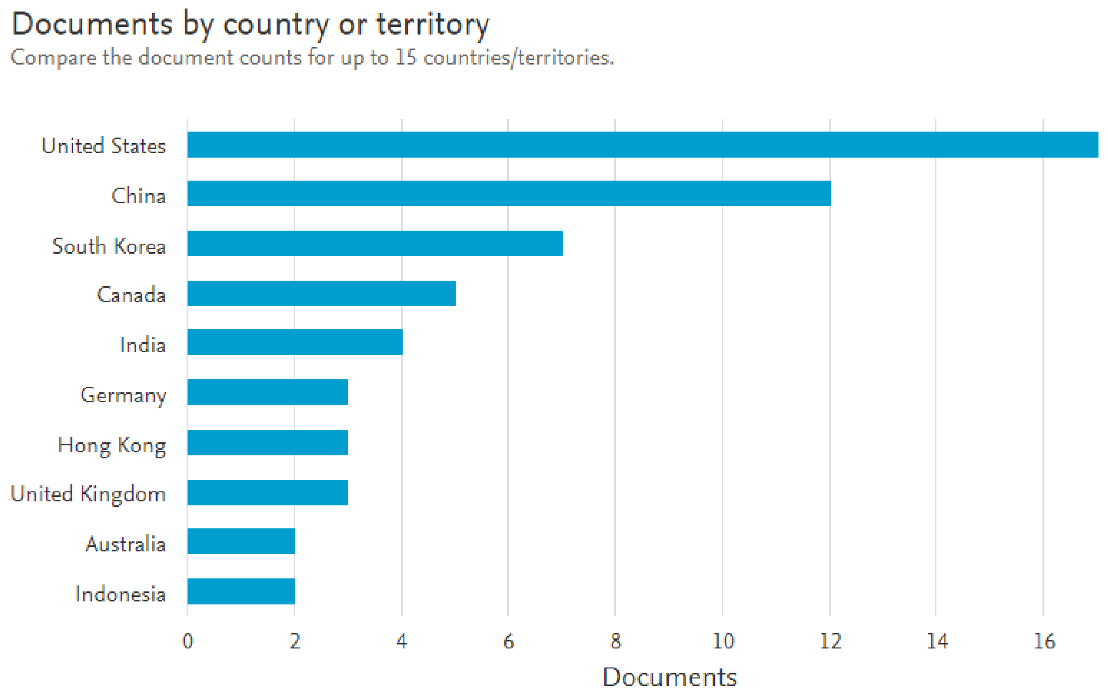

Figure 4: Number of publications by the country of origin.

Stage 3

At this stage, the list of the articles those mainly focus on Construction Schedule Management and Building Information Modeling between 2005-2020 are examined and showed in Table 1.

Table 1 show that in general there are still fewer discussions mainly focus on Construction Schedule management and BIM in the peer-reviewed academic media.

An advanced construction schedule and planning system can be incorporated for the entire life cycle of project starting in the early stage of project planning and design stage. However, it can be seen from Table 1 that the studies are very scarce which focus on the early integration of construction schedule and BIM. Developing 4D BIM- schedule system using an integration of 3D design geometry and rolling wave planning would be implemented in order to reduce schedule risks, uncertainties and delays. Also, BIM and Construction Schedule management integration should be examined from the perspectives of different stakeholders.

In addition, it has been identified that the studies that focus on the BIM and optimized Construction Schedule method selection model are very scarce. However, BIM would contribute to the method selection by showing clearly the project scope such as size and complexity.

Table 1. Articles mainly focused on Construction Schedule Management and BIM.

Publication Name	Authors	Publication Year	Publication Medium
Project schedule risk management through building information modelling	Sami Ur Rehman et al.	2020	International Journal of Construction Management
Work package-based information modeling for resource-constrained scheduling of construction projects	Wang et al.	2020	Automation in Construction
Simulation of construction sequence using BIM 4D techniques	Tirunagari et al.	2019	International Journal of Recent Technology and Engineering
BIM-based integrated management workflow design for schedule and cost planning of building fabric maintenance	Chen et al.	2019	Automation in Construction
Strategy management of construction workspaces by conflict resolution algorithm and visualization model	Rohani et al.	2018	Engineering, Construction Management
Maturing construction management up the BIM model & scheduling using Primavera	Subramani et al.	2018	International Journal of Engineering and Technology(UAE)
Application of architecture construction scheduling on the basis of a parallel hadoop-BIM cloud service framework	Jing et al.	2016	Journal of Computational and Theoretical Nanoscience
BIM-based integrated approach for detailed construction scheduling under resource constraints	Liu et al.	2015	Automation in Construction
BIM-based construction scheduling method using optimization theory for reducing activity overlaps	Moon et al.	2015	Journal of Computing in Civil Engineering
Formalized knowledge of construction sequencing for visual monitoring of work-in-progress via incomplete point clouds and low-LoD 4D BIMs	Golparvar-Fard et al.	2015	Advanced Engineering Informatics
Research on information models for the construction schedule management based on the IFC standard	Xue et al.	2015	Journal of Industrial Engineering and Management
Construction scheduling using Genetic Algorithm based on Building Information Model	Faghihi et al.	2014	Expert Systems with Applications
Construction projects scheduling using GIS tools	Bansal et al.	2011	International Journal of Construction Management

Conclusion

Project schedules are the necessary tools for organizing the construction sequence. Through these schedules, project management teams can optimize the actual construction sequence from time and cost perspectives. When the importance of these factors is taken into consideration, the development of project schedules should be done very carefully. In cases where the project and its scope are very complex to be easily implied, the supposedly favorable 2D construction schedule can turn into a time- and cost-consuming tool, which would also mislead the project's workforce.

This study aims to visualize the research gap in Building Information Modeling and Project Schedule Management. The analysis can help to clarify the issues surrounding these two terms and identify untouched areas of interest for academic researchers in the context of the subject matter.

In a further step, other databases, like Web of Science, could be taken into consideration for relating to the analysis.

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State-of-the-Art Review on Information Requirements for Facilities Management

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Abstract

Facilities management (FM) is a long standing yet rapidly changing profession with a multidisciplinary and information intensive nature. Due to the increasing awareness of buildings as important assets for organizations, more emphasis is being given to better and more efficient operation of buildings. Comprising the longest period in the building life cycle, the operational phase is inherently an information management issue. But despite continuous development in information technologies for advancing design and construction processes, using and benefiting from them during building operations is still lacking due to several factors. Among those, identifying and gathering the required information for FM purposes remains as the prime challenge to accomplish. Therefore, this study aims to represent a state-of-the-art review on the FM information requirements from the built environment point of view. A content analysis including journal articles as well as industry reports is applied to; (1) identifying the scope and information requirements of FM tasks, (2) determining existing barriers against information handover, and (3) unveiling a future research agenda to improve the operational phase practices of buildings.

Keywords: *content analysis, facilities management, information requirement.*

Introduction

Facilities management (FM) practice has roots in the 1970s with the primary intention of cleaning buildings and maintaining building equipment (Atkin & Brooks, 2009; FMA, 2012; Steenhuizen et al., 2014). Throughout its half century long journey, the scope of FM has widened from operational functions to strategic management of organizations. Since the 1990s, FM has become known as a profession encompassing multiple disciplines to ensure the functionality, comfort, safety, and efficiency of the built environment by integrating people, place, process and technology (IFMA, 2020). From the Architecture, Engineering and

Construction (AEC) point of view, FM refers to the activities needed for efficient and effective operations of physical assets. These activities can be grouped under several areas, such as, maintenance and repair, energy management, emergency management, occupancy planning and space management, renovation, refurbishment and retrofitting and FM personnel training (Atkin & Brooks, 2009; Chotipanich, 2004). In addition to the diversity of activities and the number of disciplines involved, the operations and maintenance (O&M) phase covers the longest period in the building life cycle. Therefore, it is the most information intensive phase (Tezel & Giritli, 2020), where various types of data and information are both created and utilized.

Each FM task requires different types of information and uses different software systems, such as computerized maintenance management system (CMMS), building automation system (BAS), computer-aided facilities management (CAFM) or integrated workplace management system (IWMS) to process them. However, in most of the building projects, data and information needed for O&M period is handed over after the construction is finished and in unstructured and non-digital formats, which requires additional time and cost to be transferred into these FM systems (Patacas et al., 2015). At this point, Building Information Modeling (BIM) offers promising potentials in terms of information creation, storage and management throughout the building life cycle. BIM is an IT-enabled approach that involves applying and maintaining an integral digital representation of all building information for different phases of the project life cycle in the form of a data repository (Gu & London, 2010). It provides a platform for project stakeholders to create and coordinate the building information during design and construction, and also stores them in a ready-to-use format for the operational period (Becerik-Gerber et al., 2012; Parn et al., 2017).

Recognizing FM as an information management problem while considering BIM as a managerial approach brings out new opportunities to investigate. Over the past decade, an increasing number of researchers are directing their studies on the BIM-FM axis. On top of the promising potentials of BIM use for FM purposes, there are various challenges in BIM-FM integration. Apart from the technology related problems such as interoperability issues or digital capabilities of FM personnel, the greatest challenge is identifying the information requirements of FM tasks and defining the data exchange process (Wijekoon et al., 2018). Although various standards, such as the Industry Foundation Classes (IFC) and the Construction Operations Building Information Exchange (COBie) are being developed to define the data standards and exchange process, their implications remain unsatisfactory.

It seems that there is a need for an overarching resource to improve the information flow during the operational phase of buildings. This study aims to respond to this need by providing a state-of-the-art review on the FM practice. Following the holistic literature search on academic databases as well as industry resources, content analysis outlines the information requirements of FM tasks, reveals the barriers against information handover process and proposes future research dimensions.

Research Method

This study involves journal articles as well as industry reports that focus on the scope of FM tasks, their information requirements and hindering factors for efficient O&M practices. The overall research process is adapted from Gao and Pishdad-Bozorgi (2019) and illustrated in Figure 1.

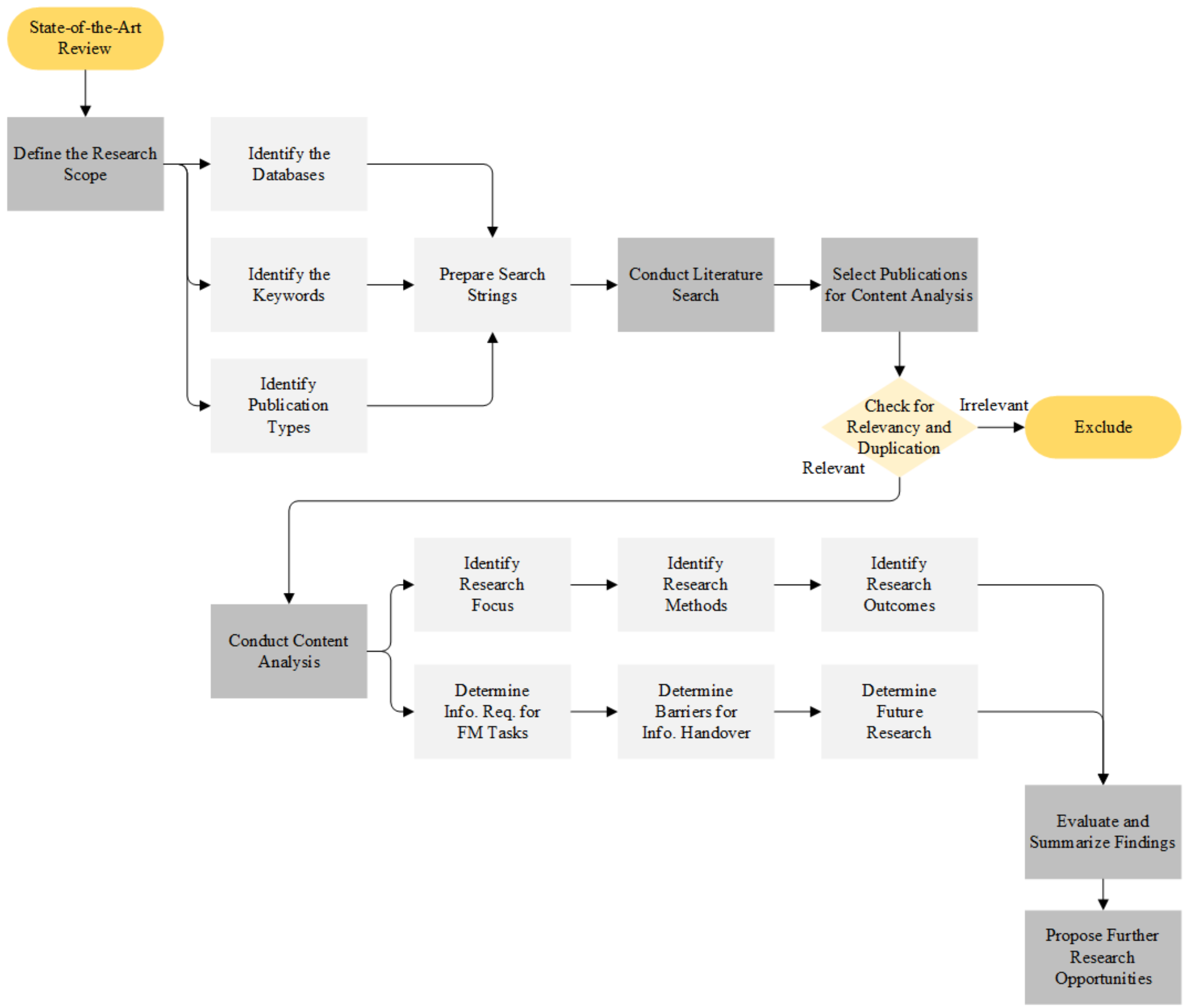

Figure 1: Research design and process.

Initially, we conducted a holistic literature search in Scopus and Web of Science, the two prestigious databases. In this step, a total of 135 publications containing (“data requirement” OR “data need” OR “information requirement” OR “information need”) AND (“facility management” OR “facilities management” OR “operation and maintenance” OR “O&M” OR “operation phase” OR “operation stage” OR “operation period”) terms in their title, abstract and keywords were identified. We intentionally left the time period tab blank to obtain all studies in this subject. Then, we thoroughly examined these publications to eliminate duplicates and exclude irrelevant ones. It is important to indicate that, we interested in studies directly focusing on the FM processes of buildings. Therefore, we excluded the studies those analyzed infrastructure projects or have focuses other than FM itself. Eventually, we selected 44 academic publications including 28 journal articles, 15 conference papers and 1 book chapter published from 1997 to the first quarter of 2020. Additionally, we included 6 reports prepared by international facilities management associations for further analysis.

Finally, we carefully reviewed the 44 selected resources through content analysis. In this step, we examined each resource based on: (1) the research focus, (2) the research method, and (3) the research outcome. We also analyzed the papers regarding the data and information requirements of FM tasks and the main obstacles for obtaining them. In the end, we summarized further research directions for future studies.

Findings

Researchers show a growing interest both in the identification of information requirements for FM tasks and data exchange processes to improve the O&M of building, especially in the past decade. Among the selected 44 publications, the majority of them focus on data/information identification (59%), data exchange process (7%) or both domains (7%), and the remaining 27% focus on other aspects such as alternative as-built data capturing technologies, benefits and challenges of BIM-enabled FM practices or FM personnel training. Apart from the two conference papers published in 1997 and 1999, the early studies in this field can be said to have started after 2010.

Figure 2 shows the number of selected publications regarding their research focus and research method, and Figure 3 shows them regarding their research focus and research outcome. Both figures consist of bars in four different colours each represents a different type of research method or outcome. Research methods in the former figure are; review of previous studies or existing documents and standards (Review), interview with experts, focus group meetings or ad hoc communications (Interview), questionnaire surveys (Survey) and real-life observations, shadowing and case studies (Case study). On the other hand, research outcomes in the latter figure are summary or comparison (Summary), template or guideline (Guideline), framework or conceptual model (Framework) and prototype or software application (Application).

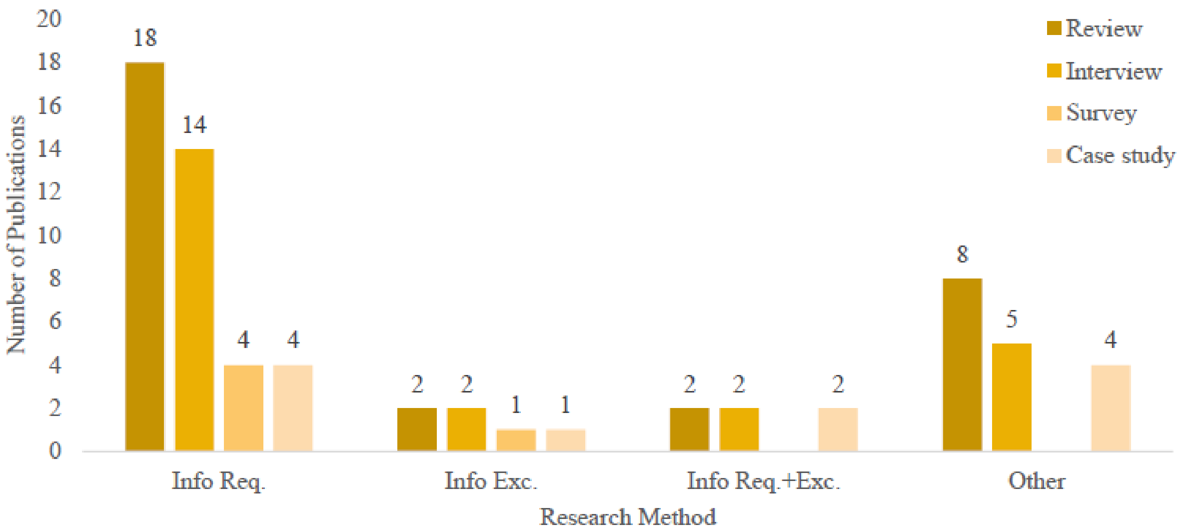

Figure 2: Distribution of publications by research focus and method.

In Fig. 2, the sum of bars is greater than the total number of publications. It shows that most studies benefit from mixed methods when investigating the information requirements, exchange process or other aspects. Not surprisingly, most authors aim to identify the information requirements using literature search or document and standard reviews. However, since it is relatively a new topic, they also get help from expert interviews or real-life observations to understand the routine FM workflows and identify required information types. Only a limited number of studies used questionnaire survey or case study techniques when identifying information requirements for specific FM tasks. Similar approach is seen in other focus domains of FM studies as well. For example, researchers use expert interview, review and interview or review and questionnaire survey techniques when investigating the data/information exchange process during the O&M phase.

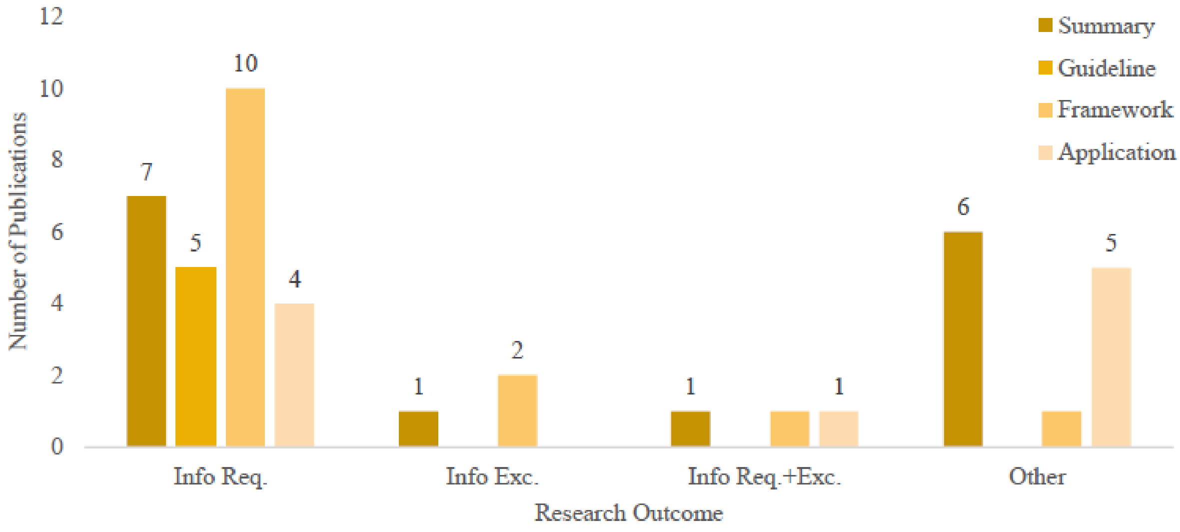

Figure 3: Distribution of publications by research focus and outcome.

As seen in Fig.3, slightly more than half of the studies (55%) propose a framework or a software application either for the identification of the required information for FM tasks and enhance the data exchange process between disciplines or project phases, while 34% of them provide a summary or comparison on existing studies, models or technologies. Again, slightly more than half of the proposed framework or application are validated using expert interview or case study techniques. Interestingly, the highest number of software application outcomes are observed in the Other category. The reason is studies comparing existing 3D point cloud generating technologies or investigating the user experience with alternative data capturing approaches and devices are grouped under the Other category.

Information Requirements for FM Tasks

Identifying, retrieving and processing relevant data for efficient FM practices has been one of the main competencies of FM teams (IFMA, 2018) and one of the primary concerns of researchers. Currently, FM professionals are using a variety of software applications for miscellaneous FM tasks. However, required information is fragmented for each task and increasing complexity of building projects make it even harder to develop a one-size-fits-all solution. Therefore, the main research focus is improving the fragmented, laborious and error-prone data handling approach through BIM-integrated information management system.

In one of the earliest studies about BIM-enabled FM, Becerik-Gerber et al. (2012) proposed a structure for non-geometric data requirements after assessing the data capture process of existing FM systems and conducting interviews with FM professionals. In their classification, they adopted a sequence-based approach for information production and proposed a responsibility chart for providing and maintaining the information. Similarly, Lucas et al. (2013a, 2013b) documented the information needs, interactions and communications between different actors during interviews and developed sequence diagrams of FM tasks in a healthcare facility. In another study, they applied a spreadsheet-based method for collecting and transferring information of a large educational institution (Thabet & Lucas, 2017). Despite their framework focus on FM activities related with patient safety within healthcare facilities, it has potential to cover other tasks if the documented actions flows are varied. In the following years, Patacas et al. (2015, 2016) assessed the open BIM standards (IFC and COBie) and proposed a framework to identify, validate and visualize different types of data that are stored in various models and databases. In their studies, they categorized data into three groups: graphical data, non-graphical data, and documentary data. With the intention of creating a base deliverables list for owners, Mayo and Issa (2016) identified the most required product information and its format applying a Delphi survey with FM experts. Similarly, Cavka et al. (2017) also focused on the owner information requirements in BIM-enabled project delivery and developed a conceptual framework linking the project's digital and physical products with owner requirements. According to their framework, the required information is divided into three groups: space, system and components. Same year, Rodriguez-Trejo et al. (2017) proposed a decision support system for owners through identifying and prioritizing sustainable FM KPIs, those are expected to be included within the projects' BIM Execution Plans. Those KPIs are grouped under six categories namely, cost, space, energy, sustainability, quality and safety, security, wellbeing. Two years later, Ashworth et al. (2019) developed an employer's information requirements template cooperating with the British Institute of Facilities Management (BIFM). They initially developed a draft based on literature and best practice documents, then conducted focus group discussion with FM and BIM experts, applied it to a case study and collected feedback from FM experts to revise it. The final guideline includes six sections namely, purpose and scope, BIM and asset management strategy and objectives, project details, management requirements, technical requirements and commercial requirements. Differing from the previous studies, Abdirad et al. (2020) developed a workflow for collecting reliable and verifiable asset management data, which is customized for existing facilities, and validated their model using a case study approach in a higher education institution.

Alongside with the studies focusing on BIM and FM integration in general, there are other studies orienting their research on data requirements for specific FM tasks. For example, in the energy management category, Mousa et al. (2016) developed a methodology to visualize CO_2 emission of buildings integrating BIM and carbon estimation models. They identified four different types of data to be retrieved from BIM models that are spatial information, electricity usage, natural gas usage and time of performance measurement information. As another example, Mantha et al. (2016) aimed to identify different types of data influencing energy consumption in buildings and classified them into two groups as static parameters and dynamic parameters. In the maintenance and repair category, Yang and Ergan (2017) focused on BIM-enabled corrective maintenance practice and identified required information for HVAC troubleshooting as work order characteristics, complaint logs, static information, dynamic information, historical information and space related information. In the emergency management category, Jung et al. (2020) aimed to develop a building fire information management system for first emergency responders. With this aim, they identified a three-levelled information breakdown structure for static fire related information. Differing from these studies, Matarneh et al. (2019b)'s study focused on multiple FM tasks, including general facility management, maintenance management, energy management, space management and asset management. They employed a task-based approach to identify information needs, where they conducted a questionnaire survey with FM practitioners and developed a process for data identification, compliance and exchange using COBie.

On the contrary side, a recent discussion of BIFM (2018) about the disconnectedness between expected and actual BIM-FM integration claimed the importance of "starting everything with the end user in mind". According to the report, instead of emphasizing specific technology or software, main focus should stand on the early involvement of the FM team in projects to identify required information itself and how to capture it. In line with this, Wikejoon et al. (2018)'s study focused on the value of the information for BIM-based FM practices.

Clearly, most studies are concerned with the information requirements, process and technologies, but with a limited understanding the use and utility of it. However, the integration of place, process, technology and people is strongly emphasized in the definition of FM. Therefore, instead of identifying information requirements merely through a task-based approach, evaluating the value of information in the whole life cycle can enable more unifying results.

Information Handover Process and Existing Barriers

Alongside with the identification of information requirements of FM tasks, exchanging accurate data and information during different phases of the project life cycle and between different software systems is standing on the other side of the coin. Professionals need to overcome the interoperability problems and ensure the maintenance of digital models for efficient FM practices. Interestingly enough, compared to the number of studies focusing on the information requirements field, the number of studies in this category seems scarce.

In one of the earliest studies in this domain, Hosseini et al. (2018) identified differing data requirements of FM team members and developed a data and information handover matrix regarding the project delivery models. In their model, they divided required data into three typologies namely, operational data, tactical data and strategic data, and indicated which data is relevant for whom. Same year, Cavka et al. (2018) developed a project compliance verification system to obtain, process and control project information regarding the technical and functional requirements of owners. A three-level approach was developed including the verification of model structure, content and design compliance review. A similar motivation was adopted by Sadeghi et al. (2019), where a BIM-enabled workflow was developed to capture and retrieve information as final handover deliverables. Matarneh et al. (2019a) aimed to identify the information exchange challenges between BIM and FM systems and developed a method for seamless information flow between them. Their questionnaire survey finding once again proved the interoperability issue as the biggest challenge. Therefore, they developed a system benefiting from an industry solution, COBie. In the last publication of this category, Alnaggar and Pitt (2019) developed a detailed process model for asset data creation, flow, and management throughout the building life cycle. Their model guides all project stakeholders at each project phase by indicating the responsible party of data management and the data quality standard.

Naturally, data handover process gives more emphasis to the project stakeholders. Including all stakeholders into the project as early as possible and clarifying the responsible parties in data creation and maintenance will not only help to achieve a more collaborative environment, but also will ensure a well-organized information flow between them.

Future Research Agenda

Fig. 4 represents the distribution of selected publications regarding the FM task group they focused. It is seen that almost half of the studies (48%) focused on FM in general or maintenance management issues (27%) in particular. Additionally, 14% of the studies focused on more than two task groups at a time. However, FM covers a wide range of areas including energy, water and waste management, emergency management, occupancy planning and space management, security, contract management etc. (FMA, 2012). Besides, according to the National Institute of Building Sciences (NBS, 2015)'s report, building operation tasks covers the biggest part (50%) of an FM personnel's daily activities, followed by optimizing the facility (20%), conducting planning activities (15%), supervising personnel (8%) and contributing the budgeting activities (7%). Therefore, in the near future, more research on other areas of FM and other duties of FM teams may be required.

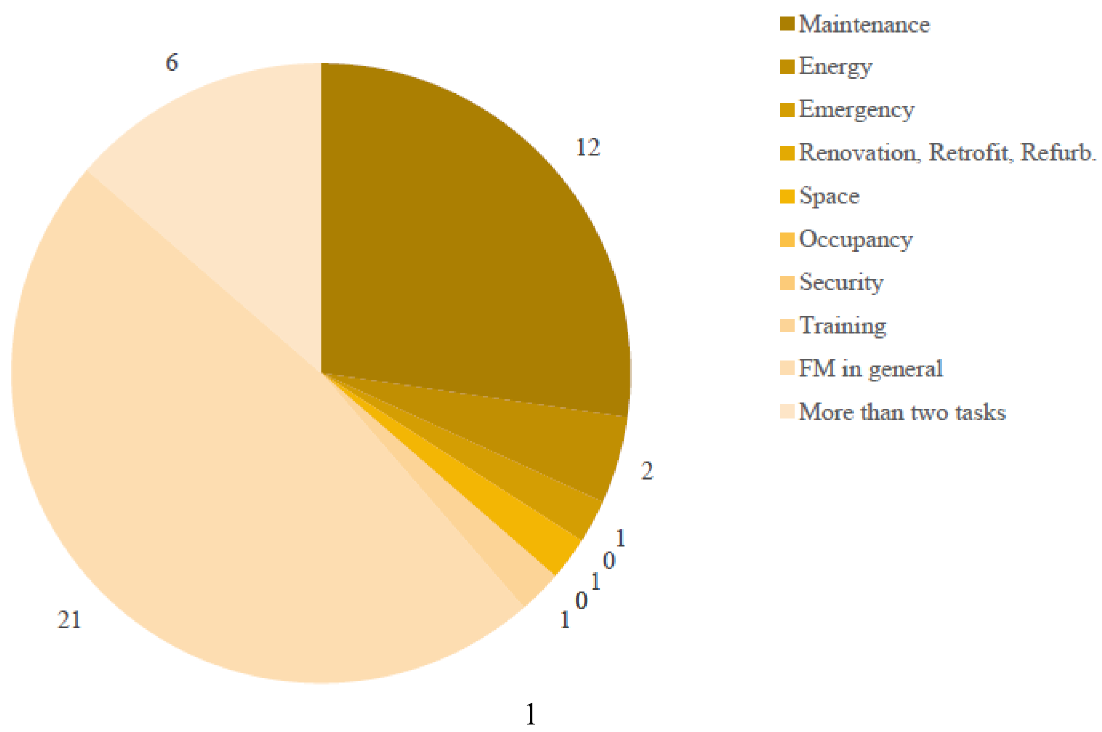

Figure 4: Distribution of publications by FM task groups.

Apparently, most of the selected publications in this study focused on BIM-FM integration, however, as stated in IWFM (2017)'s report, FM is expected to become a more automated practice and there exist various technologies regarding the needs of FM tasks. On top of that, BIFM (2013) emphasized the need for a more collaborative and cooperative environment where FMs are not expected to be experts in everything. Therefore, more studies to improve the collaboration culture with alternative technologies rather than concentrating on a particular technology may be needed. As an example, Re Cecconi et al. (2017) targeted the non-BIM users and aimed to help them to access and modify asset data in a digital model. Future research is encouraged to have similar motivation that may help to overcome the technology related problems in the FM industry.

Conclusion

There is still an on-going debate on the definition and scope of FM profession. However, this study approaches FM from the AEC point of view, and it aims to understand what are the required information for FM tasks and what are the main challenges hindering the data exchange process during the project life cycle.

Results of the state-of-the-art review of the existing literature show that the majority of these studies aim to identify BIM-based FM information requirements, while only a limited number of them focus on data exchange process. On the other hand, considering the research methods or research outcomes, these studies can be classified under various groups. In terms of research methods, it is important to note that most of the studies benefit from mixed methodologies where literature or best practice document reviews are supported with focus group discussions, interviews with industry experts or real-life observations from different types of buildings, such as healthcare, educational or even military facilities. As it is relatively a new area of research, such a result is quite expected. In terms of research outcomes, most studies either provide a comprehensive summary, propose a framework, or develop a software application.

With all those, considering the distribution of studies regarding FM task groups and adopted technologies, further studies are expected to focus on other FM tasks and other technological opportunities that contribute to the collaboration among stakeholders and project phases. At this juncture, the matter is the collaboration between academia and industry. Since the definition and scope of the FM profession is subject to rapid changes, sole academic or sole commercial publications would cause biased results. Therefore, both parties should build-up a collaborative environment.

This study is not without limitations. Firstly, it uses several search strings with alternative keywords in two scientifically reputable databases to collect as much study as possible. However, there are of course other studies in the same field. Even so, in order to provide the most comprehensive review of the BIM-FM domain, this study benefits from both academic studies and industry reports. Additionally, despite 44 scientific publications being identified, only some of the selected journal articles were referred to in the content analysis due to the publication limitations of this conference. For interested readers, a supplementary document including all selected papers and reports is available at the corresponding author.

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Cost Estimating in Construction Projects: The Relationship Between Cost and Macro Economic Indicators

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Abstract

Accuracy of cost estimating in construction projects is one of the most fundamental issues for each of the stakeholders involved in projects in the construction sector. One of the main approaches to cost estimation is based on the use of macroeconomic indicators. In this study, an approach to integrate the use of indicators related to macroeconomics with artificial intelligence in cost estimating and to create the infrastructure of cost estimating tools that are as strong theoretically as practically is examined. For this purpose, the official square meter cost data of construction projects of reinforced concrete buildings between the years 2010-2020 in Turkey have been used to investigate the above stated relationship between economic indicators and cost of the projects, to demonstrate the relationship between them. Consequently, it has been concluded that economic indicators can be used in the determination of costs of construction projects. Furthermore, this approach provides a more effective cost estimating method compared with the other approaches/models proposed on this subject since it allows to determine much more relationships between economic indicators and cost with the support of artificial intelligence tools in practical dimension.

Keywords: *Construction projects, cost estimating, economic indicators, reinforced concrete buildings, cost per square meter, artificial intelligence.*

Introduction

The cost estimate of projects closest to the actual cost is one of the main challenges that stakeholders of construction projects face. While Bledsoe (1992) underlines that there are studies on cost estimates to be adopted at various stages of projects and intended to prove many arguments/hypotheses on accuracy/precision, Zakwan and Ara (2011) argue that there are lots of tools and methods for cost estimation.

Scientific studies on macroeconomic indicators in construction business analyze the dynamics of the business (Akintoye & Hardcastle, 1998). Macroeconomic indicators are one of the methodologies to estimate construction costs, and there are many scientific studies on them.

Among them are studies by Oteng-Abayie and Dramani (2018), Arıoğlu and Girgin (2003), Olga and Antonios (2019) and Diler (2018). While the aforementioned studies are focused on the correlation between any situation in construction business and macroeconomic indicators in their context, they do not address how macroeconomic indicators can be utilized as a cost estimation instrument. In addition, the aforementioned studies are limited in context, and as they do not consider all the factors that affect costs of construction projects, they do not offer any practice and means to make inferences, and any solution on how to effectively/reliably update cost estimation data as it remains a major problem.

The large-scale and complicated nature of modern construction projects and constant and instantaneous changes in today's globalized world leave no choice but to continuously revise original cost estimates of construction projects at a short notice, and make the revisability of cost estimates a major problem.

Objective: The aim of this study is not only to reveal the correlation between construction costs and foreign exchange rates as a well-known case but also to set forth how to correlate cost items/cost components, which are generated based on a core analysis of items of construction costs, with economic indicators based on a sample. This study will establish a cost estimate and revision model depending on macroeconomic indicators irrespective of cost estimation methods. This will help outline a paradigmatic and conceptual model of cost estimation that can be configured by artificial intelligence to estimate and revise construction costs based on economic indicators. Relying on the establishment of a correlation between project cost estimates and continuously monitorable/accessible economic indicators, this revisable cost estimation model will provide a major input to minimize deviations from original cost estimates. This study is an attempt to combine the use of macroeconomic indicators and artificial intelligence for cost estimation, and address an approach that can serve as a basis for the infrastructure of cost estimation instruments that are theoretically and practically favorable to use. Key concepts, opportunities and barriers of this approach intended to suggest such an input are going to be addressed, and a proposed model is going to be outlined as a part of the study.

Scope: For the scope of the study, a data set that enables to make a significant and weighted/high-rate correlation with macroeconomic indicators generated as a result of country-wide complicated and dynamic relations. In this context, the scope of the study was designated as residential buildings constructed based on a reinforced concrete load-bearing system, and this is based on the fact that residential buildings rank first among all types of buildings in Turkey, making up 84.62% of them, and 99% of the residential buildings are equipped with a reinforced concrete frame/reinforced concrete load-bearing system (TURKSTAT, 2020). The study will attempt to achieve consistency of a chain ranging from a macroeconomic scale to the extreme/core cost within the boundaries of the aforementioned limitations. This research is limited to investigating the relationship between the economic indicator of foreign currency (USD) and the cost per square meter of housing. However, it should not be forgotten that it is open to expandable research on cost relations with other economic indicators.

Method: An economic indicator-construction cost relation will be mapped out based on weight/rate of macroeconomic building cost estimates to be addressed as a part of the study to establish a significant and consistent correlation between macroeconomic indicators, which are outputs of complicated correlations at a macroeconomic level, and construction costs. In other words, a chain of relations will be established based on a weighted/high-rate data set. This will show that economic indicators can serve to make construction cost estimates, and an effective cost estimation method can be introduced with a lot more correlations between economic indicators and costs based on means of artificial intelligence. A sample structure was created for learning with the *decision tree*, which is one of the artificial intelligence methods, using statistical distribution, arithmetic mean and correlation methods.

Data Set: The data of the Turkish Statistical Institute (TÜİK) and publicly-available data of the Turkish Ministry of Environment and Urbanization, the Presidency of Strategy and Budget, the Turkish Central Bank, and trade unions from 2010 to 2020 are going to be utilized for the study. Details on sources of data and calculations are as set out in TURKSTAT's reference statement on data (TURKSTAT, 2020a). The data of the study are data released in official documents and serve as a basis for major legal procedures such as taxation (Turkish Official Gazette, 1970). Testing the reliability of the data is beyond the scope and purpose of this study. The structure of the primary data set used in the study and the methods used in its creation are explained in TURKSTAT resources. On the other hand, it is not possible to access primary sources of secondary data, some primary data have been accessed for the purpose of verifying secondary data; However, disclosure of these data according to The Turkish Penal Code (TPC) no.5237 embodies "the reveal of confidential business information and documents" as a crime could not be presented because it is a commercial secret.

Economic indicators, which are a key part of the data set to be utilized as a part of the study, are statistics about economic operations and data that enables to analyze those operations and make prospective estimations. In addition, economic indicators have the potential to make significant inferences as they are generated by a statistical analysis of many data. Such statistical data are collected by the Organization for Economic Co-Operation and Development (OECD), the Organization for European Economic Co-operation (OEEC) and many statistical institutes from a great deal of sources. The main economic indicators, which are established by TURKSTAT in Turkey, are categorized by the TURKSTAT, and the Presidency of Strategy and Budget based on national income, production, fixed capital investments, equilibrium of foreign trade and payments, money, bank, capital market, prices, employment and fees.

In this study, it has been concluded that the building type is residential and reinforced concrete structural system is used in residential buildings, with statistical distribution based on TURKSTAT construction m2 cost data between 2010 and 2020. Reinforced concrete structural system costs, data on 68 housing projects were analyzed and it was concluded that the statistical distribution, steel and concrete costs were among the inputs that significantly affect the building cost. When the inputs that constitute the cost in the production of steel and concrete with the statistical distribution were examined, it was seen that the common and highest cost input was the energy cost. When the acquisition of energy is investigated, it is concluded that foreign dependency in energy is carried out with foreign currency (USD). In order to determine what the root input cost of the construction m2 cost is dependent on foreign currency (USD), by selecting the 'luxury housing m2 cost' data, which includes more imported inputs, from the average annual exchange rate values between 2010-2020 and the housing cost data between 2010-2020. The correlation between exchange rate-m2 housing cost has been calculated. In order to question the continuity of the dependency relationship between the exchange rate and the cost of housing, a comparison was made with the exchange rate housing m2 cost data between 1986-1993 for a reinforced concrete house. In conclusion, it has been revealed that the strong relationship between the exchange rate and housing m2 cost with the correlation values in the graphical representations of 2010-2020 existed in the past and continues today, and a cost estimation model based on this strong relationship can be suggested.

Establishment of a Correlation between Macroeconomic Indicators and Items of Cost

Main cost items are composed of production inputs as it is well known. Once a cost correlation chain is formed based on items of production with the highest rate of cost, it is possible to draw up a cost correlation map that typifies the cost. To define this cost correlation map based on a sample of residential buildings constructed by a reinforced concrete load-bearing system designated as the scope of the study, the main production items of cost and economic indicators likely to be correlated were analyzed, and it led to the following results:

Residential Construction: Residential buildings make up 80.35% to 87.08% of buildings constructed in Turkey according to the figures of the TURKSTAT on New and Additional Buildings Constructed for Intended Use Based on Building Permits Issued from 2002 to 2020. The mean value of 19-year data shows that residential buildings make up ***84.62%*** of all types of buildings, ranking first (TURKSTAT, 2020b).

Reinforced Concrete Frame Buildings in Residential Construction: The data of the TURKSTAT on Intended Use and Load-Bearing System by the Type of Building Permit from 2015 to 2020 were collected to analyze residential buildings in Turkey. The figures show that 97% of all buildings are of reinforced concrete frame, and the rate goes up to **99%** in residential buildings.

Reinforced Concrete Load-Bearing System: Systems that are commonly known as reinforced concrete skeleton structural systems are load-bearing systems where static and dynamic loads are carried by structural elements such as floor cover, columns, beams and foundation, and they are shifted onto the foundation. As it is known, a building cost is composed of many items of cost. The literature review shows that the cost of a reinforced concrete load-bearing system is much higher than the cost of other items. Seyfi et al. (2017) reported that the cost rate of a load-bearing system for residences of 4 to 8 floors is **34.52%** on average as presented in Table 1. Esra et al. (2004) compared costs of masonry, wooden and reinforced concrete load-bearing systems and reported that the cost rate of the reinforced concrete load-bearing system is 26%. In a way to corroborate the aforementioned results, Saner (1993) reported that the cost ratio of reinforced concrete load-bearing systems to other costs is over **40%** as in Pişirici (1981) research

Table 1. Analysis of main items of cost (Seyfi et al., 2017).

Main Cost	**Min. Cost**	**Avrg. Cost**	**Max. Cost**	**Min. Percentage**	**Average. Percentage**	**Max. Percentage**
Items	**(TL/m²)**	**(TL/m²)**	**(TL/m²)**	**(%)**	**(%)**	**(%)**
Rough Works	219,323	372,688	516,603	24,28%	**34,52%**	49,54%
Finishings	317,036	472,685	778,635	33,30%	43,20%	54,44%
Electr. Wiring	24,245	61,621	125,014	2,87%	5,53%	8,64%
Gas Inst.	20,550	63,387	134,295	2,19%	5,74%	8,40%
Plumbing	35,076	73,165	136,452	3,60%	6,60%	10,00%
Elevator	15,428	50,379	105,56	1,86%	4,42%	7,69%
Total	-	1.093,93	-	-	100%	-

The figures revealed that it is possible to make a projection about the total construction cost based on the cost of a reinforced concrete load-bearing system, which has a large share in total cost. In addition, it was considered that simple and computable items of cost such as concrete, steel and mould in this sample will provide an advantage to establish a clear correlation between economic indicators and items of cost.

Items of Cost for A Reinforced Concrete Load-Bearing System: Ready-mixed concrete, ribbed steel, hollow bricks, wooden moulds and supporting scaffolds were regarded as items of construction costs with a reference by the Ministry of Environment and Urbanization in a dissertation titled "Estimating the Cost of a Reinforced Concrete Load-Bearing System Based on Artificial Neural Networks" by Ünsal (2017) who analyzed the cost of reinforced concrete load-bearing systems. Performed based on the cost estimates of reinforced concrete load-bearing systems in 68 actual projects included in the dissertation, the study revealed the following results that are not indicated in the aforementioned dissertation:

- It was reported that 54 out of 68 projects (79.41%) were built on C30/37 ready-mixed concrete, Ø8- Ø12 mm ribbed steel and Ø14- Ø32 mm ribbed steel.
- Of the total cost computed based on all items of cost, their unit prices and quantities, it was reported that ***ribbed steel*** **made up** ***31.71% of the total cost, and the ready-mixed concrete made up 22.98% of the total cost***, and both combined made up **54.69%** of the total cost.

These results show that the cost of ribbed steel and ready-mixed concrete, two items of cost for a reinforced concrete load-bearing system, is higher than the cost of all the other items of cost such as moulds, scaffolds and hollow bricks. Performed to establish a correlation between the core cost and economic indicators, the analysis on the cost of ribbed steel and ready-mixed concrete led to the following results:

Cost of Steel: As for items of cost in steel production, steel as a raw material ranks first and electricity energy cost ranks second making up 15 to 25% of the total cost. It is reported that more than 50% of primary raw materials needed for Energy Efficiency Works in Iron & Steel Industry are imported (Turkish Ministry of Development, 2014) This shows a direct correlation with foreign exchange rates as steel as a raw material and electricity rely on importation.

Cost of Ready-Mixed Concrete: "*Aggregate, which makes up 75% of ready-mixed concrete, is produced naturally from coasts and river beds or artificially from stone crushers. The cost of energy spent on machines operated to produce aggregate and use for concrete mix, and of the energy spent for shipment is equal to the total energy cost of concrete production. However, it is the energy spent for cement production that takes the largest share of energy consumed for concrete production. The energy spent for cement production is equal to over* ***90%*** *of the energy spent for concrete production* (TUBITAK MAM, 2018). That is why cement costs were analyzed.

Cost of Cement: Items of cost for cement production, which is one of the items of production cost for reinforced concrete load-bearing systems, are other extreme-core items of cost, and items of cost that enables to make a correlation for economic indicators. An analysis on the items of cost for cement production shows that fuel and energy costs made up 33% to 40.7% of the total cost in cement production described as dry and wet systems from 1964 to 1968, having the largest share of cost compared to others (MPM, 1970). The Report of the Ministry of Science, Industry and Technology on Cement Industry (2013) indicates that fuel and electricity costs have the largest share in total cost, and *fuel* costs currently make up **38%** of the total cost while *electricity* costs make up **21%** of the total cost. In addition, raw materials and auxiliary materials makes up 9.60%, Laborship is 9.40%, amortization is 7.00% and other expenses are 14.90%. The figures show that fuel and electricity costs in total, which are energy costs in other words, amount to 59.10% of the total cost. Despite saving on fuel and energy over time thanks to cutting-edge technologies that serve for production, it is still the top item of cost for energy, and likely to remain so in the future. These results are repeated in a verifiable way and detailed in terms of the types of fuel used for energy in Çevik (2016) research. These results show that energy input cost is the main item of cost that is decisive for the cost of cement production. One can infer from this result that the cost reinforced cement namely the cost of reinforced cement construction has a clear and significant correlation with the cost of energy.

Energy Cost: As for how energy is supplied, Turkey seems to be forced to keep importing energy as it meets more than 75% of its energy needs from imported resources (Özalp, 2019). Reliance on import brings about foreign currency as a means of purchase. Apart from imported resources, the unit price of purchase for energy to be generated in Turkey under the Law No. 5346 of 5/15/2005 on Utilization of Renewable Energy Resources for the Purpose of Generating Electrical Energy is also based on USD cent. In addition, energy prices tend to be based on USD as it is acknowledged as a reserve currency in the global economy. As a result, the fact that Turkey meets whooping 75% of its energy needs from imported sources in USD clearly reveals correlation with USD as one of the macroeconomic indicators. Likewise, Bilirgen (2019) reported that electricity, oil and gas prices are set based on foreign exchange rates and supply-demand equilibrium. In an article intended to provide data for energy producers and titled "High exchange rates multiple energy costs", Oral (2017) reported that the effect of USD as a foreign currency on energy prices is dramatic.

Economic Indicator: Foreign currency is an economic indicator that projects many economic-political relations at a global and domestic scale. In addition, ***the foreign currency (USD)*** is an economic indicator for the cost chain correlation established in the light of the data in the study. The fact a foreign exchange rate is a data to be instantly revised based on economic indicators provides a means to roll out an instantly-revisable cost estimation model based on foreign exchange rates.

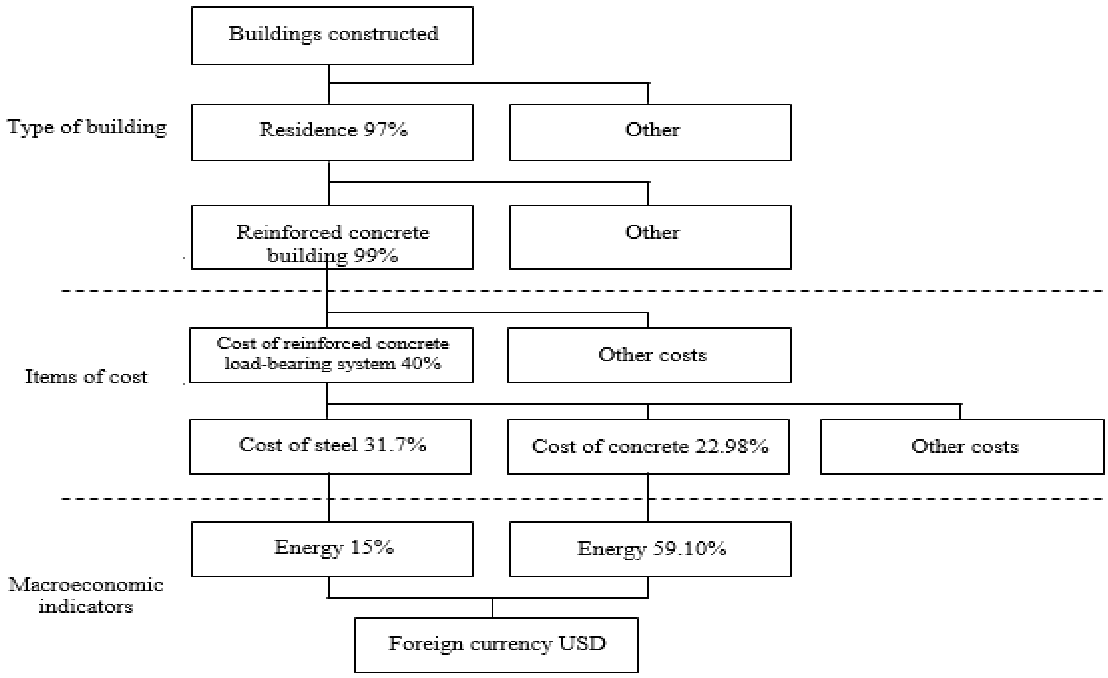
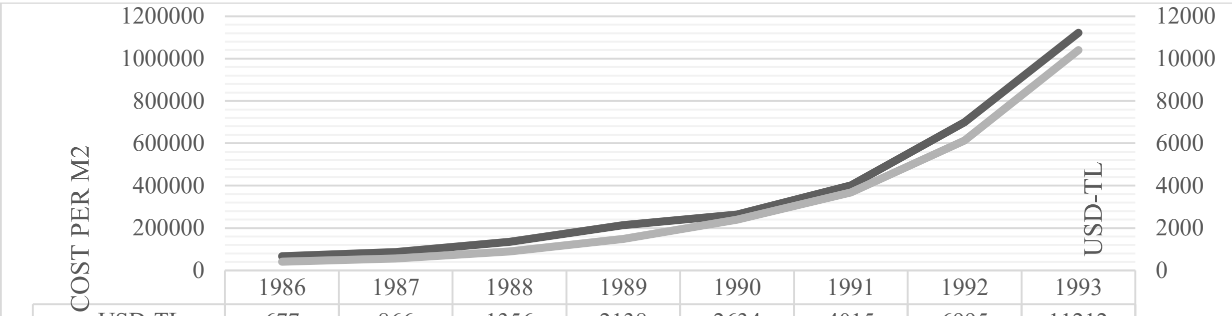


Figure 1: Items of weighted/high-rate construction cost and macroeconomic indicators.

Macro-economic indicators in the levels of literature survey revealed the relationship to the cost of construction, was built between building types in Turkey was seen as having the highest share of residential construction type. In the total cost of housing construction, it has been observed that the cost of the structural system has the largest share, and the cost of the structural system has the highest share in the cost of steel and concrete. It was concluded that the energy cost has the highest share in the steel and concrete cost inputs. Thus, the relationship chain extending from macroeconomic level to cost input level has been reached. The relationship chain expressing the artificial intelligence decision tree model is shown in Figure 1.

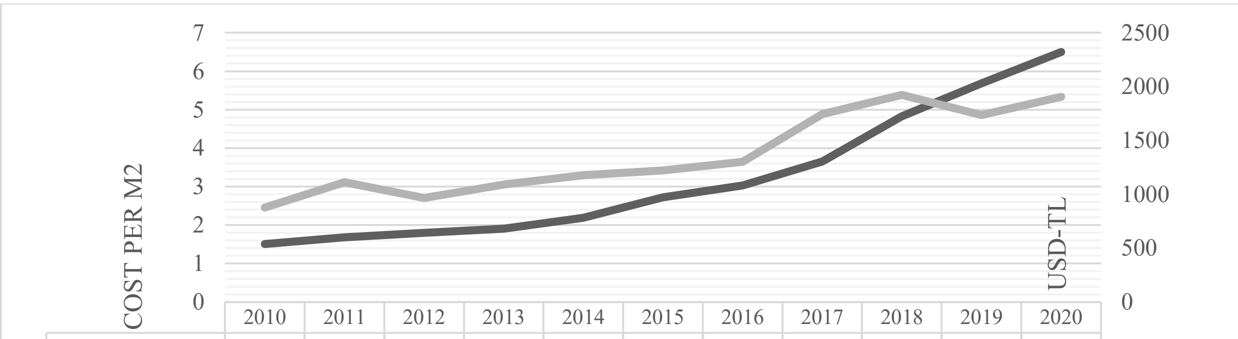
The analytical results of building cost estimates point to a correlation between the cost of a building and foreign exchange rate, one of the macroeconomic indicators. Revealing a correlation between the cost of a building and foreign currency, this result shows that economic indicators can serve as a means of cost estimation. Proving the established relation by tangible data; the relationship between m2 costs by years and the exchange rate of a reinforced concrete housing project, which is taken as an example in the thesis study based on the real project data between 1986-1993, is stated. Figure 2: correlation between USD and cost per m2 1986 is very high, such as 0,998902 **(99%)** (Yazıcıoğlu, 1994).



	1986	1987	1988	1989	1990	1991	1992	1993
USD-TL	677	866	1356	2138	2634	4015	6995	11212
Cost per M2	40727	56795	90003	148663	239865	368374	613867	1039408

Figure 2: 1986-1993 years USD-Cost per m2.

In this study, based on data between 2010 and 2020, it is stated that the relation between reinforced concrete housing m2 building cost and exchange rate have continued strong and continuously. It is seen that the correlation between USD and cost per m2 between 2010 and 2020 has continued at a very high level such as 0.926683 **(92%)** Figure 3.



	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
USD-TL	1.5084	1.6788	1.8007	1.9061	2.1921	2.7258	3.0277	3.6557	4.8241	5.6826	6.5004
Cost per M2	876.7	1112.34	966.65	1090.67	1175.74	1221.94	1302.1	1744.28	1923.94	1735.77	1905.88

Figure 3: 2010-2020 years USD-Cost per m2.

The results of the analysis of building cost data in both 1986-1993 and 2010-2020 show that the relation between building cost and macroeconomic indicators exists in the past and present. In another study that supports these results, it is stated that there is a bidirectional causality relation between exchange rates and house sales prices, and imported raw materials, which can be a cost element in house sales prices, are affected by the exchange rate of the country (Diler, 2018). All these results evidently demonstrate that the exchange rate can be used from macroeconomic indicators in a model for cost estimation and updating.

Conclusion and Recommendations

The study not only introduces a new approach to cost estimation methods that are already available but also enables to revise cost estimates irrespective of cost estimation methodologies. This will improve the efficacy of cost control and management.

Based on this study, one can argue that more correlations between items of cost and economic indicators and introduction of artificial intelligence would lead to a much more effective and revisable cost estimation model. Each correlation with economic indicators constitutes a part of a cost estimation model that enables to expand its scope, and a cost estimation model would improve in efficacy and precision of results as more and more correlations with economic indicators are established.

As a similar set of rules established for the sample of this study can be utilized as a method to correlate different items of cost with different economic indicators, As Makarov (2019) study on the relationship between building materials and economic indicators points out, other economic indicators and different cost levels, for example; In the case of researching and expanding the effects of economic indicators on construction costs such as oil prices-insulation material cost, unemployment values-labor cost, it will be possible to create a cost estimation model for multiple economic indicators-cost relationship in cost estimation by revealing cross-economic indicators and cost relations.

The results obtained from the weighted distribution of the data in the research from the statistical methods exemplify the possibility of constructing a configurable artificial intelligence model between economic indicators and construction costs with the "learning with decision tree" methodology, which is one of the artificial intelligence methods. These results obtained from the limited data set sampled in the research can be expanded to other economic indicators and cost relationships at different levels (such as oil prices-insulation material cost, oil prices-excavation costs, unemployment values-labor cost) through data mining methods. It will provide the opportunity to construct more advanced decision tree learning models over the new data sets created by the expansion of the data set. Integrated models in which decision tree models are structured together to produce cross results will increase the efficiency of cost estimation. In particular, online updatable structures to be established over computer networks with instantly updatable data such as the exchange rate in the research sample will provide instant monitoring of costs during the project process. As a result, the project will be able to manage decision-making processes much more effectively.

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Classification of Construction Waste According to Lean Management Approach

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Abstract

Waste is a concept that appertaining to unnecessarily expenses such as material, duration, cost and occurred in almost every sector. In the researches, it is revealed that the construction sector (CS) has the largest share considering the other sectors, with a rate of over 35% in waste generation. So, it is important to determine plans and strategies for managing the waste in CS. In order to manage waste properly in CS, it is necessary to define and classify the waste in an effective way. There are many publications in the literature that classify the construction waste in different ways such as waste according to the source spent type, waste's causes, and its impacts. Those classifications of waste evaluate just a part of waste. But it is believed that all the classifications should be investigated with a holistic perspective for managing the construction waste in an effective manner. Lean thinking is a waste-oriented concept that aims to reach highest value and eliminate the waste. So, in this study, waste in CS will be defined and a new waste classification system (WCS) will be introduced according to the lean management approach with a holistic perspective considering current classifications.

Keywords: *construction waste management, lean construction wastes, lean waste management, waste classification system.*

Introduction

Construction industry is symbolized as the level of development at many countries. Above of 200 sub-sectors present their goods and labor to the construction industry. On that sense, construction industry could be described as a locomotive sector. Because of the fact that, the construction sector is closely related with the both national and world economic conditions, it gains importance to be managed all the conditions in an effective way at the sector, especially during the recession and economic growth periods. Therefore, construction industry needs new management approaches to control its conditions. One of them is lean construction which making adaptation of lean approach to construction industry.

Lean is a systematic approach which has generic principles, techniques and tools that aims to identify and eliminate waste. Eliminating waste in a process is one of the top priorities in the lean construction theory (Mao & Zhang, 2008). In general, waste is interpreted as just material losses which is physical waste (Koskela, 1992). But, there is so much significant waste that named non-physical waste, too. Due to the fact that, the construction industry has been severely vexed by several waste, Senaratne and Wijesiri (2008) evaluate that all types of construction waste should be managed effectively. So, in this paper, current construction waste type classifications will be evaluated. Later on, a new waste classification system (WCS) will be introduced considering lean thinking approach with value stream activities.

Waste Perception According to Lean Approach

One of the most important concepts which is named as 'lean construction' has introduced in 1990s. Lean construction concept bases on 'lean production' which is an application of a successful manufacturing theory. The concept of 'lean production' has been developed as a method of eliminating waste by Taiichi Ohno, an engineer working Toyota. Lean production has five key steps consisting of defining value, mapping value stream, creating flow, using a pull system, and pursuing perfection. Second step which is called mapping value stream is one of the most important steps during any production process. At this step it is identified all the production process steps considering the idea of waste elimination (Womack & Jones, 2003). Mapping value stream step defines the production process steps as value adding activities and non-value adding activities.

Value adding activities are closely related with defining value which is the means of identifying the final form, feature or function of the product/service that the customer is willing to pay for (O'Connor & Swain, 2013). Generally, value adding activities are less than the other activities and they are approximately %5-10 of all activities during the whole production process (Figure 1).

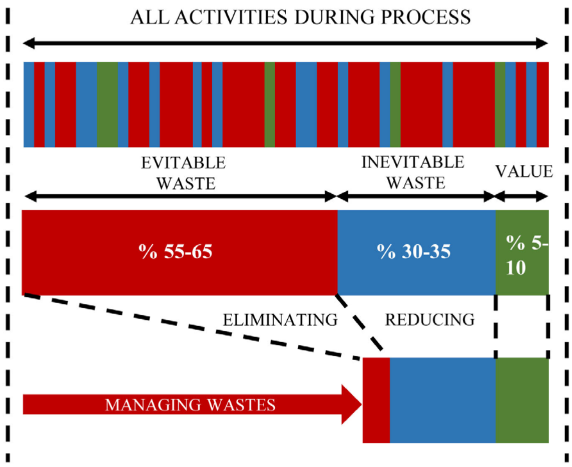

Figure 1: Value adding & non-value adding (waste) activities (adapted from: Mossman, 2009; O'Connor & Swain, 2013).

Womack and Jones (2003) define non-value adding activities with two types as the first type waste and the second type waste (Figure 1). First type is inevitable waste which is the tasks that must be done to enable the value adding activities to be completed, but do not add value. This type of waste is near %30-35 of all activities and they can be exemplified such as procurement, taxes, insurance, logistics, accounting, cost estimating, commercial management etc. at the construction industry. Second type waste is evitable waste that the activities associated with carrying out a particular work activity. That type waste could consist of in the nature of work for doing it such as excessive walking, looking for tools and materials or poor quality etc. Enforced works that has prevented work activity from being carried out such as waiting for information, materials not supplied are also second type waste. Second type waste is approximately %55-65 of all activities during process. That type of waste is generally accidents, delay, waiting, rework, over-ordered materials, damaged materials, poor payment systems, multiple handling systems, tendering etc. at the sector (O'Connor & Swain, 2013; Sarhan et al., 2014).

While improving the work and creating value, value stream should be mapped with all the activities. Then, three main steps should be kept up with aiming to eliminate evitable waste activities, reducing the inevitable waste activities and improving efficiency of value adding activities (O'Connor & Swain, 2013). Defining of these steps for each construction project plays a big role to manage waste. Therefore, it is thought that defining waste classification as a basis of evitable and inevitable waste will help to manage them according to eliminating or reducing decisions. Thus, as a lean approach, the work capacity could be increased while doing same work as O'Connor and Swain (2013) say's as more for the same or more for less.

Construction Waste Classifications

Construction waste has been categorised in literature with different ways. In spite of different classifications, many of them follow the same basic concept. Excess materials, delays, rework and defects are those waste commonly mentioned by researchers (Senaratne & Wijesiri, 2008). Although there are many classification about construction waste on literature, it is thought that there is not effective classification to manage the waste especially considering lean value stream perspective.

It is believed that the best extensive classification of construction waste belongs to Castelo Branco (2008)'s research. In the research, construction waste is divided 4 main groups. First part is waste according to type of resource consumed (physical waste which is comprised of material, man-hour, equipment and financial wastes that are comprised of material purchase and due physical waste). Second is, waste according to its nature (direct waste comprised of substitution, over allocation, negligence and indirect waste comprised of delivery, over production, transportation, execution, reworks etc.). Third is, waste according to its control avoidable and unavoidable and fourth is waste according to its origin like materials, manufacturing, design, materials supply etc. Apart from that there are different researches about construction waste classification. A great majority of those classifications has been evaluated. Due to the fact that the term, "construction waste" is identified in different ways in the literature, construction waste in the literature are evaluated together and presented with dividing 3 main groups at this study's literature research part. These are waste according to source spent type, waste according to its causes and waste according to its impacts.

First group is waste according to source spent type. That group of waste is grouped as physical and nonphysical waste by some researchers (Nagapan et al., 2012; KalilurRahman & Janagan, 2015; Ismam & Ismail, 2014). While Nagapan et al. (2012), and KalilurRahman and Janagan (2015) have evaluated physical waste as just material waste; Ismam and Ismail (2014) have approached to physical waste as material, labor, machinery waste. Also, all those researchers handled non-physical waste as time overrun and cost overrun.

Second group is waste according to its causes. That group has also divided 3 sub-group as waste of stemming from process, waste of stemming from stakeholders and waste that according to its controllability. Nagapan et al. (2012) analysed the process waste as design process, handling process, site process, procurement process etc. while Kozlovská and Spišáková (2013) have evaluated process waste according to project life cycle basic steps such as design process, construction process, management process and demolition process. As those researchers, Mortaheb and Mahpour (2016) have grouped waste according to process such as feasibility process, design and engineering process, procurement process, construction process, start-up and operation process. Both Al-Aomar (2012) and Hosseini et al. (2011) have evaluated the construction process waste such as correction, over-processing, delay, inventory, conveyance, ever-production, and motion while considering lean waste categorization. Second sub-group waste which is stemming from stakeholders has been analysed by Wrap (2010) as owner, contractor, sub-contractor, and project team. Last sub-group waste which is according to its controllability has been evaluated as controllable or non-controllable in the literature. Controllable waste is flows, conversion and management activities. Just as lack of resources (material, equipment, labor) and lack of information (poor information quality, timing of delivery is inadequate etc.) are flow based waste causes; inappropriate method (inadequate procedures, inadequate support to work activities etc.), poor planning (lack of work space, too much people working in reduced space, poor work conditions etc.) and poor quality (poor execution of work, damages to work already finished etc.) are conversion based waste causes. Also, bad allocation and poor distribution that are related with decision making and ineffective control are management-based waste causes. According to Serpell et al. (1995), non-controllable waste causes are directly related with suppliers' and designers' performance while some causes of non-controllable waste could be related to the environment, like weather conditions and festivities.

Third group of construction waste is that waste according to its impacts. There is not sufficient research about that group in the literature. Seyis et al. (2016) have evaluated the impacts of construction waste in terms of cost and time impacts. Akhir (2015) has evaluated the impacts of construction waste as environmental impacts (environmental pollutions, shortage of land, climate change, loss of raw materials etc.), economic impacts (increase in transportation charges of construction waste, increase cost of project, increase in landfill fee, increase price of raw materials, delay of projects, economic losses etc.), social impacts (dangerous to the people’s health and negative effect to the society).

Construction Waste Classifications System (WCS) via Lean Approach

Koskela (1992), has stated that a systematic attempt for identifying waste in construction processes (flow waste in lean thinking terms) has not been done by the construction management practitioners until lean construction concept was introduced. Also, he has emphasized that construction is mainly managed based on transformation concept and principles related to the flow and value generation concepts as the basis of lean thinking are largely neglected.

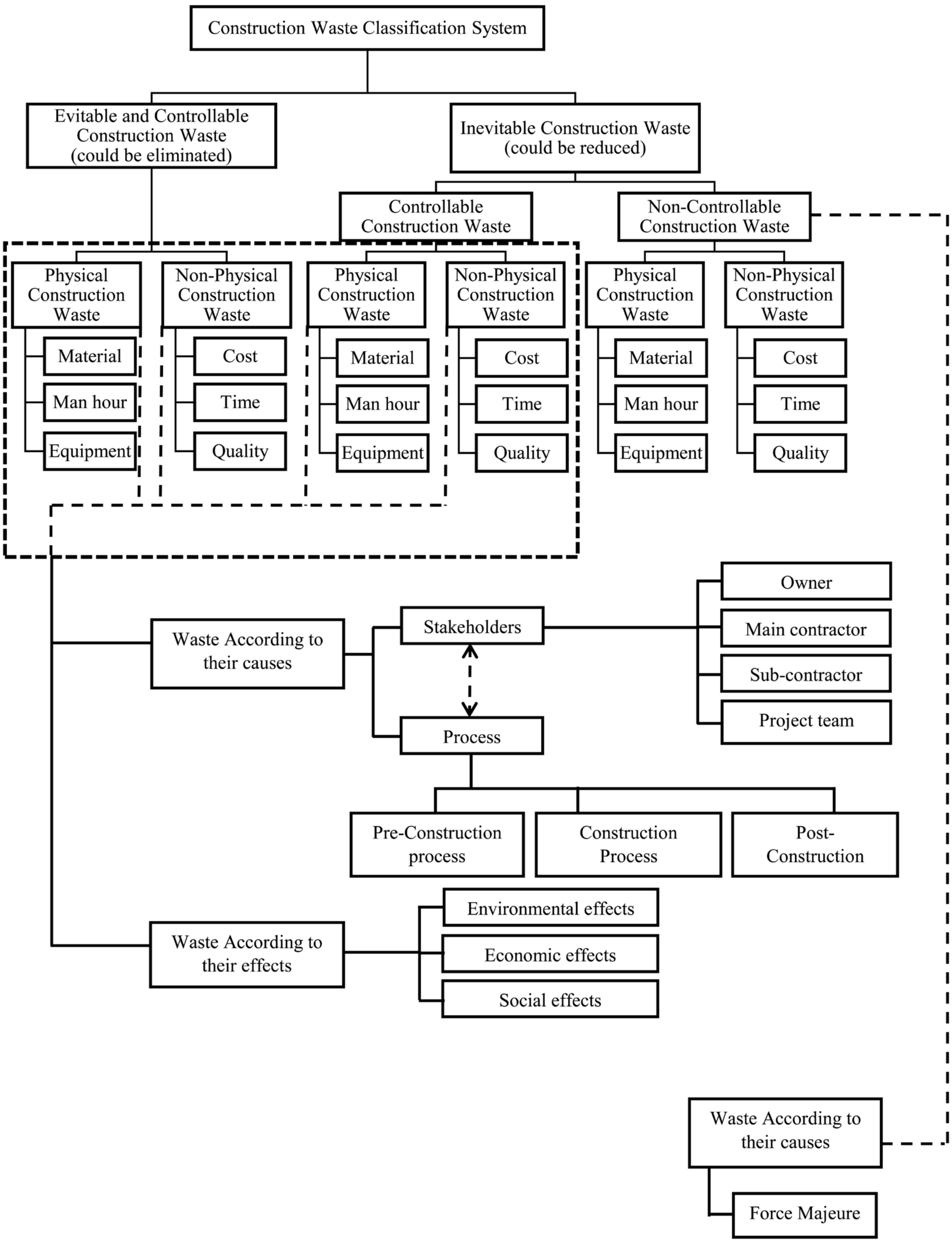

Figure 2: Construction waste classification systems (WCS).

The current construction waste classification system in the literature has been reviewed at the previous part of this study considering according to Koskela (1992)'s thought. As a result of that part, it is determined there is not still a clear and holistic classification system based on lean approach considering value and waste relation in spite of many classification.

In this study it has been aimed to generate a new and global construction waste classification systems (WCS) with a holistic perspective considering flow and value concepts via lean approach because of the fact that it is a necessity for comprehending the construction waste and managing them. Because; it is believed that construction waste should be determined in a holistic perspective firstly for managing them in an effective way. Therefore, a new WCS has been composed and proposed as Figure 2.

Because of the fact that the waste is stated as non-value adding activities according to lean approach, it is thought that waste should be grouped considering the idea of non-value adding activities. At the Figure 2, first of all waste is evaluated according to lean approach which is shown at Figure 1. Therefore waste is categorised basicly two main group as first type (inevitable) waste and second type (evitable) waste. Evitable waste is also controllable waste that can be eliminated if they are managed effectively. Inevitable waste is also divided two other categories as controllable and non-controllable waste. Controllable waste which is deal with internal flows, conversion process and products, could be reduced. Inevitable and controllable waste is due to procurement, taxes, insurance, logistics, accounting, cost estimating, commercial management activities which are the tasks that must be done to enable the value adding activities to be completed, but do not add value. Those activities are not eliminated but could be reduced. Non-controllable waste is deal with external flows and environmental issues. Non-controllable waste could be consist of effect of weather, accidents, pilferage, lack of legislative enforcement, vandalism, damages caused by third parties, festival celebration, unpredictable local conditions etc. Those factors could not be controlled but risk of them can be reduced. Therefore, that group is named as inevitable but non-controllable. All the evitable and inevitable waste is divided two main sub categories that are named as physical and non-physical waste which as shown at Figure 2. Because, waste is thought as a result and waste could be occured as physically or non-physically way. For this reason, it is thought that waste should be determined firstly and after that all the causes and effects should be evaluated.

When the waste is divided as physical waste and non-physical waste; physical waste could be ensued as material, man-hour and equipment waste while non-physical waste is ensued as cost, time and quality waste. It is believed that quality should be thought as a kind of non-physical waste because of the fact that quality is evaluted as a lost when it is not generated through expectation of customer. After categorisation the waste as physical waste and non-physical waste, all the waste could be examined according to their causes and according to their effects. If all the controllable waste is evaluated according to their causes, it can be also considered either according to stakeholders such as owner, main contractor, sub contractor and project team or process such as pre-construction process, construction process and post-construction process. Also controllable waste could be evaluated according to their effects considering environmental effects, economical effects and social effects. Due to the fact that non-controllable waste is generated out of control, they could be evaluated according to their causes as only force majeure.

It is important to manage waste for maximizing the value in the construction sector, too. For this reason, it is believed that the necessity of determining the waste firstly, for improving and applying effective management methods. So, categorisation of the construction waste could be evaluated as the first and basic step of waste management.

Conclusion

Construction waste is directly related with construction management. So, it is important to know the waste and manage them for effective construction management. Because of the fact that lean thinking is a waste-oriented concept that aims to reach highest value and eliminate the waste, it is thought that evaluating construction waste within the scope of lean thinking is the best option to manage them. For deciding the best management approach as eliminating or reducing the waste, it should be decided what kind of waste are evitable or not. Also, it should be evaluated that not only waste is occurred as physically such material, equipment waste but also it is occurred as non-physically like time, cost and quality waste. In this way, if a construction manager determines the waste type such as physical waste or non-physical waste, the manager could analyse all the construction process according to the highest priority type of waste for improving the value. Thus, the manager could investigate the reason and effects of the waste according to the type and evaluates all the process improvement not only material and equipment waste but also cost, time, quality waste.

When the waste is analysed according to the kind of reasons that effect to waste generation such as stakeholders or since the waste occurred in which process, the physical and non-physical waste could be controlled at the root. Similarly, after obtaining waste it could be evaluated according to their effects, too. Thus, all the impacts of the waste according to type of waste could be analysed and priorities could be determined. In this way, such a categorisation could present the construction waste is not evaluated just as material waste anymore and classifying the waste such a holistic perspective could support the analysing process of the waste in a directly way.

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Performance & Forecasting Methods in Construction Industry; Deterministic Approach

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Abstract

The success of a construction project can be determined by evaluation of performance. Performance does not only show the comparison between planned, earned and actual, but also provides forecasting in terms of cost and time. Performance can be monitored in activity, project and organization levels in construction sector. The main purpose of this study is to classify the performance & forecasting methods and analyze the deterministic methods based on review of literature. The methods which already defined in literature have been categorized under five main groups such as 'Deterministic Methods', 'Probabilistic / Stochastic Methods', 'Fuzzy Methods', 'Financial & Managerial Methods / Quality Related Frameworks' and 'Miscellaneous Methods'. This literature review study will provide the chronological development, main characteristics, pros and cons of deterministic performance & forecasting methods, categorize them in a framework and will be helpful for new researchers in terms of classification of literature.

Keywords: *construction projects, deterministic, forecasting, performance, project control.*

Introduction

Performance **measurement** can be defined as the process of quantifying the efficiency and effectiveness of action. Performance measurement system can be examined at three different levels: (1) the individual performance measures; (2) the set of performance measures – the performance measurement system as an entity; and (3) the relationship between the performance measurement system and the environment within which it operates. (Neely et al., 1995). Performance **monitoring** allows a project team to track project triple constraints; cost, time and scope, in a timely manner (De Marco & Narbaev, 2013). According to Mosselhi (1993), the performance **evaluation** method is used to calculate the deviation of time and cost from its control baseline and assesses the value of the deviation (as cited in Li, 2004). Neely et al. (2002) defined performance **measurement** and **management** system (PMS) as a balanced and dynamic system that enables support of decision-making processes by gathering, elaborating and analyzing information (as cited in Taticchi et al., 2010).

As seen from the abovementioned samples of literature, the subject of performance can be explained with the keywords 'performance measurement', 'performance evaluation', ‘performance monitoring’ and ‘performance management’ separately. In this study, the word ‘performance’ has been considered alone which comprises the others.

According to Ahuja et al. (1994), when controlling project performance, it is important to not only monitor cost and time variances for actual project progress, but also to properly establish the actual project status based on objective predictions (forecasts) of final project performance (as cited in Barraza et al., 2004). According to Al-Tabtabai (1996), forecasting project status is essential function in tracking and control (as cited in Li, 2004).

Performance can be defined as the comparison between planned, earned, and actual, determination and interpretation of variances at a certain period or time. On the other hand, forecasting is estimating the project completion in terms of cost or time, considering the planned, current, or combined performances as a reference. There are researches that list the performance methods and researches that classify the forecasting methods separately in the literature. In this study, ‘performance’ and ‘forecasting’ have been considered together as two separate but related and complementary subjects and the ‘performance & forecasting’ methods have been classified as a whole. The main purpose of this literature review study is to classify the performance & forecasting methods based on review of literature, categorize deterministic methods in a framework and detailly analyze the deterministic methods and their chronological development separately.

Performance & Forecasting Methods

Li (2004) in his PhD thesis explained the existing performance evaluation methods as 1) Traditional Evaluation methods like planned vs actual single/standard, double and superimposed/integrated s-curves, 2) Pert/Cost Method, 3) Integrated Evaluation Methods such as EVM. Li (2004) also classified forecasting methods as 1) Stochastic methods, 2) Earned-Value Based and Its Extension Methods, 3) Social Judgment Theory and 4) Fuzzy Modelling Methods. Kim (2007) in his PhD thesis explained forecasting methods as deterministic and probabilistic. Kim (2007) added that some forecasting methods use objective data observed in a quantitative way, while others rely on subjective information. Kim (2007) mentioned Earned Value Management (EVM), Critical Path Method (CPM) and Monte Carlo Simulation as conventional methods for performance forecasting. Abdul-Rahman et al. (2011) classified the project forecasting methods mentioned in literature as; 1) Deterministic methods; 2) Stochastic methods; 3) Fuzzy logic model; 4) Miscellaneous methods. Willems and Vanhoucke (2015) classified 187 academic research papers published in the selected journals on earned value management (EVM), project control, time and cost control, based on a framework along the following classes: (i) research problem, (ii) contribution, (iii) methodology, (iv) analysis, (v) validation and (vi) application. ‘Performance evaluation’ and ‘forecasting’ subjects have been considered under (ii) contribution section. The methodologies (iii) indicate the techniques used to achieve the proposed contribution such as observational analysis, extended EVM analysis, statistical analysis, artificial intelligence and computerized analysis. And the analysis (iv) represents the degree of uncertainty that is incorporated into the methodology, ranging from purely deterministic techniques to highly stochastic procedures such as deterministic, fuzzy and stochastic techniques. Deterministic approach results in point estimate, stochastic techniques incorporate a larger degree of variation and fuzzy methods used when data are imprecise and vague (Willems & Vanhoucke, 2015).

In this study, ‘performance’ and ‘forecasting’ have been considered as complementary tools. The performance & forecasting methods which already defined in literature have been categorized under five main groups. The methods that have both ‘performance’ and ‘forecasting’ capability have been classified due to their uncertainty level such as deterministic, probabilistic and fuzzy. The methods that have only ‘performance’ capability considered under financial & managerial / quality related methods. The methods except these two groups considered under miscellaneous methods.

a) **Deterministic Methods:** Crandall and Woolery (1982) describe the deterministic approach as the estimates of final cost and project duration considering for the project activities the most likely cost and duration values, respectively (as cited in Barraza et.al, 2004). Deterministic Methods are applied under certain conditions and define specific figures. ‘Earned Value Project Management System’(EVPMS) is the well-known deterministic method. The development has been started with schedule related methods such as ‘Gantt Charts’, ‘Line of Balance’ and ‘Critical Path Method’. Later on, ‘Cost/Schedule Planning and Control Specifications’ and ‘Criteria’ created the foundation basis of ‘Earned Value Method’. Planned Value, Earned Schedule and Earned Duration Methods are the main extensions of EVPMS in terms of forecasting of time/schedule. Deterministic S-Curves such as traditional S-Curve (planned vs actual) and Integrated Cost / Schedule S-Curve Method are also considered under deterministic methods.

b) **Probabilistic / Stochastic Methods:** According to Crandall and Woolery (1982), the probabilistic approach estimates the planned cost and duration values based on the variability of cost and duration inherent in each of the project activities (as cited in Barraza et al., 2004). Probabilistic / Stochastic methods define a range of figures between pessimistic and optimistic conditions for forecasting and generally used for project level. ‘Program Evaluation and Review Technique (PERT)’, PERT/Cost, ‘Kalman Filter Forecasting Method’, Bayesian Adaptive Forecasting Method’, Stochastic S-Curves, Stochastic Critical Path Method are some of the samples of this group.

c) **Fuzzy Methods:** Fuzzy theory has been first introduced by Zadeh (1965) and explains uncertainty in events and systems where uncertainty arises due to vagueness or fuzziness rather than due to randomness alone (Naeni et al., 2013). Fuzzy methods generally consider fuzzy theory and used under high degree of uncertainty for activity / project levels.

d) **Financial & Managerial Methods / Quality Related Frameworks:** This group focuses on performance and applicable for generally organization / stakeholder levels in terms of mainly financial / quality issues and consists of Financial & Performance Management Techniques like ‘Return on Investment’, frameworks like ‘Balanced Score Card’, metrics like ‘Key Performance Indicators’, best practices like ‘Benchmarking’ and quality based models like ‘EFQM Excellence Model’, ‘Baldrige Award’.

e) **Miscellaneous Methods:** The methods except abovementioned groups such as artificial, digitalized, information modelling, subjective judgement approaches and others.

In this literature review study, only the deterministic methods will be analyzed detailly. Earned Value Management (EVM) is one of the reason of selecting to analyze deterministic methods which is a well-known method that has the ability of both performance and forecasting, heavily analyzed in literature and used especially for EPC projects in construction sector. Also, deterministic approach is more result oriented based on its nature and easy to apply in construction sector. The analysis of probabilistic / stochastic methods, fuzzy methods, financial & managerial methods / quality related frameworks and miscellaneous methods will be the subject of further studies.

Deterministic Approach

Deterministic methods define a specific figure for both performance / forecasting and generally used for activity / project levels in terms of cost / schedule. The main aim of this section is to classify the deterministic methods in terms of purpose and area of usage such as cost and/or schedule, specify the focus and special concern of each method if any and introduce the establishment by whom and when. 134 articles with related keywords in 'Google Scholar' and 'ProQuest' databases have been reviewed to achieve this goal. After this literature review, 'deterministic performance & forecasting methods' have been summarized and categorized in a framework (Figure 1).

Sub-Section	Methods			Purpose	Special Concern	Establishment
1- Schedule Related Methods	1.1-	Bar / Gantt Charts		Schedule	('Factory Floor' studies) basis of Earned Value	Gantt (1903)
	1.2-	Linear Scheduling Methods / Line of Balance (LOB)		Schedule	(Repetetive activities)	Fouch - Goodyear Aircraft Co. (1941)
	1.3-	Network Scheduling / Critical Path Method (CPM)		Schedule	(Critical Path) (ES, EF, LS, LF, Float)	DuPont-Remington Rand (1955)
2- Earned Value Related Methods	2.1- Earned Value Method (EVM)	2.1.1-	Cost/Schedule Planning and Control Specification (C/SPCS)	Cost & Schedule	PV & EV & AC Variance - SV, CV Performance Index - CPI, SPI	U.S. Air Force (1966)
		2.1.2-	Cost/Schedule Control Systems Criteria (C/SCSC)	Cost & Schedule		U.S DoD (1967)
		2.1.3-	Earned Value Project Management System (EVPMS)	Cost & Schedule		U.S DoD (1967) & U.S. Federal Government (1996)
	2.2- Extensions of EVM	2.2.1-	Earned Time Method (ETM)	Schedule	(Variance Analysis) (ET = PD x %)	Carr (1993)
		2.2.2-	Planned Value Method (PVM)	Schedule	(PV Rate, SV, TV)	Anbari (2003)
		2.2.3-	Earned Schedule Method (ES)	Schedule	SV(t), SPI(t)	Lipke (2003)
		2.2.4-	Earned Duration (ED)	Schedule	(ED = AD x SPI)	Jacob and Kane (2004)
		2.2.5-	Assured Value Analysis (AVA)	Cost & Schedule	(Procurement)	Bower (2004)
			Phase Earned Value Analysis (PEVA)	Cost & Schedule	(Phase)	Bower (2005,2006)
			Phase-Assured Value Analysis (PAVA)	Cost & Schedule	(Procurement & Phase)	Bower (2007)
		2.2.6-	Extended Method - Learning Curve (EVM/LC)	Schedule	(Learning Curve)	Plaza and Turetken (2009)
		2.2.7-	Earned Duration Method (EDM)	Schedule	TED, TAD, TPD EDI, DPI, PPI, API	Khamooshi and Golafshani (2014)
		2.2.8-	Customer Earned Value (CEV)	Cost & Schedule	(Workflow, Value Gen.) (CEV, P-CEV, VIP, WIP)	Kim &Ballard (2002) Kim et al.(2016)
		2.2.9-	Earned Incentive Metrics (EIM)	Cost & Schedule	(Incentive Contracts)	Kerkhove and Vanhoucke (2017)
		2.2.10-	Others			
3- Deterministic S-Curves	3.1- Traditional S-Curves	Standard S-Curve Method, Single S-Curve Method		Cost & Schedule	(Comparison of PV&AC)	
	3.2- Integrated S-Curves	Integrated Cost/Schedule Work Method (Int. S-Curve Method)		Cost & Schedule	(Relationship between Cost & Progress)	Lockwood, Andrews & Newnam, Inc. (before 1986)

Figure 1: Deterministic performance & forecasting methods.

The deterministic methods have been classified into three sub-levels considering the review of literature;

1- Schedule related methods,
2- Earned value related methods and
3- Deterministic s-curves.

Each sub-level will be analyzed chronologically.

Schedule Related Methods; such as Bar / Gannt Charts, Linear Scheduling Methods / Line of Balance (LOB) and Network Diagrams / Critical Path Method (CPM). Scheduling has been considered as an essential component of performance.

1.1- Bar/Gannt Charts: Gantt (1903, p. 1322) first described a version of his charts in an article published alongside Frederick W. Taylor's Shop Management paper (Taylor, 1903, p. 1337) (Wilson, 2003). These studies which created the concept of earned value can be considered as the 'Factory Floor' studies mentioned by Fleming & Koppelman (1996). Bar / Gannt charts can be used for scheduling purpose for both activity and project levels.

1.2- Linear Scheduling Methods are well-suited to projects that are composed of activities of repetitive nature (Arditi & Albulak, 1986). Line of Balance (LOB) (originally called Production Analysis) was developed in 1941 by Mr. George Fouch at Goodyear Aircraft Company (Sobczak, 1963). LOB is well-known in construction sector which fits for repetitive activities or projects like motorway and pipelines with scheduling purpose.

1.3- Network Scheduling Methods: Critical Path Method was developed by DuPont and Remington Rand Univac in 1957 (Sobczak, 1963). In a typical Critical Path Method, the total duration of an on-going project is determined based on the assumption that future tasks will proceed as planned regardless of past performance. (Kim, 2007). CPM is the well-known deterministic scheduling method for project level in terms of scheduling purpose.

Earned Value Related Methods consists of Earned Value Method and its extensions.

2.1. Earned Value Method (EVM); has been developed with Cost/Schedule Planning and Control Specifications (C/SPCS), Cost/Schedule Control Systems Criteria (C/SPCC) and Earned Value Project Management System (EVPMS).

2.1.1 Cost/Schedule Planning and Control Specification (C/SPCS): In 1966, the Air Force initiated a new performance measurement system known as Cost/Schedule Planning and Control Specifications or C-Specs. This system instituted project accounting specifications that the contractor's in-house accounting and planning systems were required to meet (Cummings & Schneider, 1992).

2.1.2 Cost/Schedule Control Systems Criteria (C/SCSC): In 1967, the United State Department of Defense (DOD) issued thirty-five cost/schedule control system criteria (C/SCSC) consists of Organization (5), Planning & Budgeting (11), Accounting (7), Analysis (6) and Revisions & Access to Data (6) sub-sections. The earned value concept is embedded within the C/SCSC (Fleming & Koppelman, 1996). Around 1967, EVM was introduced by agencies of the U.S. federal government as an integral part of the C/SCSC and was used in large acquisition programs (Anbari, 2003).

2.1.3- Earned Value Project Management System (EVPMS): To encourage wider use of EVM in private sector, the U.S. federal government decided to discard C/SCSC by the end of 1996 and turned toward a more flexible earned value management system (EVMS), also called the earned value project management system (EVPMS) (Anbari, 2003). Fleming and Koppelman (1996) described the earned value project management concept very detailly. Anbari (2003) showed the major aspects of the earned value method and provides logical extensions. The cost management component of EVM is considered to be very effective whereas its schedule aspect has been questioned conceptually in the last few years (Khamooshi & Golafshani, 2014). EVPMS is a project management and control tool that compares planned value (PV), earned value (EV) and actual cost (AC) to evaluate performance with the interpretation of variances, indexes and forecast estimation to completion in terms of cost and schedule for activity and project levels.

2.2. Extensions of EVM

2.2.1 Earned Time Method (ETM) is described by Carr (1993) and introduced as a project duration control method by Borges and Mário (2017). Earned time (ET) equals to the percentage complete multiplied by the total planned duration (PD) of an activity or project (Borges & Mário, 2017). Carr (1993) defined variances as a sum of more detailed variances and defined element variances as sum of quantity variance, rate variance and start variance.

2.2.2 Planned Value Method (PVM) is described by Anbari (2003) and introduced as a project duration forecasting method by Vandevoorde and Vanhoucke (2006). Anbari (2003) called the 'average planned value per time period' as PV Rate. Schedule Variance (SV) can be translated into time units by dividing SV by the PV Rate. The result is the SV in time units or the Time Variance (TV) (Anbari, 2003). This method can be used for schedule purpose for mainly project and activity levels.

2.2.3 Earned Schedule Method (ES) has been firstly introduced by Lipke (2003) considering the insufficient behavior of EVM for schedule performance. EVM measures schedule performance not in units of time, but rather in cost. Additionally, SPI and SV reflect unreliable values, an index value equal to unity and zero variance respectively, for every project finishing late (Lipke, 2003). ES method has been validated by Henderson (2004), Vandevoorde and Vanhoucke (2006), and Vanhoucke and Vandevoorde (2007). Henderson (2004) also defined further extensions of ES such as forecasting of duration. ES is an alternative to EVM in terms of schedule performance & forecasting for project level.

2.2.4 Earned Duration (ED) is a project duration forecasting method described by Jacob (2003) and extended by Jacob and Kane (2004). Earned duration (ED) is the product of the actual duration (AD) and the schedule performance index (SPI) (Vandevoorde & Vanhoucke, 2006). The method will be shown with the abbreviation (ED) to avoid any confusion with (EDM).

2.2.5 AVA, PEVA and PAVA: Assured Value Analysis (AVA) has been introduced by Bower in 2004, built on EVM concept and considered the effect of procurement and signed contracts in terms of performance evaluation and forecasting with new measure. Phase Earned Value Analysis (PEVA) has been also introduced by Bower in 2005 and 2006 which is an extension of EVA and analysis the entire project in phases. Phase-Assured Value Analysis (PAVA) is a combination of AVA and PEVA, resulting in a new EVM methodology which takes into account the assurance provided by procurement, simplifies the calculation of earned value through phases, and provides powerful forecasting and charting features (Bower, 2007). AVA, PEVA and PAVA can be used for cost and scheduling purposes for project level.

2.2.6 (EVM/LC) is an extended version of EVM considering the learning curve. It was developed to improve the accuracy of duration forecasts generated by EVM considering the learning effects (Plaza & Turetken, 2009). EVM/LC can be used for project level in terms of scheduling purpose by using new indices like performance reduction index and others.

2.2.7 Earned Duration Method (EDM) has been developed by Khamooshi and Golafshani (2014). They argue that still there are some issues associated with the use of ES method for schedule performance measurement. The main drawback of SPI(t) is the fact that, similar to SPI, it measures schedule performance using monetary terms of Earned Value (EV) and Planned Value (PV). The Earned Schedule method uses EV as a proxy to get to corresponding duration. Performance measures which use a cost profile to offer a schedule measure will not be accurate. The higher the disparity between time and cost profiles of a project, the more inaccurate the schedule performance offered will be (Khamooshi & Golafshani, 2014). EDM uses duration instead of cost to calculate performance & forecasting in terms of schedule for activity / project levels with newly introduced duration-based indices.

2.2.8 Customer Earned Value (CEV) has been first introduced by Kim and Ballard (2002) as a performance measurement concept from the customers perspective. CEV has been improved and combined with EVM by Kim et al. (2016) to investigate work-in process between trades and level of collaboration. CEV proposes a project metric system to supplement the EVM in terms of the workflow and value generation (Kim et al., 2016). CEV can be used for cost and schedule purposes especially for project level.

2.2.9 Earned Incentive Metrics (EIM) is an extension of the traditional EVM/ES techniques and EIM is a novel project control metric specifically tailored to projects subjected to incentive contracts (Kerkhove & Vanhoucke, 2017). EIM can be used for cost and schedule purposes for incentive projects with newly introduced indices.

Deterministic S-Curves: There have been many attempts in the past to develop S-curve forecasting models to represent the running value of different types of construction projects by Hardy (1970), Balkau (1975), Bromilow & Henderson (1977), Drake (1978), Hudson (1978), Oliver (1984), Singh & Woon (1984), Miskawi (1989), and Khosrowshahi (1991) (as cited in Kaka, 1999). In this section, instead of above mentioned ‘S-Curve’ shaped forecasting mathematical functions, deterministic S-Curve methods related with performance and forecasting will be considered such as traditional S-curves (planned versus actual) and Integrated Cost/Schedule Work Method.

3.1 Traditional S-Curve Methods: Standard S-Curve Method compares the actual progress with the standard S-Curve where the project progress is compared to three stages that begin slowly up to %25 of the project duration, accelerate from %25 to %75 of the project duration and then slowly again to completion (Li, 2004). **Single S-Curve Method** is project dependent. Schedule-based projects compare budget with actual progress. Projects that are not schedule-based projects use a ‘Standard S-Curve’ for comparison which is a different curve-fitting model of collected data from pervious projects as a benchmark (Li, 2004). Traditional

S-Curve methods compare planned and actual figures for cost and scheduling purposes for project level.

3.2 Integrated Cost/Schedule Work Method is a cost control tool and a visual summation of cost, performance and time used at Lockwood, Andrews & Newman, Inc. The Integrated Cost/Schedule Performance Curve provides: (1) actual cost in relation to the scheduled budget; (2) actual accomplishment as compared to scheduled performance; (3) cost performance in relation to work accomplished; and (4) measurement (or illustration) of various slippages in the key parameters (Stevens, 1986). Superimposed Cost and % Complete S-Curves use two S-Curves (one represents the budget cost of work scheduled and the other represents the percentage schedule accomplishment) as the basis for evaluating project performance (Li, 2004). This method can be used for cost and schedule purpose for project level.

Conclusion

Performance and forecasting are two separate, related and complementary subjects of project management. Forecasting will be incomplete without measuring and considering actual performance. On the other hand, measuring actual performance without forecasting will only show the existing status of project. Collaboration of performance and forecasting will add value to project controls.

This is a literature review study. In this study, first the performance & forecasting methods which already defined in literature have been classified under five main groups. Then the deterministic performance & forecasting methods have been analyzed based on review of literature.

The main output of this study is the framework of deterministic performance & forecasting methods (Figure 1). The framework summarizes the main purpose of each method like cost and/or schedule, additionally defines the specific focus point of methods if any. Finally, the framework shows the establishment of each method by whom and when. This framework is alive and can be updated by other researchers according to their research aims.

It is believed that this literature review study will provide the main characteristics and properties of deterministic performance & forecasting methods and will be helpful for new researchers in terms of classification of literature.

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Muğla Metropolitan Municipality Project Management System Model

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Abstract

Muğla Metropolitan Municipality (MMM) produces projects to make Muğla a livable and sustainable city, to inherit future generations and to be the most livable city in the world. In order to make the time, cost and scope targets more achievable and successful in the Department of Public Works and Engineering (DPWE) projects, a project management system has been established and processed in the process charts. The design of the project management system model took place in three phases. In the first phase, current situation analysis was done by organizing Delphi method and focus group meetings. At this stage; Project Groups & Project Types, Success / Failure factors, Qualifications required in Project Manager and Team, Risks encountered in Projects, Problems-Solution Suggestions were discussed. In the second phase, considering the analysis results; System Setup specific to the institution was made with the Project Management Institute (PMI) infrastructure of the current system. Project Management System specific to the Muğla Metropolitan Municipality, Department of Public Works and Engineering (MPMS), special forms for Project Management processes, duties and responsibilities of the Project Management Office, Project Management roles, duties and responsibilities were defined. In the third phase, pilot projects were selected on completed projects and system tests were carried out. In this context, System Test Analysis, Project Management Office Structure and Action Plan-Road Map were created. As a result of the system test and simulation studies, it has been determined that it can be used in a healthy way with the sub-components of MPMS and it can provide gains in the projects. Throughout the process, as a result of the trainings received, the Project Management System started to be implemented in the projects within the Department. The purpose, scope, processes, work breakdown structures, stakeholder analysis, risk definitions of the projects; The follow-up and reporting of the application have been defined effectively with the necessary coordination and communication channels.

Keywords: *project management, project management offices, system management, Muğla Metropolitan Municipality.*

Introduction

Municipalities that are active local government institutions in Turkey; They are administrative units that produce services that closely concern the lives of citizens. By offering the produced services through projects, it increases the living standards of citizens.

Muğla Municipality gained metropolitan status on 06.12.2012 with the Law No. 6360 and consisted of a total of 13 districts, and the central district is Menteşe. Muğla Metropolitan Municipality has a wide service area with an area of 13.247 square kilometers and a coastal length of 1.479 kilometers.

In Muğla, one of Turkey's most special natural and historical richness of the city, covering all metropolitan municipality serves a specific geographical area in terms of history, nature, culture and economy with all departments.

In Muğla, which has become a metropolitan city, many projects that are different from each other in terms of scope, time, budget and quality have come to the agenda and Muğla Metropolitan Municipality practices many projects taking into consideration the needs of the local people with its technical, administrative and administrative staff approaching 5050 in total.
The unit that has the capacity to produce the largest project within the MMM and hence the authority to spend is the Department of Public Works and Engineering (DPWE) The main objectives of DPWE are; the construction of qualified superstructures that serve the public with environmentalist, innovative, aesthetic and complete projects by installing the best function solution in the area allocated to it. DPWE evaluates public financial and human resources effectively and efficiently; It produces projects within the framework of its objectives and completes the construction of the projects. In projects produced for public service, it is important to use the resources effectively, to follow the project schedule, and to measure performance and control based on current accurate information. Therefore, the need for the establishment of DPWE Project Management System specific to Muğla Metropolitan Municipality (MPMS) has arisen in order to realize the goals and objectives in the projects.
The main purpose in the establishment of the Project Management System; Planning, organization, implementation and control processes of DPWE projects' performance, scope, cost areas.

The main objectives are; stakeholder satisfaction, reducing errors in project processes, ensuring that projects are completed within desired times, enabling organizational learning and teamwork. In addition, it is aimed to set an example as a pioneer among the municipalities in the public.

Muğla Metropolitan Municipality Project Management System Installation

Project Management System Establishment Project of Muğla Metropolitan Municipality (MMM) Department of Public Works and Engineering (DPWE) is positioned as a 6-month project. As the important work packages of this project; analysis, planning, implementation, monitoring and control processes are defined. A project team was selected from various units within the institution, assigned to the project, and the project coordinator and project sponsor responsible for the project were determined. The project is divided into phases in order to manage processes effectively and efficiently. The approach to work with Phases in the project has been defined with reference to the system building approaches (Günaydın & Biçer, 2018) that were previously carried out in various institutions.

Phase-1: Current Situation Analysis
Phase-2: Design and Installation of Muğla Municipality Department of Public Works and Engineering Project Management System
Phase-3: Testing the Project Management System with Simulation Projects and Completing the Project

As an important project within the Muğla Metropolitan Municipality, PMI (Project Management Institute) project management processes and techniques have been applied in all stages of the Project of the Department of Public Works and Engineering Project Management System (MPMS). In the establishment of the project management system, a systematic adaptation of PMI methodology to the institutional culture has been adopted as a very important approach (Günaydın & Biçer, 2014).

The project phases follow one another, and when one phase is being realized, detail planning is made when the information of the next phase becomes clear. The information, document / record and action plans (outputs) obtained at the end of the phases were used as the input of the next phase.

Project Phases and Obtained Findings

Phase-1: Current Situation Analysis (CSA)

In order for the MMM-DPWE project management system to be used effectively and efficiently, and to be compatible with the corporate culture and methods of doing business, the current situation was analyzed before the design and installation of the project system.

In the Current Situation Analysis that started with the project team, Project Groups and Project Types were first classified. It is determined that the projects are currently grouped in 6 main groups and these main groups are also having sub-groups. In addition, it was observed that 8 different types of Projects were carried out in MMM DPWE, apart from the main and subgroups (Table 1). Classification of Main group, Subgroup and Project types revealed in the Current Situation Analysis also formed the basis for Project monitoring and control in Project Portfolio Management, which will be revealed during the system setup phase.

In the current situation analysis, the types of projects carried out at the seven branch offices in the Department of Public Works and Engineering are classified as shown in the table below:

Table 1. Project Types

	PROJECT TYPES	FEATURES / QUALIFICATIONS
1	Vision Projects	Meaning assigned prestige projects
2	Municipal Projects	Projects included in the mandate / duty description Requests from in-house needs and external needs
3	Social Projects	Projects interested by public
4	Service Buildings	Projects for the municipality's own functioning
5	Consulting Projects	Special/original, technical projects
6	Featured and Innovative Projects	Ecofriendly, Shaped according to the local policy of the Metropolitan Municipality Compatible with nature Often invisible to the public Specially designed with special materials Special / Qualified projects Renewable Energy / Smart Building
7	Type Projects	Standard / Similar projects
8	Other Projects	

With the Delphi study (Expert Opinion) conducted within the scope of determining the Institutional Project Management capacity of the Current Situation Analysis, 17 experts and managers were interviewed. In Delphi analysis, face-to-face interview technique was applied based on the "Factor affecting the success of the projects" and the "Question Form which consists of 12 questions" in the titles of "Qualifications required by the Project Manager". In order to analyze the project factors in more detail, the most frequent in-house stakeholders were determined in the projects being carried out at DPWE (Road Construction Branch Mgr., License and Control Branch Mgr., Planning Branch Mgr., Building License and Control Branch Mgr., Transportation Coordination Branch. Mgr.) and stakeholder meetings were held with 10 experts. Among the team members who carried out the Project Management project, a Brain Storming study was carried out and these results were included in the Stakeholder Analysis studies.

The information obtained from the Questionnaire used in the Current Situation Analysis was refined and Pareto Analysis, the second phase of CSA, was started.

Project Success Factors

Using the Pareto Analysis method, "Factors affecting the success of the projects were re-evaluated by 17 Experts and listed on the Likert scale based on the scoring and the standard deviation of each factor was calculated as well as the mean. Accordingly, the part colored in dark blue in Table 2 represents the most important first 20% slice that emerged according to the Pareto principle. Those that are colored in light blue are factors that have a higher than average significance compared to the standard deviation.

Table 2. Project success factors.

FACTORS	ORDER OF IMPORTANCE	MEAN	STD. DEVIATION
Preparation of technical project in sufficient details (System Details, Technical Specifications)	1	5,00	0,00
Complete preparation of the contract and its annexes (Technical specification-details etc.)	2	4,94	0,24
Providing accurate information to the relevant stakeholders fully and on time in the projects	3	4,82	0,39
Timely, complete and clear determination of the project scope	4	4,76	0,44
Clear, accurate and timely identification of needs analysis with relevant stakeholders	5	4,71	0,59
Establishing a feedback system regarding problems encountered in the project processes	6	4,71	0,59
The study and feasibility of the project is done in sufficient detail	7	4,71	0,59
Ensuring effective coordination between directorates	8	4,65	0,70
Harmonious work of the project team	9	4,65	0,61
Project planning in full and required detail	10	4,65	0,49
Periodic monitoring of scope, duration, cost and quality in projects	11	4,65	0,61
Assigning expert and competent team in the project	12	4,59	0,62
Determination of the project duration as a result of technical studies	13	4,59	0,51
Detailed and accurate determination of project costs	14	4,53	0,87
Giving sufficient time to the projects	15	4,53	0,51
Determination of duties, powers and responsibilities in projects	16	4,53	0,51
Average of the factors		**4,47**	
Establishing revision tracking systematic in projects	17	4,47	0,62
Project team getting the necessary training (technical, legislation, on-the-job, project management etc.)	18	4,47	0,80
Clear definition of the project's goals and objectives	19	4,47	0,62

Taking technical concerns into account when making decisions in projects	20	4,41	0,71
Complete and complete identification of project stakeholders (internal and external)	21	4,35	0,86
Change of project scope during project design and implementation	22	4,35	0,61
Defining the business scenario of the project	23	4,35	0,79
Considering the processes of the project in the related branch offices as a whole	24	4,35	0,61
Identifying risks and managing risk in projects	25	4,29	0,85
Placing all documentation in the corporate archive	26	4,29	0,47
Measuring the satisfaction of users at the end of the project	27	4,29	0,51
Evaluation study for institutional learning	28	4,12	0,78
Selecting the appropriate contractor / author for the project	29	4,06	1,03
Clearly setting the expectations of the project stakeholders	30	4,00	0,68
The institution has a project pool and all institution projects are collected here and followed up	31	3,94	0,83
The project team consists of relevant staff from different branch offices.	32	3,65	1,11

The MPMS setup was based on 16 factors above the Project Success Overall Average of 4.47 out of 32 factors, especially focusing on the problems in the first 6 topics that correspond to the 20% rule.

Project Manager and Team Features

As a result of the analysis studies, 28 factors, which constitute the basic competencies that a project manager should have in order to reach the goals of quality, duration, scope and cost, have been identified. The factors obtained in the study are given in the table below.

In this context, the data were reevaluated by 17 Experts according to the Likert Scale and listed as shown in Table 3 in the Pareto study and the most important first 20% slice was calculated and the standard deviation was calculated. In Table 3, the dark green part is the highest 20% slice; the light green section also shows the factors above the Standard Deviation.

Table 3. Qualifications required by project managers at DPWE.

FACTORS	ORDER OF IMPORTANCE	MEAN	STD. DEVIATION
Sound coordination	1	4,94	0,24
To be able to produce solutions to problems	2	4,88	0,33
Supporting the team spirit	3	4,76	0,44
Be neutral and equitable to team members	4	4,76	0,44

Being open to innovations and innovative thoughts	5	4,76	0,56
Being competent for technical issues	6	4,71	0,47
Knowing the business processes of the institution	7	4,65	0,49
Planning, analysis and control	8	4,65	0,49
To be able to manage the scope, cost and time of the project	9	4,65	0,49
Realistic decision making under stress and pressure	10	4,65	0,49
Effective communication abilities	11	4,59	0,80
Emphasis on the project team's thoughts and using group decision making techniques	12	4,59	0,62
To have knowledge about urban texture	13	4,59	0,51
Managing meetings effectively and efficiently	14	4,59	0,62
Overall Average Of Qualifications of the Project Manager		**4,54**	
Being experienced (application, field, project etc.)	15	4,53	0,80
Having leadership qualifications	16	4,53	0,80
Be able to use initiative by taking effective and quick decisions	17	4,53	0,62
Having information about the legislation	18	4,47	0,72
Having project management knowledge	19	4,47	0,87
Keeping the morale and motivation of the team high	20	4,47	0,62
To make the problems visible and defined	21	4,47	0,62
Empathy ability	22	4,47	0,72
Having a vision	23	4,41	1,06
Awareness of top management's local policies	24	4,35	0,61
Being accommodating and flexible	25	4,29	0,92
Being able to use the negotiation techniques	26	4,18	0,81
Being able to convince the project stakeholders	27	4,12	0,78
Effective presentation skills	28	4,12	0,78

Considering that all of the success factors listed in both Delphi and Pareto analysis are equivalent in the project management system, the Project Management System (MPMS) with PMI infrastructure in accordance with MMM DPWE has been initiated in Phase-2 studies in order to reference all of the factors. In addition, considering the qualifications required in MMM DPWE Project Manager, job descriptions of project managers have been designed in PMS.

With the Current Situation Analysis Study, public opinion on project management in DPWE was ensured, and the experience of project management in DPWE was recorded. Based on this information and factors determined for DPWE, their equivalents in the PMI methodology were determined and Phase-2 studies were carried out taking these data into consideration.

Phase-2: Design and Installation of Project Management System

With the installation of MPMS, improvements in the following topics are targeted within the Institution:

- ✓ Creating accurate, reliable corporate information and corporate memory related to projects,
- ✓ Reporting the information about the projects to the top management and making the decisions of the top management based on real and accurate data,
- ✓ Measuring and controlling the performance of projects using a certain methodological and technological platforms,
- ✓ Correctly planning, managing and increasing resource efficiency of the institution's resources,
- ✓ Dissemination and adoption of modern project management culture in the institution.

In the project management system design and installation phase, an interface management is envisaged between the current processes of MMM DPWE and the processes of PMI. The form infrastructure, which will be used when running the project management system and contains 10 information fields of PMI, has been created and finally, the Project Management Office (PMO), which will make the whole system functional, has been defined within the organization and its duties and responsibilities have been determined.

The forms prepared considering the basic processes of project management have been developed in a flexible, easy-to-understand and usable way. While creating forms, the principles of easy comprehension, simplicity and integration are taken into consideration. These forms are designed as integrated and also designed to feed key performance indicators.

In Figure 1, the scheme of the DPWE Project Management System Model, designed by consultants and the project team created within DPWE and proposed by DPWE experts, is given. Accordingly, it is planned to collect Project Suggestions from different sources in the Project Pool and then immediately after the evaluation to the Projects in Practice list. The projects included in the Implementation List will be carried out in accordance with the PMI methodology through 5 project processes.

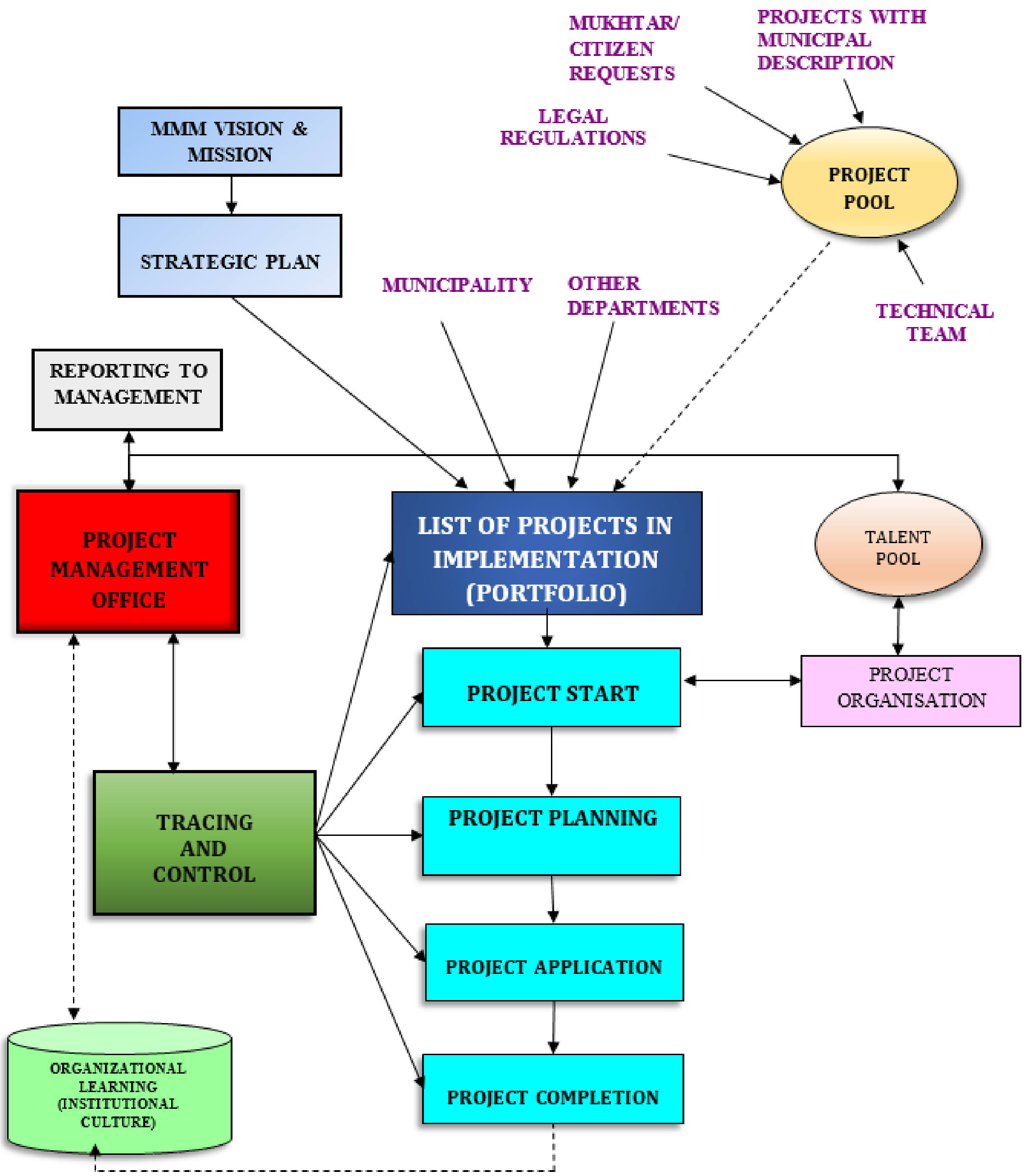

Figure 1: Muğla Metropolitan Municipality project management system.

Interface Management

Functional units within DPWE (Survey and Project BM, Road Construction and Maintenance BM, Construction Works Tender BM, Machine and Supply BM) continue their functions according to the current regulations and regulations of the institution. In the project management system prepared for DPWE, project management processes (Initiation, Planning, Implementation, Monitoring and Control, Closing) have been defined in a systematic developed in accordance with the PMI infrastructure and local management dynamics of the projects.

Interface system defined by considering the relationship between project process steps and information fields and business steps in DPWE is shown in Figure 2. While the projects are monitored and controlled according to the criteria demanded by the top management, it is planned to make a systematic effort to finish the projects within the planned period, in defined scope and quality, at the targeted costs.

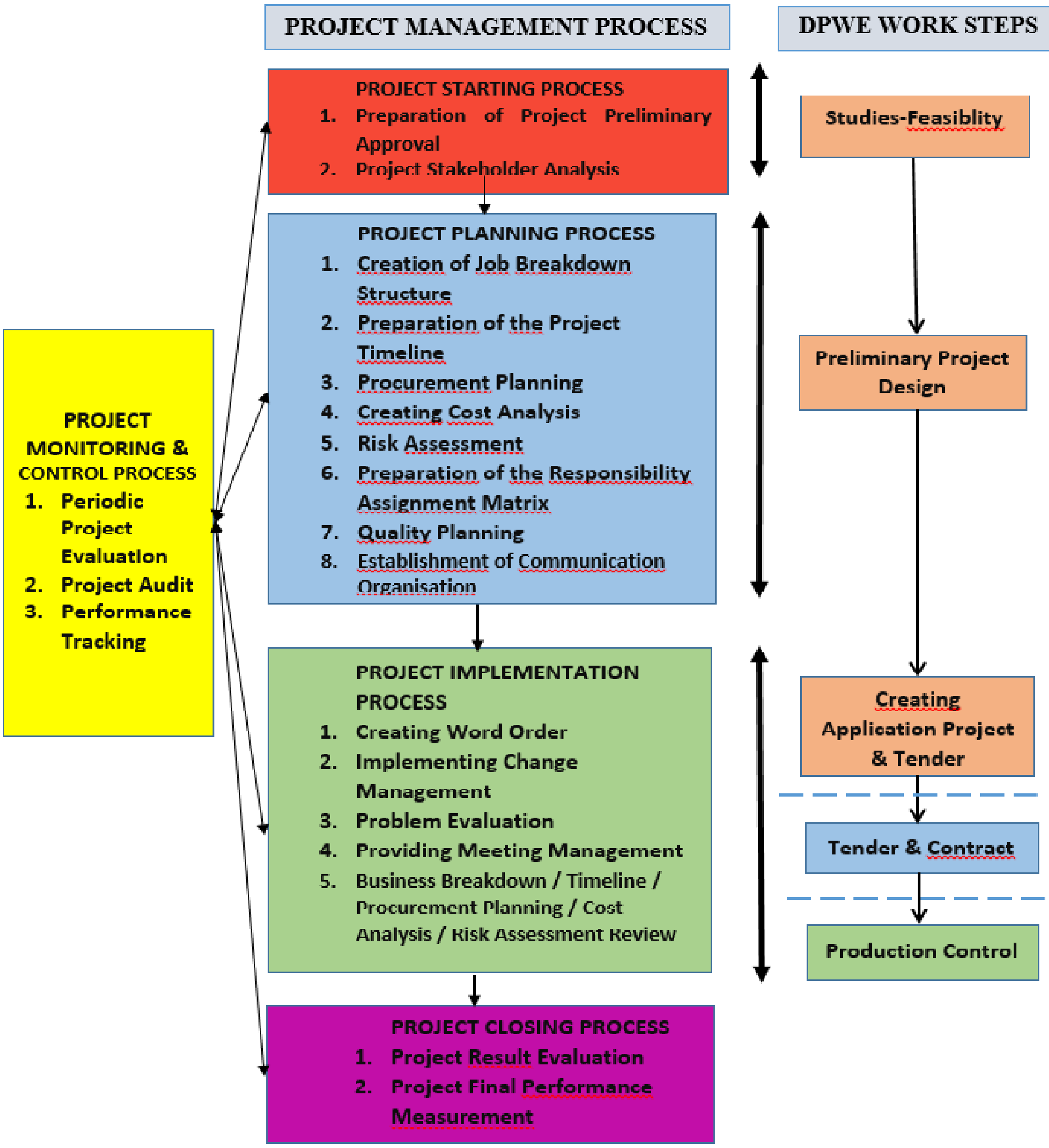

Figure 2: Project management process steps and DPWE work steps (Interface Method).

MPMS Project Management Offices (PMO) and Functions

The Project Management Office has been defined at 2 levels, taking into account the internal dynamics of the organization, to serve the functioning of DPWE.

Level 1 Project Management Office - Project Application and Control Office (PACO)

The unit that defines the boundaries of the project manager and the project team, where the projects are executed, is named as the Level 1 Project Application and Control Office (PACO).

Level 2 Project Management Office - Project Management Office (PMO)

PMO has been defined as the owner of the system on behalf of the top management from the establishment, implementation, development and sustainability of MMM DPWE PMS. For this reason, it is envisaged to establish PMO, to make organizational authorization and to be positioned under DPWE under the Head of Department.

Phase-3: System Test (Simulation)

With the simulation study, the project management processes and knowledge areas that were designed in DPWE projects were utilized using two already completed projects. The objective here was to understand whether a systematic, disciplinary approach was effective in achieving efficiency and success in projects. As a result, the validity and reliability of MPMS has been tested with finished projects. During the test studies, Project Management processes were run through the system forms filled by the project team participating in the study and analyzes were carried out for the project teams to internalize the project management methodology.

Two important projects of the institution have been selected to carry out the testing process. With the recently completed Menteşe Terminal Project and with one of the road projects, which are important in terms of budget and scope. Experts from different departments of the municipality that have experience in these already completed projects participated in these table-top exercises. It was observed that the implementation of the project management system designed specifically for the institution can reduce the problems and complaints in the projects, and gain the project scope, duration, cost and quality requirements. As a result of the project management system test studies;

- The problems experienced in both projects have become visible and solutions in MPMS have been introduced.
- When the system was utilized, the teams found that their ability to work together in accordance with the system rules is significantly improved.
- MPMS form infrastructure is found to be working with real life projects.
- Team members stated that they can adopt and use the MPMS easily with upper management’s support and commitment.
- The individual learning obtained from the problems and solutions found in both projects started to be utilized with the similar projects. MPMS also started to act like organizational learning tool.

Conclusion

The institution-specific project management system has been designed in Muğla Metropolitan Municipality for efficient and effective use of public resources and increasing the capacity of success in projects, taking into consideration traditional public institutions and management approaches. The management of the projects, which are the public service vehicles of the municipalities, is defined as the most important function of the Project Management system. With this feature, Muğla Metropolitan Municipality carried out systematically in the field of project management, methodological and technological studies in Turkey said that led to other public institutions.

The Project Management System (MPMS) within the Directorate of Science Affairs of Muğla Metropolitan Municipality was established with reference to the methodological approach of the Project Management Institute (PMI), which is known and recognized on the international platform. 5 basic project management processes (Initiation, Planning, Implementation, Monitoring and Control, Completion) determined by PMI are defined specifically for corporate projects, taking into account business processes. A series of forms have been designed to guide project managers and teams in the designed processes to enable them to perform the processes required by the processes completely and more effectively. While the forms serve as a guide in the implementation of MPMS, it also measures the performance of the projects implemented. It is envisaged that these indicators will be kept and evaluated by the Project Management Office.

MBB-DPWE Project Management System has been developed by using modern project management processes and techniques to reduce time and budget deviations in existing projects, to increase productivity / performance, and to develop the potential in the project management culture. Particularly, while the projects are being carried out, the request of reporting, monitoring and control activities by MPMS and reporting by PMO will contribute to the maturation and settlement of the project management culture.

In the analysis of the projects carried out by the institution; Preparation of technical project in sufficient details, preparation of contracts and annexes in full, making accurate information in projects complete and timely to the relevant stakeholders, determining the scope of the project on time, fully and clearly, defining the needs analysis with relevant stakeholders in a clear, correct and timely manner, The establishment of the notification system has been identified as the most important factors that bring success in the projects.

The most important competencies that should be in the Project Manager are; It is defined as being able to coordinate well, to produce solutions to problems, to support the team spirit, to be neutral and equitable to team members, to be open to innovations and innovative ideas.

While MPMS is structured within DPWE, it has been revealed that there are differences between the processes required by project management and the business processes of the institution. Interface management has been designed to harmonize business processes with project management processes, integrate them with each other, and manage projects successfully, taking into account business processes. Thus, both processes were enabled to work together efficiently and harmoniously.

The life period between the beginning and the end of the Project Management services is defined by interface management so that it can adapt to the operation in the existing MMM institution.

When installing MPMS, special attention was paid to system testing and simulation studies. Analysis of 2 important projects, which were recently completed in the simulation, was carried out on forms. As a result of the simulation, it was examined that MPMS works with all dimensions, the form infrastructure is appropriate, and the roles and responsibilities, PMO structure can be integrated into the institution. It has been determined that risks can be reduced in projects to be carried out using MPMS, gains in scope, duration, cost and quality can be achieved. In simulation projects; In the complex environment of project-based work, the sharing of application networks that facilitate open information circulation and the development of common 'know-how' have been provided. In addition, it was concluded that the inadequacy of the pre-production period works was the biggest factor that caused the waste of resources, the studies of this period should be questioned carefully and should be revised and improved (Alten et al., (2019) Project Management in the Construction Sector).

Project sponsor, project manager and project teams are defined, and periodic meetings are held for managing the project. While the project team members carry out the project management processes defined for the project success, they carry out the processes in the internal functioning of the institution through the institutional structure. Project plans are prepared and realizations are monitored according to the plan. In monthly coordination meetings, presentations and reports on projects to the Mayor and the senior management of the institution are regularly made by PMO.

During the project, the team members identified the major risks for MPMS application as; not being able to create PM culture, problems with vertical and horizontal communication channels, low level of commitments from the upper management, and prejudices against the change with the project management system. Along with the project management system implementation, researchers observed process improvement suggestions for the supporting functions.

It is also aimed to start some initial works (to be positioned as a separate project) for an IT application. This software development part is going to an in-house project. This will increase the Municipalities' abilities further for the better development of MPMS. Final step before full scale utilization is going to be official recognition of the system by the managing boards (i.e., Municipality council) of the Municipality and the development of system specific regulations.

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Location Selection and Project Designing for the Penitentiary Institution by using the TOPSIS Method

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Abstract

In this study, it is aimed to select the most appropriate location for penitentiary institutions, which is one of the high cost public buildings, among the 6 alternative locations in Sivas. Factors that are important to select the location of penitentiary institutions are determined and they are weighted according to critics of experts. In order to select the most appropriate alternative, TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method, which is one of the multi-criteria decision-making methods, is used. Alternative locations are ranked according to their suitability, using the TOPSIS method. Finally, the second alternative (ALT-2) is selected as the most appropriate location.

Keywords: *penitentiary institutions, multi criteria decision making methods, TOPSIS, location selection.*

Introduction

Penitentiary institutions are institutions in which convicts, and detainees are placed by the state, have decisive safety criteria. Health, education, rehabilitation, sports and employment facilities are also provided according to certain criteria and the execution of punishment is provided (Sağlam, 2003). Penitentiary institutions have a great importance on investment plans due to their high cost. Moreover, construction time of penitentiary institutions is approximately 2 years and considering there will be significant increase on convicted prisoners during that time, it is obvious that penitentiary institutions requires a serious planning.

Laws, regimes, even believes, might be subject to changes in a fast manner. However, buildings and the ideas to create those buildings live long (Fairweather & McConville, 2000). Indeed, buildings, which are the results of the ideas during design stage, serve in a same manner even after the change of ideas. A building, which has low efficiency, i.e. has bad design and a building that has good design have similar initial costs. However, operation the well-designed building is more economical (Spens, 1994).

The current penitentiary institutions in Turkey, as of 2018, are represented in Table 1, below. The overall capacity of those institutions is 210682 people. Until 2023, it is planned to construct 226 penitentiary institutions suitable for contemporary execution systems. At the same time, the total capacity will be reached to 341912 by the closing of 108 district penal execution institutions where training and improvement conditions are limited due to physical conditions and capacities (www.cte.adalet.gov.tr, 2018).

Table 1. Existing penitentiary institutions in Turkey.

#	Institution	Number
1	Closed Penitentiary Institution	289
2	Independent Open Penitentiary Institution	73
3	Reformatory School	3
4	Women Closed Penitentiary Institution	10
5	Women Open Penitentiary Institution	7
6	Children Closed Penitentiary Institution	7
	OVERALL	**389**

Building place selection process consists of following stages; definition of alternatives, analysis of alternatives, evaluation of alternatives and final selection (Yang & Lee, 1997). In location selection of a business, the most important criterion is maximizing the profit; in location selection of penitentiary institution the most important criteria are security and providing best execution services. In this study, it is aimed to select the most appropriate location for a penitentiary institution, which is one of the high cost public buildings, among the 6 alternative locations in Sivas, using TOPSIS method.

In the literature, there are many studies from various fields, which utilize one of the multi-criteria decision making methods, TOPSIS method, in order to select the most efficient option (Chang et al., 2015; Choudhary & Shankar, 2012; Erdal et al., 2019; Kaşak & Erdal, 2019; Kurt, 2014; Senvar, 2016; Suder & Kahraman, 2015).

Erden and Coşkun (2009), used Analytical Hierarchy Process (AHP), which is one of the multi-criteria decision-making methods, to determine fire station location. In their study, it has been determined that 35 different fire brigades in Istanbul do not meet international standards and they proposed 17 station areas. Demirdöğen and Bilgili (2004) conducted studies to determine the factors that should be considered in the selection of places for the organized industrial zones in Erzurum. In the study, several criteria such as additional facility facilities, qualified labor, rent, transportation costs and proximity to residential areas were considered. Aydın et al. (2009) investigated optimum location selection of a hospital, which is planned to be built in Ankara. In the study, which utilizes AHP as a multi-criteria decision-making method, alternatives were ranked considering; environmental factors, building characteristics, investment costs, demographic structure and building location etc. Yücel and Ulutaş (2009) have conducted research on location selection of a cargo company in Malatya using ELECTRE method. In the study, alternative lands were ranked according to criteria such as proximity to the market, competition conditions, traffic conditions and closeness to the center. As a result, Şıra Pazar was determined as the most suitable area. Karabacak et al. (2016) used the TOPSIS method in the construction sector, in order to select the location of highway construction sites. In the study, which used 3 main criteria and 9 sub-criterion levels, the most appropriate site was selected considering the weight of each criterion.

The Criteria to be Considered in the Selection of the Place for the Penitentiary Institutions

As stated in the related sections of the Law on Criminal and Security Measures Enforcement No. 5275, the penitentiary institutions are the institutions in which the convicts are kept safely in accordance with the basic principles of the execution system. The penitentiary institutions were built in 23 different types throughout the country until this time. Today, however, there are 7 types that are under construction, which are: High Security, L, S, T, R, Open, Child (Figure 1) and Women prison execution institutions. Studies are being carried out in the regions, where penitentiary institutions are required, considering both the prisoner profile and the conditions of the region. In order to determine the suitability of the parcels examined in the study for the construction of the penitentiary institution, evaluation criteria and weight ratios of these criteria are determined by experts in the field. Following that the most suitable option among the alternatives is determined. The selected criteria determined according to the results of the questionnaire with the experts, and the reasons for selecting these criteria are explained below.

Figure 1: Child closed penitentiary institutions.

Expenditures Required for Infrastructure

Under the title of infrastructure, the basic elements can be listed as water, electricity and natural gas facilities and sewerage lines. Water cut for 24-hour in prison institutions will cause undesirable events in the institution. In the case of a water supply line built by the related municipalities near the land, water is supplied using the connections through the land. However, for example, if a penitentiary institution is constructed at a remote location from the province/district center, the construction of an intercity line by the relevant municipality will increase the cost and extend the construction period.

Slope of the Surface

Due to the fact that the penitentiary institutions have large ground area, even the small changes in the level of the surface can lead to very large excavation and filling costs. The balancing option in parcels with +/- inclination in itself depends on the quality of the material to be filled. The ground area for a 492-person high-security penitentiary closed penal execution institution is approximately 22000 m^2. In the construction of the structures with such a large foundation area in the site plan study, the positioning of the long side of the building in a relatively less inclined direction reduces the excavation and filling costs.

Width of the Land

The penitentiary institutions are composed of main building, control building, visitor acceptance building, heat center, gendarmerie building and lodgings. In the open penitentiary institutions, large workshops are being constructed in addition to these constructions. For this reason, the size of the proposed land provides convenience in the study of the site plan. In addition, if a new penitentiary institution is needed in the region in the future, the breadth of the existing land may enable the construction of a second penitentiary institution in the same parcel.

Feasibility for Workshop Activities

If the necessary workshops are built for the products that can be produced in the region on the parcel, as a consequence of workshop activities, convicts can get a profession. Moreover, those activities would be a revenue source for the state. For this reason, the conditions of the area in which the proposed immovable is located are also considered in the preliminary examination stage for the construction of the penitentiary institution.

Building Area to be Demolished on the Land

If there are already existing structures in the parcels proposed for the construction of the penitentiary institution, it should be considered to use these structures in line with the needs of the institution. However, the buildings will have to be demolished if they are in the way of obstacles to the construction of the penitentiary institution. In this case, additional costs for demolition should be considered in land selection.

Transportation to City/District Center

Penitentiary institutions are constantly in need of outsourcing materials due to their 24-hour work. Distances to regional centers are important in meeting the essential needs of food, cleaning and maintenance. Moreover, if the staff in charge of the institution stay in the center of the city, problems that they will encounter during the transportation to institution, will affect their performances'. For this reason, the penitentiary institution should not be built far away from the regional centers.

Settlement in Surrounding Parcels

Penitentiary institutions are the ones for which your safety is preliminary. For this reason, the circulation around the institution is always perceived as a threat. The penitentiary institutions built many years ago and filled with the surrounding structures due to the development of the region are always at risk of prohibited substance entry and security weaknesses. Attention should be paid to this issue in the investigation of the land in order not to encounter similar situations.

Ground Reinforcement Costs

For security reasons, the penitentiary institutions consisting entirely of reinforced concrete walls, should be built on high grounds with high carrying capacity due to the weight of the building. Otherwise, due to the different amount of settlement, cracks can occur in the building. This situation also causes security weakness. For this reason, soil surveys to be carried out in the land investigation process should be analyzed correctly.

Weather Conditions

Penitentiary institutions are the places, where there is a continuous detention and transfer occurs, due to its dynamic structure. Especially, transportation between the courthouse and the hospital should be continuous. The construction of a penitentiary institution in a region where transportation cannot be provided or can be provided with difficulties during certain periods of the year can lead to both security problems and difficulties for the visitors of detainees and prisoners. For this reason, during the land survey, extensive information about the seasonal conditions of the region should be obtained and the information should be analyzed well.

TOPSIS Method

TOPSIS was developed by Hwang and Yoon in 1981. TOPSIS is also defined as positive ideal dissociation similarity or relative affinity index (Lin et al., 2008). It is preferred to obtain the ideal solution by profit maximization and cost minimization. In the TOPSIS method the result is obtained step by step (Dumanoğlu & Ergül, 2010).

Step 1: Formation of the decision matrix (A)

The decision matrix is the first and most important step of the TOPSIS method. Therefore, the input data must be correct when this matrix is generated. Otherwise, even if the mathematical calculations are done correctly, the correct alternative will not be found. In the decision matrix, the rows indicate alternatives, and the columns indicate criteria.

$$A_{ij} = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1p} \\ a_{21} & a_{22} & \dots & a_{2p} \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ a_{m1} & a_{m2} & \dots & a_{mp} \end{bmatrix} \tag{1}$$

Step 2: Obtaining normalized decision matrix (N)

For each value in the matrix created in the first step, Eq. 2 is applied. The new matrix generated is called as normalized decision matrix.

$$N_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{m} a_{ij}^2}} \; (i = 1, \dots, m \; ve \; j = 1, \dots, n) \tag{2}$$

Step 3: Obtaining weighted normalized matrix (V)

At this stage, the weight coefficients (w) of each criterion obtained in the course of earlier studies for the solution of the problem are multiplied by the data given in the matrix in the second step. This new matrix created is called the weighted normalized matrix.

$$V_{\mathrm{i}J} = \begin{bmatrix} w_1 n_{11} & w_2 n_{12} & \cdots & w_n n_{1p} \\ w_1 n_{21} & w_2 n_{22} & \cdots & w_n n_{2p} \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ w_1 n_{m1} & w_2 n_{m2} & \cdots & w_n n_{mp} \end{bmatrix} \rightarrow \quad V_{\mathrm{i}J} = \begin{vmatrix} v_{11} & v_{12} & \cdots & v_{1p} \\ v_{21} & v_{22} & \cdots & v_{2p} \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ v_{m1} & v_{m2} & \cdots & v_{mp} \end{vmatrix} \tag{3}$$

***Step 4:* Obtaining ideal (S_i^*) and negative ideal (S_i^-) solution values**

In this step, the analysis of numerical data becomes important. The optimum values required by the project manager for each criterion must be determined. This situation may correspond to the highest value for some criteria and the lowest for the others (Azizi, 2017).

***Step 5:* Determination of distances to ideal (S_i^*) and negative ideal (S_i^-) solution values**

The predetermined ideal distance values are determined by Eq. 4 and the negative ideal distance values are determined by Eq. 5.

$$S_i^* = \sqrt{\left(\sum_{j=1}^{a} \left(V_{\mathrm{i}J} - V_J^*\right)^2\right)} \tag{4}$$

$$S_i^- = \sqrt{\left(\sum_{j=1}^{n} \left(V_{\mathrm{i}J} - V_J^-\right)^2\right)} \tag{5}$$

***Step 6:* Calculation of relative closeness to ideal solution**

The coefficient C_i^* varies from 0 to 1. Considering the ideal and negative ideal values, these coefficients obtained separately for each alternative are sorted from 1 to 0. The closest value to 1, will be the best alternative.

$$C_i^* = \frac{S_{\mathrm{i}}^-}{S_{\mathrm{i}}^- + S_{\mathrm{i}}^*} \tag{6}$$

Selection of The Best Land Alternative in Sivas for Construction of Penitentiary Institution Using TOPSIS Method

The information on the 6-land proposed for the construction of the penitentiary institution in Sivas is given in Table 2 and the criteria to be used in practice are given in Table 3.

Table 2. Proposed parcels and the abbreviation to be used in application.

Alternative	Abbreviation
Block Number 5584, Parcel 304, Çayboyu District,	ALT-1
Block Number 181, Parcel 12,14,15,16,17,43,44,45,46,64,203,204,205, Kılavuz District,	ALT-2
Block Number 195, Parcel 8, Kılavuz District,	ALT-3
Parcel 576, Budaklı District	ALT-4
Parcel 1576,1577,1578, Şarkışla -Elmalı District,	ALT-5
Block Number 104, Parcel 1, Hafik-Durulmuş District	ALT-6

Table 3. Abbreviation for the criteria to be used in application and their weight coefficient.

Criteria	Notation	Weigh Coefficient (w)
Expenditures Required for Infrastructure	A	0,15
Slope of the Surface (%)	B	0,23
Width of the Land (m^2)	C	0,21
Feasibility for Workshop Activities (Annual Profit ₺)	D	0,05
Building Area to be Demolished on the Land (m^2)	E	0,02
Transportation to City / District Center (km)	F	0,11
Settlement in Surrounding Parcels (m)	G	0,03
Ground Reinforcement Costs (₺)	H	0,13
Weather Conditions (0-100)	K	0,07

The weighting coefficients (w) given in Table 2, consist of the arithmetic mean of the values determined on the basis of the questionnaire survey conducted with the persons who were involved in the place selection for the penitentiary institutions.

Step 1: Formation of the decision matrix

At this stage, each alternative has been classified according to the previously mentioned criteria. It should be noted that an error in decision matrix will lead to wrong results (Table 4).

Table 4. Decision matrix.

	A	B	C	D	E	F	G	H	K
ALT-1	1 250 000	15%	59 000	550 000	250	8,00	400	150 000	80
ALT-2	250 000	5%	250 000	2 500 000	1000	5,00	750	500 000	100
ALT-3	200 000	7%	80 000	800 000	0	4,00	500	1 000 000	100
ALT-4	2 000 000	6%	81 000	800 000	0	20,75	400	450 000	75
ALT-5	1 000 000	5%	150 000	1 500 000	0	75,00	850	1 000 000	50
ALT-6	2 000 000	3%	70 000	700 000	0	29,00	750	5 000 000	15

Step 2: Obtaining normalized decision matrix

The normalization of decision matrix is done by applying Eq. 2 to each criterion (Table 5).

Table 5. Normalized decision matrix.

	A	B	C	D	E	F	G	H	K
ALT-1	0,38276	0,78087	0,18093	0,16915	0,24254	0,09561	0,25726	0,02862	0,42915
ALT-2	0,07655	0,26029	0,76663	0,76887	0,97014	0,05975	0,48237	0,09539	0,53644
ALT-3	0,06124	0,36441	0,24532	0,24604	0,00000	0,04780	0,32158	0,19078	0,53644
ALT-4	0,61242	0,31235	0,24839	0,24604	0,00000	0,24798	0,25726	0,08585	0,40233
ALT-5	0,30621	0,26029	0,45998	0,46132	0,00000	0,89632	0,54668	0,19078	0,26822
ALT-6	0,61242	0,15617	0,21466	0,21528	0,00000	0,34658	0,48237	0,95390	0,08047

Step 3: Obtaining weighted normalized matrix (V)

At this stage, the weighted normalized matrix is obtained by multiplying the weight coefficients (w), which represents effect of each criterion on the construction of the penitentiary institution as a result of institutional experiences and the values in Table 5. Obtained results are given in Table 6.

Table 6. Weighted normalized matrix.

Weight Coefficient	**0,15**	**0,23**	**0,21**	**0,05**	**0,02**	**0,11**	**0,03**	**0,13**	**0,07**
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**K**
ALT-1	0,05741	0,17960	0,03799	0,00846	0,00485	0,01052	0,00772	0,00372	0,03004
ALT-2	0,01148	0,05987	0,16099	0,03844	0,01940	0,00657	0,01447	0,01240	0,03755
ALT-3	0,00919	0,08381	0,05152	0,01230	0, 00000	0,00526	0,00965	0,02480	0,03755
ALT-4	0,09186	0,07184	0,05216	0,01230	0, 00000	0,02728	0,00772	0,01116	0,02816
ALT-5	0,04593	0,05987	0,09660	0,02307	0, 00000	0,09860	0,01640	0,02480	0,01878
ALT-6	0,09186	0,03592	0,04508	0,01076	0, 00000	0,03812	0,01447	0,12401	0,00563

Step 4: Obtaining ideal (S_i^*) and negative ideal (S_i^-) solution values

The ideal solution values have been determined for the criteria to be considered in the selection of the place for the penitentiary institution. These values are those closest to 0 in criteria that brings cost and closest to 1 in criteria that benefits the organization (Table 7).

Table 7. Ideal and negative ideal solution values.

	A	B	C	D	E	F	G	H	K
Ideal Solution Values	0,00919	0,03592	0,16099	0,03844	0,00000	0,00526	0,01640	0,00372	0,03755
Negative Ideal Solution Values	0,09186	0,17960	0,03799	0,00846	0,01940	0,09860	0,00772	0,12401	0,00563

Step 5: Determination of distances to ideal (S_i^*) and negative ideal (S_i^-) solution values

S_i^* and S_i^- values are determined using Eq. 4 and 5. These values for each alternative are used in the calculation of the value of C_i^*, which is indicated in Step 6 (Tables 8 and 9).

Table 8. Table of ideal solution values.

	A	B	C	D	E	F	G	H	K	TOTAL	Si*
ALT-1	0,0023	0,0206	0,0151	0,0009	0,0000	0,0000	0,0001	0,0000	0,0001	0,0392	0,1979
ALT-2	0,0000	0,0006	0,0000	0,0000	0,0004	0,0000	0,0000	0,0001	0,0000	0,0010	0,0322
ALT-3	0,0000	0,0023	0,0120	0,0007	0,0000	0,0000	0,0000	0,0004	0,0000	0,0155	0,1243
ALT-4	0,0068	0,0013	0,0118	0,0007	0,0000	0,0005	0,0001	0,0001	0,0001	0,0214	0,1461
ALT-5	0,0014	0,0006	0,0041	0,0002	0,0000	0,0087	0,0000	0,0004	0,0004	0,0158	0,1258
ALT-6	0,0068	0,0000	0,0134	0,0008	0,0000	0,0011	0,0000	0,0145	0,0010	0,0376	0,1939

Table 9. Table of negative ideal solution values.

	A	B	C	D	E	F	G	H	K	TOTAL	Si-
ALT-1	0,0012	0,0000	0,0000	0,0000	0,0002	0,0078	0,0000	0,0145	0,0006	0,0242	0,1556
ALT-2	0,0065	0,0143	0,0151	0,0009	0,0000	0,0085	0,0000	0,0125	0,0010	0,0588	0,2425
ALT-3	0,0068	0,0092	0,0002	0,0000	0,0004	0,0087	0,0000	0,0098	0,0010	0,0362	0,1902
ALT-4	0,0000	0,0116	0,0002	0,0000	0,0004	0,0051	0,0000	0,0127	0,0005	0,0305	0,1747
ALT-5	0,0021	0,0143	0,0034	0,0002	0,0004	0,0000	0,0001	0,0098	0,0002	0,0306	0,1748
ALT-6	0,0000	0,0206	0,0001	0,0000	0,0004	0,0037	0,0000	0,0000	0,0000	0,0248	0,1574

Step 6: Calculation of relative closeness to ideal solution (C_i^*)

The C_i^* value for each alternative is calculated using Eq. 6 (Table 10). By sorting these calculated values from largest to smallest, the first alternative has been determined as the most appropriate solution to solve the problem.

Table 10. Relative closeness values to ideal solution.

ALTERNATIVE	Si*	Si-	Ci*	RANKING
ALT-1	0,197940983	0,155630503	0,440167007	6
ALT-2	**0,032186767**	**0,242514298**	**0,882829844**	**1**
ALT-3	0,12430601	0,190159409	0,6047069	2
ALT-4	0,146140493	0,174734506	0,544556311	4
ALT-5	0,125760994	0,174812901	0,581597084	3
ALT-6	0,193931091	0,157411302	0,448028206	5

Conclusion

Public buildings are built on taxation from the citizens of the state based on the law. For this reason, every citizen has a share in each public expenditure. Therefore, for the constructions that are constructed with the contributions of all the citizens of our country, the most productive solutions should be obtained with the least cost. Public employees are responsible for providing these criteria for the relevant investments.

Penitentiary institutions are the ones that should be studied in detail because of their high costs and positive and negative effects on the region where they are built. These institutions will provide service for about 50 years. In order to ensure that the costs in both construction and use phases are minimized for those institutions and that they are built at the most suitable place, TOPSIS method is used for finding the most appropriate option. In this study, it is determined that the 2nd alternative is the most suitable option among the 6 land alternatives in Sivas, for the construction of the Penitentiary institutions. The alternatives, which are in order from highest C_i^* to lowest C_i^* are 2-3-5-4-6-1, respectively.

It is believed that the TOPSIS method, which is used in the selection of the places for the penitentiary institutions, should be preferred in all investments, in order to use public resources efficiently and effectively.

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Problems and a Solution Proposal for Abnormally Low Tenders in Construction Works Procurements

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Abstract

This paper discusses the reasons and consequences of abnormally low tenders which are one of the major problems in public procurement process. To be able to offer an effective solution to this problem surety bond system is analyzed in this study. In this framework, surety bonds contract and the practices in the world, the risks that can be guaranteed by the surety bonds and the advantages that the surety bonds can provide are examined.

Keywords: *abnormally low tender, construction works tender, surety bond.*

Introduction

Abnormally low tenders (ALTs) are tenders which are lower than the limit value determined by the Public Procurement Authority (PPA). In this study, the reasons for the emergence of the abnormally low tenders (ALTs), the evaluation of the ALTs, the risks caused by the ALTs, the precautions taken in the current system, the problems experienced and alternative solution suggestions in construction work tenders within the scope of Public Procurement Law (PPL) were discussed. Then, in order to understand the existing ALT evaluation system more clearly, the process of inquiry of the ALTs in construction works tender was touched briefly and comments were made on whether the system is effective or not. In addition, by discussing the issues such as the reasons for the ALTs submitted by the contractors, the reasons for the acceptance of the ALTs by the administrations etc., the situation regarding the formation of the proposals in the construction works tenders was tried to be explained completely. By determining the risks created by ALTs, the guarantees taken to eliminate these risks in the current public procurement system were examined and their effectiveness were evaluated.

In the current system, it has been determined that the risks arising from the beginning of a procurement to the completion of the work are tried to be eliminated with the required bid bond and performance bond at the rates determined within the scope of the legislation. However, it has been observed that these bonds are insufficient to fully cover the losses of the administration. In this study, "surety bond" application, which is applied in other countries in order to minimize such risks, was examined. Also it was examined whether surety bonds are effective or not about not being signed of the contract by contractor who won tender, not being paid of salaries of subcontractors, workers and suppliers, being compensated for the public loss caused by incomplete work due to the contractor's fault etc. As a result, a more effective solution proposal was tried to be offered to the ALT problem, and the surety bond system, which is thought to protect both public administrations and tenderers from time, labor and financial losses, was considered as the most appropriate way to solve these problems.

In the literature review, it has been seen that there are studies in which ALTs are examined from different perspectives. In addition, there are some statistical studies related with this topic. But there is no study offers a solution to problems encountered in the evaluation of the ALTs and the elimination of the risks emerged with these tenders.

In his study, Karacan (2008) examined the reasons for the emergence of ALTs, and carried out statistical studies by conducting a survey. He also included research on *limit value* determination which plays an important role in determining ALTs. Çiçek (2009) included information about the structure of the Public Procurement Authority (PPA) and the public procurement system in his master's thesis titled "The Application Problems of Public Procurement Law at Number 4734 at Construction Affairs and Solution Proposals". In this thesis there was no an effective solution proposal regarding the evaluation of the existing ALTs, it was mentioned that the PPA should play a more effective and guiding role in the evaluation of the ALTs. Savaş (2012), in his study, addressing the processes until the contract is signed in the construction works tenders, explained what should be done by the parties in terms of the ALT evaluation and expressed the points to be considered at this stage. Atabeyli (2014) examined the compliance of legislation, to which PPA is subjected, with the legislation of the European Union in her study. She evaluated that the problems related to the ALT evaluation in the construction works tenders can be reduced by setting concrete criteria in this regard.

Low Tender Price

Cost estimate is inherently difficult for construction works due to lots of different parameters and uncertainties. This situation is a fact that should be taken into account while both preparing and evaluating the tender. The step of preparing the tender is the most important part of procurement process for tenderers. That step effects the result of procurement directly. Targets of contracting companies in a construction work can be stated as following;

1. Maximizing the profit (Minimizing the loss)
2. Accelerating the fund recycling of firm
3. Keeping to produce and employ
4. Creating personal status on administration and managers by undertaking prestige projects
5. To meet owners-entrepreneurs who may be the potential source of many jobs in future
6. To enter to new geographic areas (Harrison, 1981)

While contracting companies target maximizing the profit, on the other hand, they have to tender with lower price than other tenderers because of competition principle of procurement. Consequently, contracting companies have to optimize this cost issue to be able to win the contract. Contractors constitute tender price by calculating quantities and *costs for themselves*. In addition, they add some profit according to their risk perception. This price includes some certain direct costs such as personnel salaries, equipment and material costs, and their expenses, and some uncertain indirect costs, such as financial costs (Park, 1979). However, it is a well-known fact that the exact cost of work becomes clear at the end of the completing work. The important points in determining profit margins by contractors are given in Figure 1 (Gencer, 2002).

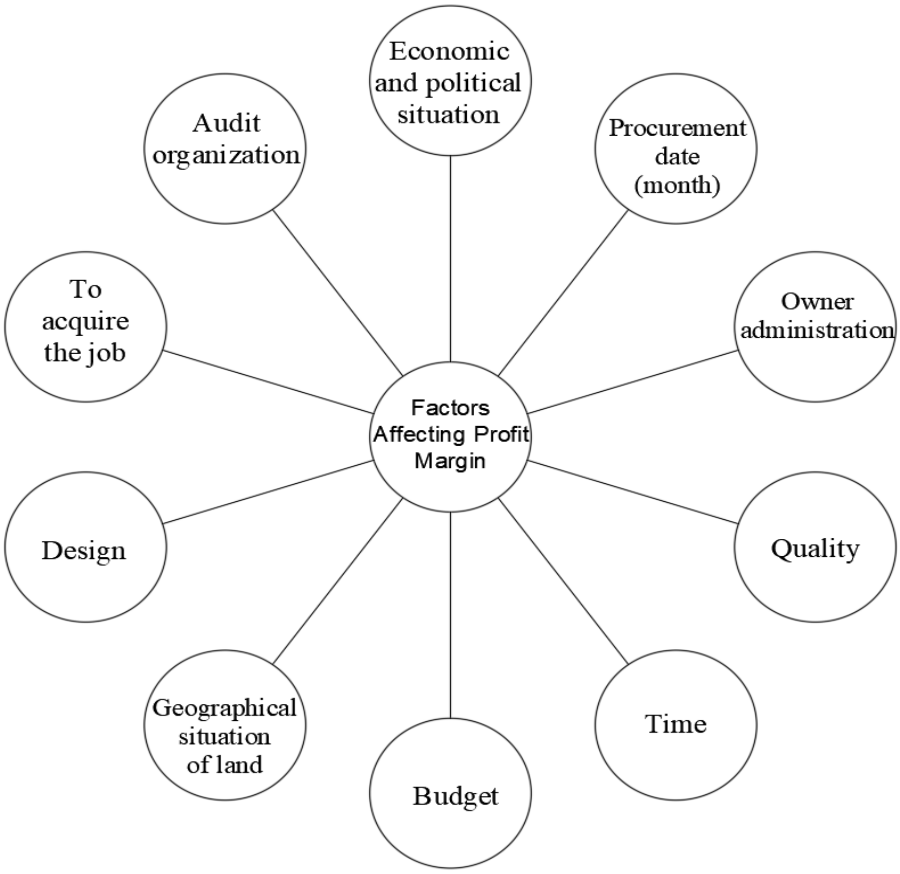

Figure 1: Factors affecting profit margins.

In the light of all of these evaluations aforementioned, it is normal to exist very different tender prices. However, although the tender prices are based on logical foundations for the contractors themselves, it is quite natural that contracting authority wants to question the authenticity of these tender prices and secure themselves.

Competition of tenderers is one of the most important principles of procurement process. That's also the main reason of low tender prices. While it is aimed to increase the efficiency and innovation in the competitive procurement system, questioning the rationality of the prices resulting from the competition is also vital in terms of whether the work can be done in the prescribed quality. In general, the reasons of ALTs by tenderers are low owning costs of tenderers, incorrectly prepared tenders or to offer consciously ALT as a strategy. Especially tenderers who are in financial trouble may adopt such a strategy with such a high risk appetite in order to survive and tend to make aggressive offers. In addition, considering the large number of companies operating in the sector and the ease of entering the sector, the probability of occurrence of ALTs increases. Due to the intense competition, tender price offers can be made even under costs. These type of tender prices cause decreasing of quality in public projects. Possible reasons of preparing a low price by tenderer, the roots related with this reasons and solution proposals are shown in Table 1.

Table 1. Reasons of ALTs by tenderers.

Reasons of ALTs by Tenderers	**Root**	**Solution Proposals**
Low calculation cost	- Misinterpreting the project and specifications - Lack in tender documents - Uncertainties	- To prepare tender documents correctly - To give enough time for tender preparation - Strong preliminary process
Extremely optimistic attitude		
Idea of *change in contract details* at the time it is not preferable for administration	- Knowledge about lacks of tender documents and to use it a strategy	
Risk taking in a bad condition economically (Dimitri et al., 2006)	- To survive economically - To keep the continuity of the works - To take work experience certificate	
Large number of tenderers (De et al., 1996)	- To reduce profit margin - Competition	

ALTs can have large negative effects on the construction sector and on the country's economy. Therefore, efforts towards reducing or completely eliminating the effects of the ALT problem encountered in construction works become important. The ALT problem is not only a problem specific to Turkey, it is also included in the legislation of many countries in terms of its importance and different precautions are taken in different countries in order to protect it from possible damages. However, given the problems arising from ALTs, it is of utmost importance in terms of preventing construction works tenders from being awarded to a tender below the actual cost of the project. In addition, realizing this is a very complex and difficult task. In Table 2, possible acceptance reasons of ALTs by administrations, the roots related with this reasons and solution proposals are shown.

Table 2. Acceptance reasons of ALTs by administration.

Reasons of Acceptance of ALTs by Administrations	**Root**	**Solution Proposals**
Misevaluation of tender price	- Lack of experience - Lack of knowledge	- Employment of experienced engineers - More transparent procurement process
To not be able to consider quality, control and transfer costs, maintenance and repair costs etc. (Günbay, 2008)		
Media and public pressure	- Inadequate transparency - Lack of trust to procurement process by public	

Evaluation of Legislation Related to ALTs Evaluation Process

According to PPL Article 38, "After evaluating all tenders, tender commission shall determine those that are abnormally low compared to the other tenders or the estimated cost determined by the contracting authority. Before rejecting these tenders, the commission shall request from the related tenderers, the details relating to components of the tender that are determined to be significant, in writing and within a specified period.

The tender commission shall evaluate the abnormally low tenders taking into consideration the written explanations documented on the following aspects:
a) economic nature of the manufacturing process, the services provided and the method of works,
b) selected technical solutions and advantageous conditions to be utilized by the tenderer in supply of the goods and services or fulfilment of the works,
c) the originality of the goods, services or works proposed.

As a result of this evaluation, the tenders of the tenderers whose written explanations are found insufficient or who fail to make a written explanation shall be rejected."

From the aforementioned law, it is understood that the tenders that are below the determined *limit value* specific to the procurement will be determined by the administration as ALT and the relevant tender owner will be asked for a documented explanation regarding the ALTs before these offers are rejected by the administration. In addition, it is understood that the tenders determined to be abnormally low are the ones that should be rejected and that destructive competition is wanted to be prevented. On the other hand, if there are tenders that can be explained within the framework of the provisions of the related Law, such tenders are allowed to be accepted without refusal, as a matter of public welfare. To accelerate evaluation process of ALTs, with a law amendment in 06.02.2014, PPA was authorized to be able to reject tenders below *limit value* without requesting any explanation in construction works tenders, the estimated cost of which is up to ½ of threshold value. Besides this prerogative, PPA was authorized to determine *limit value* and criterions for querying of ALTs too. In 06.07.2014 a new amendment more was carried out. With the arrangements made, in procurements, estimated cost of which is up to 1/3 of threshold value, administration was enabled to award the contract to the lowest valid tender without asking for an ALT description, to award the contract to the first valid tender above the limit value or to query for ALTs. In the current situation, according to PPL, tender commission is authorized to make decision for ALTs as in Table 3.

It is clear that the difficulties experienced in evaluating the ALTs are effective in making this amendment. It is aimed that administrations take initiative in line with their own preferences. However, awarding the contract on an ALT without any inquiries does not mean that ALTs will not be a risk for the administrations (Uslu & Demirel, 2010).

Surety Bond

Surety bond, which is one of the financing methods that can be an alternative to bank letters of guarantee in construction works, has emerged in the USA and has spread to the world. Unlike the bank letters of guarantee, it is frequently used in the world construction industry due to its unique features. It is possible to define surety bond as a kind of insurance that the loss of the employer will be covered by a third party (insurance company) in case the party responsible for doing the job does not fulfill the work undertaken.

Table 3. Decision mechanisms to evaluate ALTs.

The method to be applied	Type of procurement
To query of ALTs	- *Compulsory* in all construction tenders, the estimated cost of which is equal to and above 1/3 of the threshold value. - *Optional* in the open procedure, the estimated cost of which is up to 1/3 of the threshold value and in the negotiated procedure made in accordance with Articles 21 (b) and (c) of the PPL.
To award the contract to the lowest tenderer without query of Alts	Up to 1/3 threshold value of estimated cost; - *Compulsory* in restricted procedure and in the negotiated procedure made in accordance with Articles 21 (a), (d) and (e) of the PPL. - *Optional* in the open procedure and in the negotiated procedure made in accordance with Articles 21 (b) and (c) of the PPL.
To award the contract to the first lowest tenderer above the limit value without query of Alts	- *Optional* in open procedure the estimated cost of which is up to 1/3 of the threshold value and in the negotiated procedure made in accordance with Articles 21 (b) and (c) of the PPL.

If the borrower cannot pay the debt arising from the contract due to any reason stated in the policy, usually bankruptcy, the insurance company or the bank, which is in the position of guarantor, guarantees the debtor's debt and compensates the creditor's loss. It is a type of surety that Turkish construction companies, which do business abroad, encounter and is requested by the employer as an alternative to the letter of credit.

In Turkey, in February 2014, the General Conditions of Surety Bond by the Undersecretary of Treasury and in October 2014, the Communique No. 29136 were published in the official gazette and entered into force. Legal basis of surety bond was created with these prescripts in Turkey.

Surety bond is widely used in America, Europe and Asia Pacific. While the entire letter of guarantee requirement in the US market is met by insurance companies, this rate is 95% in South America, 25% in Europe and 50% in Asia Pacific. Surety Bond is mostly used for construction, manufacturing, construction-repair, energy and infrastructure projects, but demand is received from almost every sector (Sandberg, 2004).

The insurance company may directly vouch for the debtor itself or by indirect surety, the bank, credit guarantee institutions or other financial institutions may provide warrant for the debtor's commitment as a guarantor against the beneficiary. Surety bonds can be issued conditionally or on a payment basis at the first request, similar to the bank letters of guarantee. The parties to the surety insurance contract are the creditor of the original debt relationship (administrations in public tenders) and the insurer. The debtor is the relevant person of the contract. The surety bond line is given in Figure 2.

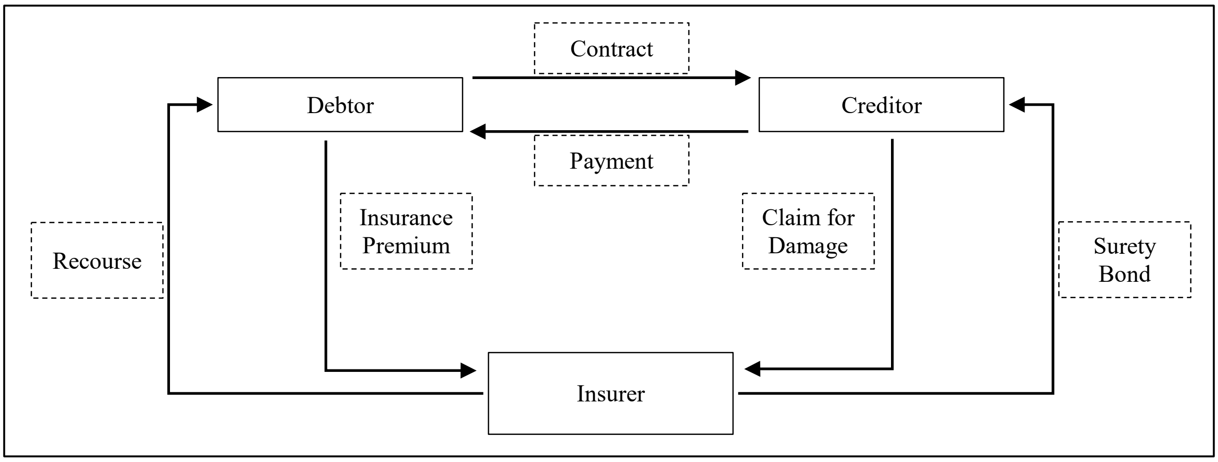

Figure 2: The surety bond line.

In Turkey, surety bond has not been used as in foreign countries. Documents issued for the risks under guarantee under the name of surety insurance are not insurance policies, but *commercial papers*. Therefore, it can be seen as indistinguishable with bank letters of guarantee. Surety bond usage of the foreign countries is quite different from the Turkey. These differences make surety bonds more preferable. For instance, in the application of performance bonds in the USA, if the risk guaranteed by the surety bond contract is realized, the option of the insurer to solve the problem experienced by other methods instead of paying compensation is one of the main differences between bank letters of guarantee and bail insurance (Barru, 2005). These methods are generally;

1. To ensure the completion of the project by agreeing with a new contractor
2. Ensuring the completion of the project by providing financial assistance to the contractor
3. Compensating the sustained damage due to the unfinished project
4. To allow the project owner to complete the job and pay the difference

The project owner (administration) and the insurer may decide together with which of the specified methods will be executed. In the performance guarantee, the upper limit of the responsibility of the insurer towards the project owner is generally 100% of the contract price in money (Donohue &Thomas, 1996).

Conclusions

The determination and evaluation processes of ALTs, which ensure the control of the rationality of bids in construction works tenders, have been challenging both for the administrations and for the tenderers. In addition, the results of this process are far from satisfactory for both parties. The most concrete evidence of this is that most of the objections and complaints made to the PPA consist of ALT inquiries. The most rational way to reduce complaints in this regard is undoubtedly the prevention of ALTs at the very beginning of the procurement. At this point, it is difficult to talk about a method that can be called perfect for the prevention of ALTs. Surety bond system, which has started to be established in our country with a new legal infrastructure but is used frequently in some countries, especially in the United States, stands out as the most effective method in this regard.

The establishment of the legal basis for the bail insurance is an important innovation for our law. Although its legal basis has been established, it is not yet effectively used in our public procurement system. When the established legal relationship with the surety bond is examined, it is seen that a three-legged relationship consists of the insurer (surety), the insurant (the contractor), the insured (the administration). The insurance company can provide guarantee both for the administrations and the tenderers participating in the tender.

In the surety bond system, the tenderers who apply to the insurance company for coverage must present all their information in a clear and transparent manner to the insurance company and prove that the bid price prepared for the tender is a rational offer that will enable the work to be carried out as requested. Insurance companies also examine whether the work can be completed with the bid price of the tenderer in accordance with the contract terms and science and art rules, taking into account the financial and technical capacity of the contractor. Investigation of the mentioned issues is done by experts within the insurance companies, and the contractor that won the tender is provided assurance. In this way, the risk is largely transferred from administrations to insurance companies and contractors. Therefore, a natural auto control system has been established during the proposal preparation stage. In this way, the contractor profile that participates in public tenders will tend to recover spontaneously.

With this system, the probability of the bidder won the tender to become a company that has the power and competence to complete the job by staying within the desired quality and within the foreseeable cost limits increases considerably. However, if the contractor fails to complete the work subject to the tender, the insurance company must use its financial and technical facilities, complete the work and deliver it to the administration, or guarantee to cover all the losses of the administration. As a result, even if the administration decides to award the contract to the contractor with lowest price offer, the risk that the work cannot be completed or the losses cannot be arranged is largely eliminated.

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Re-thinking Design Management

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Abstract

Previously, design in the field of Architecture- although inevitably supported by other disciplines- has always been perceived as the product of the architect, which results from his/ her own creativity, experience and know-how. However, with the emergence of complex building design projects requiring more multidisciplinary input and synchronous contributions in their development processes, both the project processes as well as the design itself become an issue of something that requires management. Thus, a new terminology and research domain has been introduced and raised in the field as the "design management". In continuation with this necessity, many researches have been conducted, however since these studies have been borrowed and adapted from different disciplines, they stayed insufficient most of the times. Therefore, new researches, methodologies and tools that are specific to building design processes, enabling a much more coherent management of the full processes mentioned, have had to be developed with a new understanding as re-thinking design management. Within this respect, this paper reveals the essentials of today's complex design projects and why they need to be managed with an integrated and multidimensional management approach. In order to improve the design processes, an efficient utilization of an updated design management approach is required, which does not only focus on the time- resource and quality aspects but also manages the concurrent multidisciplinary data exchanges, synchronous communication flows and integrated project delivery requirements. The search of a new and more comprehensive way of perceiving this management issue has also been studied this semester with graduate students in a specific module of a master's course. After analyzing the existing approaches and studies and revealing the insufficiencies with them through lectures and discussions, they have developed their own process maps as a guide, where they have integrated different dimensions of the process (time, correspondence, delivery, participants, conflicting requirements, priorities, technology…etc.) to be planned, monitored and controlled. The results of this study have also been included in this paper in order to foster future researches and set a base ground

Keywords: *building design process management, multidisciplinary team collaboration.*

Design: An Automatic Natural Process or a Manipulated Complex Process

Design is mainly a human activity and understanding the activities carried out by designers is very complex as Gero and Mc Neill (1998) stated. Therefore, deciding on the natural character of a design process and perceiving it either to flow automatically or needed to be executed and manipulated has opened to a lot of discussions. However, it is for sure that it is now referring to a process rather than the last output – as it used to be – especially in today's multidisciplinary complex project environments. This consensus of perceiving the design as a process have also been stated in the studies of Ballard and Koskela (1998) in which they classify design in three ways -each of which acts as a process-: (1) as a process of converting inputs to outputs, (2) as a flow of materials and information through time and space, and (3) as a process of generating value for customers.

Likewise, Girard and Robin (2006) defined project as the intention to satisfy a design objective. According to the authors design cannot be considered to be a problem-solving process, but rather a creative or innovative process, and project is not structured by the activities involved. That is why other secondary and/or tertiary actions needed to be applied to design processes to manipulate all of the contents – contents and participants throughout the process, which might be perceived as a management. Girard and Robin also continued in the same approach as stating that; the project manager thus need to decide on an appropriate organization to encourage the maximum collaboration among designers, which is called in general the design environment (Girard & Robin, 2006). All of these approaches and studies reveals that today's complex building project designs are far beyond the previous simplistic building projects which could have been run by only depending the experience and know-how of the architect. However today the design management approaches become a must rather that an additional factor on the execution of design processes which are subjected to the involvement of multiple conflicting parties and also design inputs to be synchronized and processes in a through methodology.

Why to manage the design (as a process)?

Design is a difficult process to manage. It involves thousands of decisions, sometimes over a period of years, with numerous interdependencies, within a highly uncertain environment (Akbıyıklı & Eaton, 2012). Furthermore, these interdependencies and independent involvements of different factors (parties and their works) sometimes conflict and cause undesirable delays or re-works throughout the process. Projects are often behind the schedule, over the budget and experience- poor in labour, supplies and resources. This results in clashes and disagreements with the client and other involved parties (Boujaoudeh Khoury, 2019). These and many other researches have been very clearly identifying the problematic situation in complex design environments, which cannot be left only to the individual experience and initiative of the designer or the architect from his/ her professional approach. But rather the process needs to be perceived as a structured and to some extent standardized process which is ran through certain methodologies by utilization of developed maps and tools. To manage a structured design process, the management process must be structured as well, and the two structures should correspond (Rajabalinejad & Spitas, 2011). This correspondence can only be achieved with a thorough and a multidimensional perspective to the process and an integrated synchronous management of several involvements of different parties, data, objectives etc.

Design management in AEC field is described to be involving understanding, coordinating & synthesizing a wide range of inputs while working alongside a diverse cross-section of multidisciplinary colleagues (Boyle, 2003). The main aim of Design Management is then to manage all of the issues acting in different phases of the design process. Some of these issues can be stated as; the provision of the necessary design criteria and information, controlling the necessities of data-project or information flow between the participants, managing and tracking those information…etc. No matter technical, administrative or authoritative the design is based on every type of information, the information to be translated, to be converted, to be processed, to be referenced and to be coordinated. And also, these processed data – the information- then should be managed under the so called- design Management system with the utilization of some information management tools/ techniques in order to achieve the desired product quality (value) within the mentioned constraints.

The need for specialization required several members to work on the same project, revised the design environment to a multi-disciplinary design environment – which requires a much more comprehensive systematic and adjustable management approach.

Design Management in Application

Despite its importance, less research time and effort has been dedicated to the management of the design process, than to production management and project management in general (Austin et al., 1994; Koskela et al., 1997) The linear process of existing project management tools does not permit the full potential for the design activity to produce its best results, as information necessary for the development of concepts and details will become available only as a future stage (de Blois & De Coninck, 2008; Austin et al., 2000, 2001, 2002). The iterative and highly interdependent characteristics of building design process with the contribution and involvement of complex multidisciplinary teams make those wide-spread linear project management tools insufficient and under-utilized by the design teams as well as the design management responsible.

Compared with design teams, design companies, enterprises, design data management is relatively simple, purely personal behaviour for designer but the work of managing design data for design teams and enterprises is clearly more difficult, because it involves many human blocking factors (Jin-hua et al., 2010). Jin-hua et al. (2010) also continue in their research by emphasizing the necessity of such an integration of technology within design management as stating that building a real-time dynamic network design information management platform needs to be a real-time dynamic network services platform which is a very good communication platform between design service side and being served side. The data of this platform are detailed and full as possible especially during long term cooperation relationship.

Contemporarily, design management research has focused on design planning and controlling change (Austin et al., 1998), control of design activities (Ballard & Howell, 1998); managing the integration of design phase teams (Austin et al., 1999; Austin et al., 2001; Business round table, 2002) and collaborative working (Steele et al., 2001; Akbıyıklı & Eaton, 2012)

Mostly when information transfer is not properly controlled; designers do not have the right information at the right time and / or overloaded with unnecessary information (Houvila,

1997) Therefore currently the design process should be concurrent rather than to be sequential (like it used to be traditionally) (Ballard & Koskela, 1998). These circumstances bring forth the realm of a systematic order that nothing can be left to its autonomous process, in order to optimise these complex processes and reduce waste in the design processes. The synchronisation efforts or the concurrent engineering approaches are some previous studies introducing ways to improve those problematic design processes.

Re-thinking Design Management

Since all of these approaches and methodologies focus on the already utilized previous tools and techniques of close or related disciplines, the classification headings or the topics they take account have always stayed similar and limited with those of project and construction management. However, building design processes have highly interconnected and interdependent aspects catalyzed by human behaviors and reflexes to affect the overall process and thus making it hard and different to be managed by literal systematic techniques. As Girard and Robin (2006) stated project design management not only consists of allocating resources, but also in stimulating collaboration among the people involved in the project, in order to increase the performance of the design teams. In order to achieve such a collaboration, the correspondences, data exchanges and documentary flows needs to be planned beforehand with certain check-valves, soft or hard gates that control the proceeding to next phases and enabling the managers to monitor and revise if needed the full process management. Savanovic et al. (2006) also revealed that the problems in the management of many building projects resulted in flaws and additional costs and continued as listing some important aspects herein as:

- The most important decisions are made during the conceptual phase of design, even though not all relevant information is available then (SBR, 2001)
- Some relevant disciplines are involved too late in the process (Zeiler et al., 2005)
- As the complexity and scale of design processes of buildings increase, the traditional approaches no longer suffice (Van Aken, 2005)
- Cooperation between design disciplines is unsatisfactory, better organization of the design process is necessary (Friedl, 2001)

Not ignoring or rejecting the inevitably important factors of ‘time- money-resources–quality’; this paper aims to reveal the considerable effects of different management domains; such as the relationships, documentation exchanges, communication flows, and etc. management as a whole. To encourage collaboration during the design process Lang et al. (2002) stated that the aspects those should be focused may be classified as: ownership and commitment, sharing of design workspace, organization incentives (team spirit, reputation, co-operation), roles and responsibilities assumed by members (Girard & Robin, 2006). With this respect; the “design process management” (DPM) approach previously DURAN introduced in her lectures and papers includes five different headings such as relationship management, time management, finance management, project team management and project scope management. Each of these include subheadings that are standardized in general but have alternatives to be adapted / oriented slightly within the specificity of each individual building design. [1]

[1] Duran. Ö. S has developed this methodology of Design Process Management (DPM) with an adaptation of her academic researches basing on her experiences in the Professional Practice.

Furthermore, the use of information technology has changed the conventional traditional way of face to face communication. Nowadays communication in the AEC industry both necessitates collaboration among distant participants exchanging remote project data as well as interactive communication tools utilizing IT integration in an efficient way. Traditionally for any building design project process; meetings required to be held physically between team members and other stakeholders- which also consumes a lot of time, effort and money especially for remote teams. Today's design environment on contrast mostly enables everybody to hold these meetings remotely via web based tools and online media eliminating the obligations and disadvantages of many arrangements of physical gathering. IT technologies especially increases the advantages of utilizing synchronous collaboration among especially geographically dispersed design team members.

In continuation with these discussions; on the way of re-thinking design management; a recent study has been hold in spring semester of 2020 with graduate students in a specific module to search for creating new innovative process maps. In contrast to different approaches aroused from different backgrounded design managers' conflicting priorities; a fresh and objective perspective has been required from the students to be reflected to design management approaches. The research questions raised to be answered by the students include the proposals of different approaches combining the essentials of a design management approach which has been reconsidered and integrated with today's remote design environment in a much more synchronized , integrated technology oriented and specifically standardized manner combining different dimensions of a design process (such as technical data exchanges, correspondence management, technology based control and management of project deliveries., resource/ time and cost flows and managements…etc.) . The results generally proposed 5D superimposed process maps including different constraints of the design process which has been followed by different paths, loops, check-valves and control points furthermore sub-clusters of iterative secondary management domains have been integrated in these maps to serve for the overall management to improve the whole design processes. Two selected examples of these process maps are given in Figure 1 and Figure 2.

In these process maps, the new innovation was basically on the re-interpretation of existing but independent modes of management to be combined in one single process map to be followed as a guide in the full design process management. Very briefly it has been stated that; Figure 1 specifically taking the project stages as a base process ground line; and five key headings of design process management has been integrated specially according to their relevance for each stage. At the same time, different levels of involvements of individual parties and data have been superimposed to this process ground line. There have been certain milestones also placed as check- valves (soft / hard gates) to control / revise decisions before proceed. And lastly different color codes continuously repeat to highlight essential problematic risks and their solution keys with respect to relevant project stage, related management heading and respected tool. So, this process map reflects a multidimensional but also a sequential way of process management.

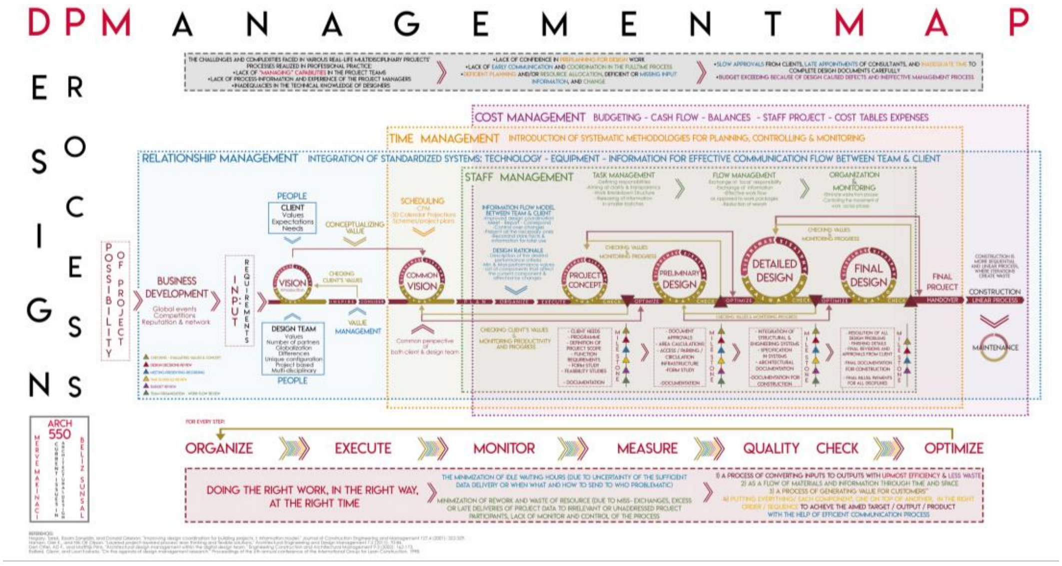

Figure 1: Makinacı M. and Sunsal B. (2020).

In the second example (Figure 2); the process map has been developed in a combination of three different clusters, all of which have been connected and integrated through the flow of process management. Iterative management tools of planning, monitoring executing (and revising if necessary) are proposed as compulsory and permanent throughout the process. However, these have been surrounded and supported by different aspects of the project environment which has been affecting the process in the reality. These three independent but related clusters have also been superimposed in between in order to emphasize their dependencies and required control points in order to proceed efficiently. Another innovation in this process map is that; it proposes different paths throughout the process which enables the design manager to control, adapt and manage that specific project process still keeping the standards to ease the design process management.

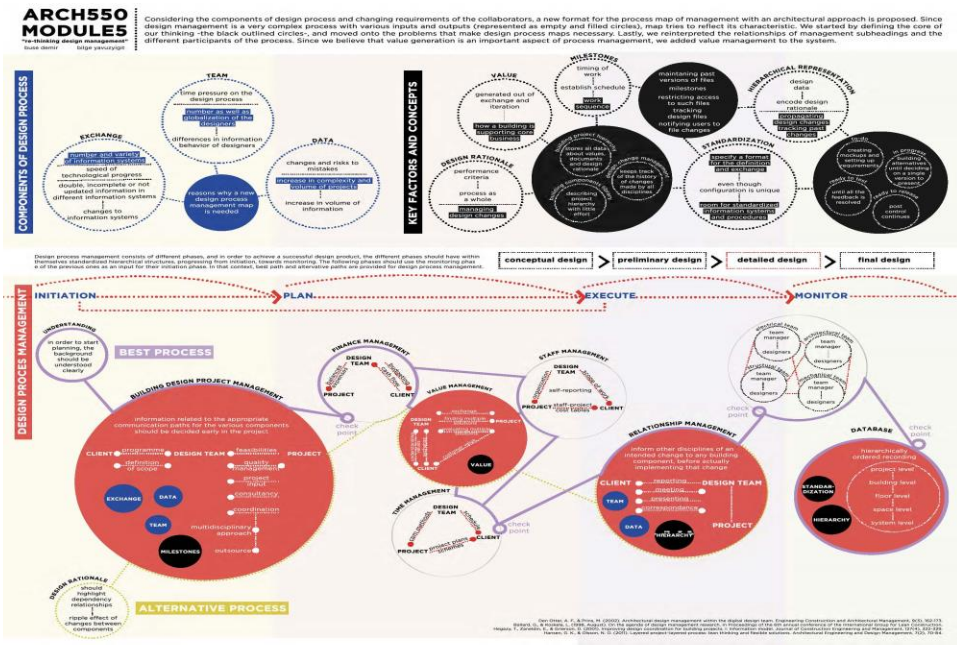

Figure 2: Demir B. and Yavuzyigit B. (2020).

Conclusion and Potentials for Further Studies

This paper intends to raise the importance of design management approaches in each and every project executed in today's complex project environments without being an alternative or an additional factor to be preferred. Furthermore, after justifying this unquestionable need for a total design management approach, within the consideration of today's recent situations of remote design environments, current methodologies should be reconsidered. Integration of IT tools with 5D superimposed mapping approaches could be utilized for this purpose.

This study brings the re-thinking of design management into discussion by developing alternative maps or multi layered exchange flow path diagrams, all of which could be followed for any kind of complex multidisciplinary building design project process. There might be some basic alternating ways to execute these roadmaps and serve them for the use of building design industry. Especially for a smoother transition of the traditional conventional project environments, these maps with simpler interfaces could have been utilized as a guide. On the other hand, for most of the project occasions among today's complex project environments; the integration of these maps with IT tools controlling, monitoring and managing the design process with AI support utilization would act in a much better way.

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Industry 4.0 Impact on Project Management Factors

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Abstract

Management has gone through many stages and has always existed in practice until it reached its modern scientific understanding. The need for industrialization has increased for environmental, social and economic activities due to the increase in the world population and urbanization. Thanks to the developing technology, meeting the expectations for faster and flexible production of industrial products with a good management; It is essential for the reduction of environmental, social and economic problems. The importance of project management has been increasing day by day because each project in the building industry is unique. In this regard, the impact of Industry 4.0, which reflects an era filled with technological applications that break new ground in many fields, is an important research subject. In this study, firstly, literature research was conducted on the transformations that Industry 4.0 brought with it. Then, in order to reveal the effect of these transformations on project management factors, management factors were explained, and an analysis was performed on the returns of industry 4.0. With the use of Industry 4.0 technologies in the project management system, in the national building industry; It has been determined that successful project management will be ensured by utilizing the material resources correctly for many years, efficient use of work force and machine. The data obtained is intended to guide the project partners and contribute to the field.

***Keywords**: project management, industry 4.0, project management factors, construction industry, real time solution.*

Introduction

The industrial revolution has led to societies' development by radically changing them and increasing their economic standards (Figure 1). With the transformations brought by the industrial revolution that started in England in the second half of the 1700s, it paved the way for courses in science, health, and social sciences. The Second Industrial Revolution (Industry 2.0) process started with the spread of cheap steel production in the 1860s, II. It continued until World War II, and electricity use and transportation networks became widespread during this period. II. In the Third Industrial Revolution (Industry 3.0), which started with the end of the world war, digital production systems developed (Ozsoylu, 2017; Yıldız, 2018). With the increase in the world population, the production processes have started to get complicated with industrialization due to urbanization (Ozsoylu, 2017).

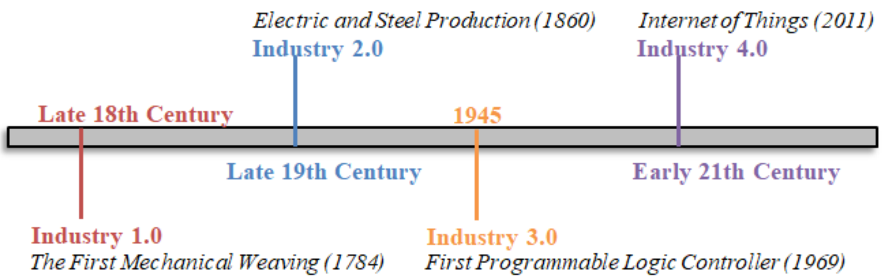

Figure 1: Industry revolutions.

With the development of internet network and automation systems at the beginning of the 21st century, complexities in the sectors were foreseen, and the Fourth Industrial Revolution (Industry 4.0) started (Ozsoylu, 2017). Thus, businesses need to manage their projects by today's technological conditions to eliminate the complexity of their production processes, be sustainable in a competitive environment, and increase their market share. It is possible to complete the projects produced in the construction sector, which has an essential share in the country's economy, by remaining within the desired time, quality, and cost, with a coordinated study. The concept of project management provides this collective work. Actions and factors involved in project management are related to each other, building products, building components, building, and building usage processes (Gültekin, 2007). For this reason, it is thought that the project management factors will not keep pace with the transformations brought by Industry 4.0 will cause severe economic problems. For the success of building production, adaptation must be provided against factors. The effect of technology, which is among the elements on display, increases day by day. The result of transformations brought by technology on the production process and how the process can adapt to the effect is an important research topic. In this study, the impact of nine technological concepts introduced by Industry 4.0 on project management factors (organization, coordination, efficiency, standardization, constraints) and the adaptation that can be developed against the effect have been investigated in the literature. Subsequently, research was made regarding the impact on project management factors, and predictions were made in line with the data.

Industry 4.0

Industry 4.0, called the new industrial revolution, was first mentioned in Hannover Fair 2011, and this term attracted significant interest from academics, politicians, and manufacturers worldwide (Sung, 2018). Experts at the Hannover fair said that Industry 4.0 brought a new dimension to the IT age (EBSO, 2015). Klaus Schwab stated that Industry 4.0 is not a continuation of Industry 3.0 with three distinctive features: speed, system effect, width, and depth (Schwab, 2016). Evans and Annunziata (2012) defined Industry 4.0 as the internet of machines, computers, people, and objects.

Industry 4.0 will improve the quality, flexibility, and robustness of products by introducing standardized interfaces and compatible business processes to the production, logistics, engineering, and planning processes of a work (Acatech, 2013). Industry 4.0 provides useful information to the production system using digital technological concepts to collect and analyze production processes in real-time (Lee et al., 2015). Lasi et al. (2014) stated that Industry 4.0 contains many concepts that cannot differentiate between classification and discipline (Figure 2). Industry 4.0 includes nine new technologies: “Big Data, Autonomous Robots, Simulation, System Integration, Internet of Things, Cyber Security, Cloud Computing, Additive Manufacturing, and Augmented Reality.” These technological concepts transform the isolated and optimized industrial production into a fully integrated production flow (Cemernek et al., 2017). Short descriptions of these titles were tried to be given.

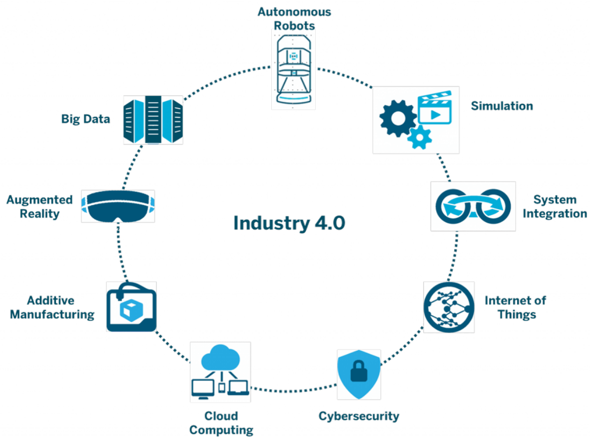

Figure 2: Structure of Industry 4.0 (https://www.smaris.com/features-2/).

Big Data

It contains a large volume, high speed, complex and variable data, advanced techniques, and technology to provide storage, distribution, management, and information analysis (Cemernek et al., 2017). Various solutions are produced to analyze the dimensions recorded in the big data system and the previously registered data, find threats in different production processes, identify new problems, and prevent them (Bagheri et al., 2015). Zhou and Liu (2015) stated in their study that big data would provide some benefits such as optimizing processes in the construction industry, reducing costs, and improving operational efficiencies (Zhou & Liu, 2015).

Autonomous Robots

It is used in places where the production method should be carried out more precisely and where human resources cannot be used. Autonomous robots can complete the given task right and intelligently within a specified period, focusing on security, flexibility, versatility, and collaboration (Bahrin et al., 2015). With the use of autonomous robots in Industry 4.0, product development, production, and assembly stages in manufacturing systems will become flexible and fast (Salkin et al., 2018). In the construction industry, robots search for recyclable materials, brick, remove asbestos, or collect construction waste to finish concrete floors (Oesterreich & Teuteberg, 2016).

Simulation

It is an indispensable and powerful tool for successfully implementing the product, material, and production processes by providing digital production (Weyer et al., 2016). Using the simulation in different production processes, future problems and opportunities can be estimated by having information about the system (Alcácer & Cruz-Machado, 2019).

System Integration

It is the coordination that enables multiple systems to operate as a single system (Bulut and Akcacı, 2017). In the integration mechanism, There are three different dimensions: horizontal integration, vertical integration, and networked production systems throughout the entire value creation network, an end-to-end digital integration in the whole product life cycle (Figure 3) (Stock et al., 2016). With the use of integrated systems in Industry 4.0, every physical object in production systems is connected via smart networks and becomes a self-organizing structure (Erboz, 2017). Newman et al. (2020) stated in her study that communication methods had expanded significantly in the entire construction industry and that team members from all over the world will be able to work on the same projects (Newman et al., 2020)

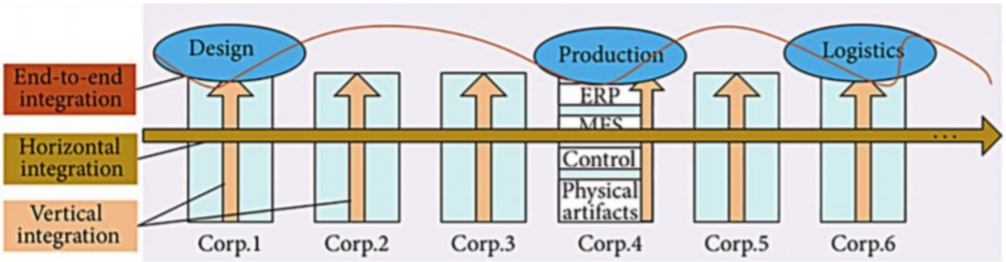

Figure 3: Types Of Integrations in The Manufacturing System (Salkin et al., 2018).

Internet of Things

It means the worldwide network of interconnected and uniformly addressed objects that communicate through standard protocols (Wang et al., 2016). In Industry 4.0, the Internet of Things technology provides real-time information about an object's location, physical or atmospheric conditions with other technologies (Hozdić, 2015). Zhou and Liu (2015) stated in their study that as the computing power and storage capacity of smart mobile devices increase, they will be used to design, produce and manage the CONSTRUCTION process in the near future and will become the "new normal" for the industry (Zhou & Liu, 2015).

Cybersecurity

It is a technology-based on protecting, detecting, and responding to attacks on the internet (Piedrahita et al., 2018). With the use of cybersecurity technology in Industry 4.0, the calculation, communication, and control processes of production systems are tightly integrated, thanks to the cyberspace (Bagheri et al., 2015).

Cloud Computing

It is the way to virtualize resources and services and consolidate the server-based system. It includes resource pools of information technologies that offer storage and processing features in a virtual network, serving multiple users. Using cloud computing systems in Industry 4.0 helps automate and integrate the information and communication technologies paradigm. At the same time, it positively affects the flexibility of companies' production management (Xu, 2012). Oesterreich and Teuteberg (2016) stated that the reflection of the cloud computing system to the construction process is Building Information Modelling (BIM). It has been determined that the communication and workflow between different disciplines in the production process can be provided remotely with the BIM system (Oesterreich & Teuteberg, 2016).

Additive Manufacturing

It refers to producing customized products for customers' needs (Kim et al., 2018). It is accepted as the process of making parts from three-dimensional model data in a computer environment (Alcácer & Cruz-Machado, 2019). Its additive manufacturing system enables firms to gain production advantage with less stock in their warehouses and reduce supply times and production volume (Erboz, 2017). It also ensures the production of structural elements with different shapes and geometries by providing quality control during the production process (Newman et al., 2020).

Augmented Reality

It is defined as an interactive technology that harmonizes between the virtual world and its users (Erboz, 2017). The working principle of augmented reality consists of digitally processed fact and the combination of two-dimensional or three-dimensional objects (Horˇejší, 2015). Augmented reality helps solve problems between product development and production operation, as it can simultaneously reproduce and reuse digital information (Rentzos et al., 2013). It also enables employees in the production process to make decisions and improve working procedures (Vaidya et al., 2018). Newman et al. (2020) predicted in her study that the adoption of artificial intelligence and robotic technology in the construction industry would likely increase productivity in the construction industry and continue with automation systems (Newman et al., 2020). This technology enhances human-machine interaction and plays an essential role in every stage of production (Figure 4) (Alcacer and Cruz-Machado, 2019).

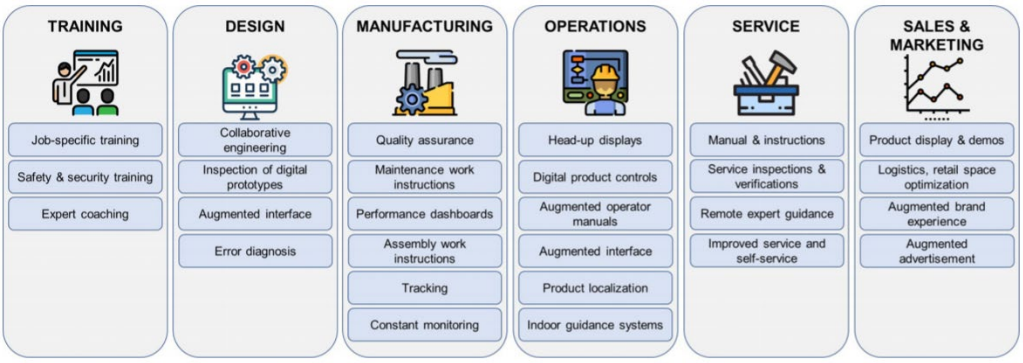

Figure 4: Duties of Augmented Reality in the Industrial Production Process (Alcácer, 2019).

Industry 4.0 Impact on Project Management Factors

Project Management: It means achieving the goal determined by individuals and organizations using all their knowledge, skills, tools, and techniques throughout the process (Ozkurkcu, 1996). The management process begins by organizing the investor's organization and continues in the preliminary design, design, tender, construction, and use phases (Sorguc, 2005). The project manager organizes interdisciplinary relationships in the management process, ensuring that it achieves its time, quality, and cost goals. Throughout the project management phases, actions and factors are related to each other, building components, building design, production, and use process (Gultekin, 2007). Therefore, factors play an essential role in the building production system.

Legal, political, economic factors, technological and social activities affect the building production process. It is necessary to minimize the impact of environmental factors that change building a production system or act accordingly (Taner, 2019). The effect of technology, which is among the elements, on production, increases day by day. Piccarozzi (2018) stated that the literature examining the interaction between industry 4.0 and the management process is still lacking (Piccarozzi et al., 2018). The effect of technology on the production and management process and how the process can adapt to the impact is an important research topic. Accordingly, in this study, the effects of nine technological concepts brought by Industry 4.0 on project management factors (organization, coordination, efficiency, standardization, constraints) and the adaptation that can be developed against the effect were examined.

Findings

Today, project management's importance has increased due to the coexistence of different disciplines in projects, the originality of the projects, and the growth of project volumes. It has become an element of competition between companies. It has become important to evaluate projects in terms of time and cost in today's technological and economic conditions. It has become the most important goal to produce the best quality work at the most appropriate time and cost. Technological developments, which are among the environmental factors that affect project management, have been examined through Industry 4.0. An analysis has been conducted to reveal the effect of technology on project management factors. The study findings about the impact of technological developments on project management factors (organization, coordination, productivity, standardization, constraints) were obtained.

Organization: The project's activities are to ensure coordination and establish a system of powers (Kerzner, 2009). The organization varies depending on the projects' nature, the disciplines, and interdisciplinary communication it contains. The usual types of organization, the internet, and technological tools in people's lives have changed communication styles with technology development. This situation has revealed the kind of virtual organization. Virtual organization: It is a type of organization where different project disciplines can communicate with cloud computing systems without meeting at a specific location (Aslan, 2014). Communication problems are prevented by using virtual organizations, which is caused by the current technology affecting the building industry's organization systems. With the increasing use of the layered production brought by Industry 4.0 in the building industry, the organization matrices must be made suitable for the current production system and system integration. Thus, it is thought that efficiency and effective organization can be achieved by preventing problems such as supply and storage occurring in today's production system.

Coordination; After the form of organization created by the project quality and discipline setup, it is the communication management between project managers, personnel, and units within the organization (Gültekin, 2007). Project coordination can be efficient and effective with the presence of experienced architects and engineers developed through extensive training and job rotation in the project, the use of simulations and computer-based tools in today's technologies, the use of cloud computing bases containing information about the product, and the project (with authorized project managers). Bailetti et al., 1994). Accordingly, it is thought that the coordination process will be more productive by combining the use of the internet technology of the objects developed by Industry 4.0 and all the data belonging to the items and employees and the data related to the production process detected by augmented reality technology. It is anticipated that project partners will be able to communicate in real-time through cloud computing systems throughout the production process.

Productivity; It is defined as the ratio of inputs or resources used in the product's production process. When manufacturers use a smaller amount of resources to produce a unit or product, productivity increases, and quality products are obtained (Heap, 1987). Kuroğlu and Sümer (2003) stated that total efficiency measurement, including equipment, materials, construction techniques, and management, gave more accurate results in the building industry (Kuroğlu and Sümer, 2003).

The Australian Government Productivity Commission (2013) has suggested that the use of advanced technology and change in management practices can increase efficiency (AGPC, 2013). Gurmu (2020) highlighted using material monitoring technology in the building industry as one of the potential areas where productivity growth can be achieved (Gurmu, 2020). Similarly, Nasir (2013) and Caldas et al. (2014), it was determined that material monitoring technology is one of the best practices that increase efficiency in infrastructure and industrial projects (Nasir, 2013; Caldas et al., 2014). With the use of autonomous robots, which are among the technologies brought by Industry 4.0, the problems experienced in the machinery and workforce; problems with engineering and construction techniques using simulation and computer-based tools; It is thought that efficiency and product quality may increase by preventing communication problems by using system integration and using cloud computing systems.

Standardization; It is a modern concept that ensures quality reliability by determining the lower limit of the product's quality after the production process (Ertug, 2015). Standards can be updated in line with the problems that arise during the production process, with means being suitable for changing technology. With the development of information and production technologies, standards have become the universal language of international trade today, where a rapid globalization process is experienced. The way to compete in global markets is to produce products that comply with the standards (BSTB, 2017). In the 21st century, environmental problems have increased with the increasing urban population and, consequently, increasing building production. The threats caused by natural resources, energy, and raw material limitations have reached a global dimension. Accordingly, it is necessary to update the construction systems, materials, equipment, and management standards using today's technologies. An effective standardization can be achieved using simulation and augmented reality technologies, using cloud computing systems containing information about project and material standards, and protecting information with the cybersecurity system.

Constraints; Cost, time, technology, and legal regulations are expressed as constraints in building the production process (Gültekin, 2007). Oberlender (2000) emphasized that effective interaction and good coordination are essential in order not to affect the production process (Oberlender, 2000) negatively. Technological developments, which are experienced today, frequently change the legal regulations of national and local administrations. The system integration of the project management team resulting from technological developments should include the cloud computing systems and the management process's layered production system. Thus, it is thought that time and cost problems can be avoided by being affected by external factors in the least way in the management process.

Results

With industrialization and technology development, projects that are getting more complex in the building sector, and each project being unique are increasing their importance to project management. The negative impact of the factors that form the building production system's environment on the parameters is an essential problem for the project management process and project partners. The influence of technological factors, which are among environmental factors, on the production system is increasing day by day. Today, adaptation to factors should be ensured for building products to achieve success by ensuring ecological, social, and economic sustainability. Within the scope of the research, the technologies brought by Industry 4.0 were examined. Problems that arise in the traditional project management process and cannot be solved negatively affect quality, time, and cost. It is thought that nine different technologies brought by Industry 4.0 will bring a radical change to the project management system. Studies on the effects of these changes on project management factors have been conducted, and the data obtained have been transferred to the table (Table 1). When the received data are examined, it is seen that Industry 4.0 technologies will bring real-time solutions to the problems in traditional project management. In this direction, Industry 4.0 technologies need to cover all concepts in project management.

Table 1. Findings for using industry 4.0 technologies in project management factors.

Predictions for Using Industry 4.0 Technologies in Project Management Factors			
Factors	**Responsibilities to Take Place in Factors**	**Traditional Project Management**	**Contemporary Project Management (Industry 4.0)**
Organization	Project management team members can prepare reports in real-time	-	√
	Ability to continually communicate with cloud computing systems of different disciplines	-	√
	Communication of the management team via internet and technological tools	-	√
	Identify and resolve problems in real-time	-	√
	Ability to manage extremely complex technical projects	-	√
Coordination	Ensuring effective communication with simulations and computer-based tools	-	√
	Real-time data of building components and workers by using the industrial internet of objects	-	√
	Real-time coordination of project stakeholders' communication with the use of big data and cloud computing systems	-	√
Productivity	Monitoring of building components by using industrial internet technology of objects in the building production process	-	√
	Avoiding problems in machinery and workforce by using autonomous robots in building production process	-	√
	Identifying problems related to engineering and construction	-	√

	techniques using simulation and computer-based tools		
	Efficient communication by using system integration and cloud computing systems	-	√
Standardization	Using big data and cloud computing systems with information about project and material standards	-	√
	Protection of information about cybersecurity systems and product standards	-	√
	Determination of production standards by using simulation, layered production system and augmented reality technologies	-	√
Constraints	System integration, using cloud computing systems and additive manufactUring systems, and minimal impact on the management process from external factors	-	√

Accordingly, Industry 4.0 technologies need to be able to cover all the concepts included in project management. With the use of these technologies in the project management system in the national building industry; Successful project management will be ensured with the correct evaluation of material resources for many years, efficient use of the workforce and machinery. In parallel, the project management process's cost, quality, and duration parameters will be used at the optimum level. This study is expected to contribute to future academic studies and contribute to the development of project partners.

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Knowledge Capturing in Design Briefing Process for Requirement Elicitation and Validation

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Abstract

Knowledge capturing and reusing are major processes of knowledge management that deal with the elicitation of valuable knowledge via some techniques and methods for use in actual and further studies, projects, services, or products. The construction industry, as well, adopts and uses some of these concepts to improve various construction processes and stages. From pre-design to building delivery knowledge management principles and briefing frameworks have been implemented across project stakeholders: client, design teams, construction teams, consultants, and facility management teams. At pre-design and design stages, understanding the client's needs and users' knowledge are crucial for identifying and articulating the expected requirements and objectives. Due to underperforming results and missed goals and objectives, many projects finish with highly dissatisfied clients and loss of contracts for some organizations. Knowledge capturing has beneficial effects via its principles and methods on requirement elicitation and validation at the briefing stage between user, client and designer. This paper presents the importance and usage of knowledge capturing and reusing in briefing process at pre-design and design stages especially the involvement of client and user, and explores the techniques and technologies that are usable in briefing process for requirement elicitation.

Keywords: *design briefing, knowledge capturing, requirement elicitation.*

Introduction

Briefing is a process of identifying requirements and objectives; articulating and matching them at the right time and in the right medium. Since briefing is crucial for the success of construction process, it has emerged and developed in parallel with the development of the construction industry, thus, a considerable number of studies was established for the improvement of a comprehensive briefing.

Knowledge capturing and reusing are major processes of Knowledge Management (KM) which deal with the elicitation of valuable knowledge via some techniques and methods for use in actual and further studies, projects, services, or products. Construction industry, as well, adopts and uses some of these concepts to improve various construction processes and stages. KM and briefing have mutual benefits and working principles with their strategies, techniques and technologies in terms of knowledge life cycle among project stakeholders in the construction industry. At the pre-design and design stages, understanding the client's needs and users' knowledge are crucial for identifying and articulating the expected requirements and objectives. Due to ending up under performing and not matching up to the expected goals and objectives, projects may finish with highly dissatisfied clients and loss of contracts for some organizations (Olatokun and Pathirage, 2015). The dimension and character of knowledge are important to consider for deciding the proper framework, tools, technique or technologies for capturing the client's knowledge. Explicit knowledge coming from site requirements, design specific necessities or construction companies' intentions may be processed by conventional KM practices, however the tacit character of knowledge that the clients have about space activities, experiences and insights make it harder to capture and reuse. A continuous process with the involvement of client, inclusive approach regarding tacit-ness of knowledge and verifiable conversion principles are essential for requirement elicitation and validation in terms of matching requirements (inputs) to proper design solutions (outputs).

Design Briefing

Construction process consists of various consecutive processes ranging from feasibility studies to facility management. According to construction typologies and techniques the process may have various kind of sub and core processes, stages and specifications. In the 1970s briefing was conceived as a process of discrete steps, where design could not begin until the briefing stage was completed (Blyth and Worthigton, 2010). As for today's view, briefing is the capturing and transformation of knowledge between client/end-user, architect/design team, and construction team with the implementation of new methods and techniques.

Briefing output is the knowledge which is structured to the intended use at the correct level of detail. Not only architects but also construction teams and clients have necessary attention to these briefing documents. Such documents are also often very long and detailed for the exact information related to the project. Although it is difficult to develop useful methods and frameworks for briefing where a designer's use is intended, there is also a need for the requirement management of client/end-user, planning for the instructed cost and time, and management of the information and knowledge of project stakeholders, the evaluation of the process and project in terms of feedback into the future and the success of project. Important goal of design briefing process is gathering knowledge about requirements from client and deliver the design project accordingly. Limitations and failures result in shortcomings on closing the gaps at briefing process.

Importance of Client Involvement

Construction clients demand a project output that maintains accurate designs regarding their demands in appropriate time and budget. Client demands are defined and stated as a client requirement by the briefing process that is established by project stakeholders. However, construction industry has poor performance of addressing these requirements owing to uncertainty and complexity of project brief (Shahrin et al., 2010). In addition, capturing and translating the knowledge from client to designers or designers to clients are important problem area for successful requirement processing resulting from lack time, framework, expertise, etc. The briefing is a tool for collaborative work for client, contractor, and designer.

Client, end-users, contractors and designers may not have knowledge or experiences in a level of expertise, but proper briefing process with collaboration is key of the capturing the important knowledge. Empowering client and appropriate user involvement at briefing process are important factors for better briefing (Barrett and Stanley, 1999). Identifying needs of the client by considering their user experience is the vital goal of briefing. Lack of clarity in communication between the client and professionals, lack of participation in briefing and lack of understanding of role and responsibilities may result in ineffective briefing (Norouzi et al., 2015).

Knowledge Cycle and Processes

Knowledge capture and reuse are major process of KM, which has a vital place within the value chain of an organization and a potential to improve effectiveness of all primary activities by learning activity (Kivrak et al., 2008). It has main processes defined and developed by various researchers differently, but briefly classified as capturing, sharing, reusing and maintaining the knowledge for creation and the benefit of the business (Tan et al., 2010). Knowledge cycle is defining the knowledge creation and sub-processes which are parts of whole process have role in capturing, archiving, understanding and reusing. Presentation of the knowledge cycle and processes differ by different researchers; however, they are commonly considered to be a continuous loop for knowledge gathering and refinement. A common and brief cycle representation is shown in Figure 1. Knowledge is captured from a source (individuals, group, world, etc.) with a technique or method, then it is archived since for reuse it must be found and understood, and finally the knowledge is created with refinement. Knowledge creation is about transferring of different form of knowledge to another one and no one department or group of experts has the exclusive responsibility for creating new knowledge (Nonaka and Takeuchi, 1995). The created knowledge could be enlarged, refined or changed by single, double or multi loop processing according to frameworks which is designed and validated for decided usage.

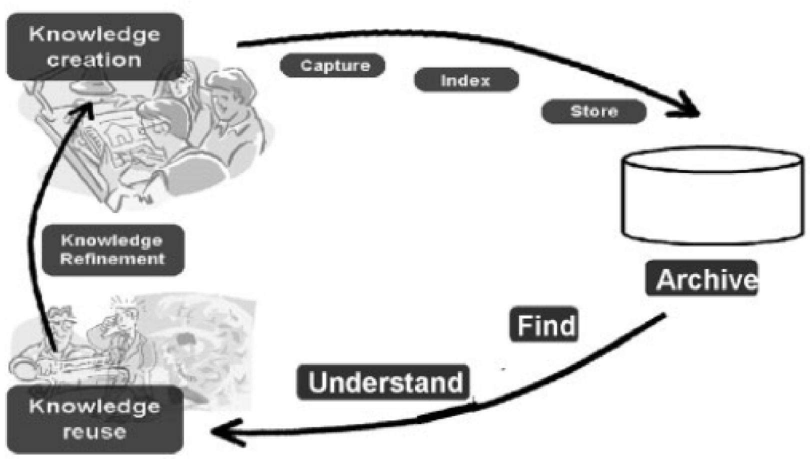

Figure 1: Knowledge cycle (Anumba et al., 2008).

Types of Knowledge

Knowledge typology is examined by various researchers and practitioners for both business environment and construction industry. Dimensions of some are related to the usage of knowledge or creation method, some are originated from the transfer concepts, some are separated according to process time and frequency and rest is presented according to contextual situations regarding to specific business environment. From the perspective of transfer, convert and creating knowledge, the important knowledge typology consisting of tacit and explicit knowledge is underlined. Explicit knowledge or codified knowledge may be understood by people with complementary knowledge who can extract meaning from the 'codes' (Fuller, 2012). This knowledge could be defined as transferrable knowledge by rules, codes, language or symbols. Tacit Knowledge comes from the experience and practice and hard to formulate. It can be characterized as inexpressible, ineffable and hard to tell (Polanyi, 2009). It cannot be communicated or transferred in spoken language, codes or symbols as explicit knowledge. The major challenges for KM in all organizations is that in all human activity there is acquired tacit knowledge through experience and internal reflection which is impossible to share with others who have never been in similar learning experience (Fuller, 2012). From the perspective of reusability of knowledge in construction projects; they can be listed as; process knowledge and knowledge about clients, knowledge about legal and statutory requirements, costing knowledge and knowledge about reusable details, best practices and lessons learned, performance of suppliers, knowledge of who knows what, knowledge about key competitors, risk management or sector specific area (Tan et al., 2010).

Importance of Knowledge Capturing

Knowledge sources in the construction industry can be divided into three groups. While these sources have overlapping areas, characterization has beneficial impact on understanding the importance of capturing. The first one is individuals or groups who are involved in the construction projects; design team, client- end-users, construction team, supervisors, consultants, contractors and suppliers. The knowledge belongs to this group may have tacit or explicit character according to their convertible dimensions. The second group is originated to unchangeable facts related to site, legislation and regulations, cost and time project specifications, labour and resources issues coming from the unique project situation. The third source group is coming from organizational or company level which is based on past experiences, knowledge repository of cases and evaluations. Knowledge capturing and sharing is a concept of creation or acquiring essential values, knowledge and frameworks into construction projects.

Knowledge capturing in the design briefing uses all the sources that brings the inputs for design development. Capturing hardness differs according to sources and character of knowledge. Tacit knowledge that belongs to the individual or groups needs techniques or technologies which are hard to accomplish. One of the important benefits of knowledge capturing in the design briefing is the capability to elicit and validate requirements from clients which is knowledge embedded in the mind of the clients what they have in mind for building requirements. and these requirements needs to be properly documented (explicit) in such a manner that the design team can produce quality designs (Olatokun and Pathirage, 2015). Lack of identification of requirements is seemed as bad design solutions against client wishes which are affecting cost and time. Thus, elicitation and validation of requirements with the help of knowledge capturing approach have an important role of the process success in construction industry as wells as other industries.

Knowledge Capturing Strategies and Technologies

There are various techniques and technologies related to knowledge capturing, reuse and creation. Some of them are designed for knowledge creation by capturing the explicit and tacit knowledge from individuals, groups or communities for the development of various kind of business sector; some of them are designed for cross-organizational learning, some of them are specific for KM practices like sustainable construction or knowledge transfer on Public Finance Initiatives; and some relate to knowledge transfer between different industries. In this section, the ones which presents and supports capturing the knowledge from the client or individual and groups who has the usage and expertise knowledge which have possible process on requirement elicitation and validation.

The Client Requirement Processing Modelling (CRPM) with Quality Function Deployment (QFD) is an approach for defining, analysing and transferring the requirements which uses QFD from the manufacturing industry. ‘Voice of the customer’ is translated to ‘voice of the designer’ by a matrix which is quality and functions based correlating what’s, how’s and target (Kamara et al., 1999). Elicitation of requirements and validation are done with the weight-based analysing by using the explicit and implicit knowledge independent from the design attempts. ClientPro is software application of CRPM in which calculations made by the program according the framework. Entities and calculation matrix are resulting in solution neutral outputs for defining, analysing and translation of requirements. The user interface makes the involvement of client and individuals representing the client possible who may not have any expertise on this model. On the other hand, DesignTrack deal with a tool in the responsibility of the designer/not involvement of the client, but it concentrates on traceability of requirements with design solutions in integrated design environment for requirement spaces. It uses geometric modelling for designs and requirement modelling for capture knowledge and integrated them in a requirement-driven design understanding automation framework (Ozkaya and Akin, 2007). The prototype software has extensions for IFC or building data model, and the captured knowledge can be used in ongoing project and further projects.

CAPRIKON is a research project that intends to develop a methodology for live capture of reusable project knowledge during the project execution. The aim is to capture and validate the knowledge through the project execution lively in an agile way for re-use and dissemination. Reusable project knowledge often exists as mixed and explicit knowledge, thus for tacit knowledge a codification strategy for convertible one’s, and links, contacts details of knowledge author’s captured for which is difficult to convert (Tan et al., 2007). Capri.net (a web-based prototype) is designed for live capture and reuse of construction project knowledge according finding of CAPRIKON project. The system is capturing knowledge from individual, groups and rationale that make changes and validate them with meetings or online validation (comments, rankings, majority’s opinion) with approval of project knowledge manager, recording in project knowledge file (database) for dissemination. This process can be for numerous projects for organizations to establish a database of construction project knowledge by capturing the knowledge created at project execution stages including end user's requirement knowledge.

e-COGNOS is EU funded project which aims to specifying and developing an open model-based infrastructure and a set of tools that promote consistent knowledge management within collaborative construction environments by using web technology and ontological framework (Wetherill et al., 2002). The project provides web-services to support the major functionalities identified in the classical KM cycle, namely: acquisition, cleansing/transformation, indexing, updating, refreshing, searching/discovering and sharing/dissemination supported by ontology service. A knowledge platform for contractors to capture in construction project (KPfC) is introduced to reduce time and cost for solution of repeating mistake, share and retain the knowledge captured (Kivrak et al., 2008). It is a web-based platform that capture the both tacit and explicit knowledge of experienced engineers and experts for contractors, validate and reuse with the retrieval from the knowledge base. It enforces the continuous improvement by transferable lessons learned knowledge and organizational learning by sharing knowledge with companies. Recently a web based online platform (LinCTool) was introduced to capture and transfer knowledge across projects which has a potential to enhance organizational learning in companies by assigning multiple users having different responsibilities/roles in the learning process, categorizing lessons learned using a taxonomy and retrieving lessons learned considering project similarities (Eken et al., 2020). The tool has detailed system lesson entry, editing, searching and accessing for capturing knowledge from knowledge sources and transferring them into new projects. The centralized system and user management capability result in an approval mechanism under the control of authorized users ensuring quality of the lessons learned.

A framework called FAST for identification, representation and structured analysing of client requirements is introduced by integration of value management with function analysis system technique (Shen et al., 2004). The knowledge is captured at briefing workshop with involvement of client, project team and experts, and is translated into functional objectives and performance specifications and evaluated assigning weighting to functions. The client requirements can be investigate and crystallized through logic of HOW-WHY relationships with the involvement of all major stakeholders into briefing process (Shen et al., 2004). Further development of this framework with the using of Case Based Reasoning (CBR) intimates a software application in which the functional performance speciation's is evaluated and analysed with retrieval of CBR database. The important concern of system is the performance of CBR related to sources and construction (Luo et al., 2010). The system offers an approach to accumulate and reuse valuable knowledge in previous construction briefing. These research attempt to investigate and analyse client requirements in structured framework, represent and store for retrieval and reuse by CBR.

Design requirements of spaces are connected to user activities and space types in a building. The relationship between them explores the requirement in terms of values of requirement types. An automated updating of space design requirement approach is introduced by connecting all user activities and space types systematically for decreasing time and errors at changing (Kim et al., 2015). This method is an example of automation on design process with the implementation of technology concepts. This kind of implementations are possible, and developed contemporary regarding various concepts.

BIM-based user pre-occupancy evaluation method (UPOEM) supports the designer-client communication with simulating user activities and representing in virtual medium (Shen and Shen, 2011). In BIM-based model environment, the schedule of user movements and activities are captured from the end-users, simulated and pre-occupancy evaluation module makes users capable of analyses and give feedback. This approach brings awareness how the briefing outcomes can be in BIM environment at the beginning of design process.

Briefbuilder is cloud based requirement management software that is available with monthly subscription and usable for requirement management of construction project (BriefBuilder, 2020). Requirements of project coming from all project stakeholders including client are captured into a web-based system by an interface. The requirements of spaces, locations and objects are defined, compared and analysed, verified by instructed phases and methods and if needed linked with BIM models. Tracking of knowledge source and verifications, comparison between items and versions are taken into consideration. The requirement knowledge's coming from the other project could be retrieved and reused which are in the same account (knowledge base) of company. To transfer knowledge between companies seems to be done with the development of methods and taxonomies, but the knowledge privacy and market value stand as a barrier that should be thought in different manner.

Specification software Avitru of Deltek is cloud and database based editor that can create, edit and collaborate project specifications (Avitru, 2020). Creating and importing third party specifications including international standards and industry specifications is possible and real-time collaboration between team make trackable environment. One of the important features of software is directly link to MasterSpec, which is a product selection tool that provides to design professional objective information on building products written by professional architects and engineers by American Institute of Architects, and it make possible to import project specific standard after purchasing. Although the knowledge is not coming from the client or project specific environment, reusability of revived and verified knowledge of specifications is valid contribution to knowledge library.

dRofus is cloud based planning and data management software which brings a centralized data centric approach to BIM with involvement of all project stakeholders (dRofus, 2020). It is not only requirement capturing and management purpose, but also project management for whole project cycle from design to facility management. It has room templates and global item catalogue for facilitating design across knowledge library. The captured client requirements can be standardized and reused for other projects within the company. A level of BIM knowledge is compulsory for usage, but the owner/client can track and make entry if necessary. The explicit knowledge and tacit knowledge which could be formulated and written into text about the requirements can be defined, analysed and compared with the design solutions. Plug-in related to known BIM modelling software's make possible to link data between. All the tracks related to inquiries, changes and coordination are recorded for verification.

Results and Findings

The approaches, techniques, methods, tools and commercial software that have contribution on the knowledge capturing at design briefing for requirement management in terms of elicitation and validation are presented and tried to be explored. Both in construction industry and other industries, there may be some other researches and applications for same purposes, however this survey tries to state broad view about knowledge capturing concept in construction. The general findings consisting of barriers, benefits and possibilities are listed below:

- Explicit knowledge has been examined more properly, convertible tacit knowledge has been developing, tacit knowledge still needs findings for process.
- Enabling further communication with individual as knowledge source affects tacit knowledge transfer.
- Client contribution stays as a milestone to achieve and still needs frameworks or method.
- Interface of systems, lack of time and expertise directly affect all project stakeholders to work collaboratively.
- Knowledge transfer between projects and companies is important, needs methodical solutions, privacy analysis and market value evaluations.
- 3D representations and virtual experiences on design solutions have effects on validation of the knowledge by vaulting design solution against demands. This knowledge generally remains on project.
- Evaluation of designs stands as an important knowledge to be captured for requirement processing.
- Lessons-learned in and across companies contributes creation of knowledge bases, and may have reflection to design briefing.
- Knowledge libraries and bases consisting of CBR, international standards and specification have important value.
- Technology developments like cloud and web-based system resulting in access to information from everywhere by everyone.
- Technology developments like BIM brings important contributions to knowledge process and BIM can be used as knowledge capturing technology.

Conclusion

Knowledge capturing for the design process and construction industry is important for the requirement elicitation and validation to enrich project success. Dimension of knowledge related to requirements coming from client and end-user varies and may be hard to capture and validate. This paper examined the existing literature on briefing, knowledge capturing, their importance and applications for considering limitations and improvement areas to increase attention to the subject. Considering survey and findings, a structured framework or a strategy which is capturing knowledge from standards, clients and previous knowledge libraries, and which is validating them via automated system to pre-verified, collaborative approval and BIM-based virtual representations for non-convertible knowledge may have contributions to knowledge and requirement management in construction project in terms of project based designer-client communication and creating a knowledge library that can be usable within and across company.

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Investigation of the Impact of Emergency Action Plans on Sustainable Development on Educational Buildings-Kayseri Scale

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Abstract

Emergency action plans: It is prepared following the relevant regulations in order to estimate the results to be experienced before emergencies such as natural disasters and fires with risk analyzes. Buildings that are not planned within the scope of emergency management suffer financial damage in emergency situations. Reducing disaster risk is an integral part of sustainable development. Therefore, sustainable development goals should be achieved by including emergency action plans in sustainable development activities within the scope of our country's strategic development. The quantitative and qualitative characteristics of educational structures show the importance countries attach to education and sustainable development. Today, with updates made in legislation in the cause of education in Turkey there have been changes in the education structure. In this process, educational structures should be planned in accordance with the "Turkey's Regulation on Fire Protection". In this research, the architectural plans of 4 educational structures in Kayseri were examined within the scope of the regulation and their suitability for emergency management and sustainable development was examined. The purpose of the research is to guide local and national administrations, school administrations and designers in creating emergency action plans and contribute to the field.

Keywords**:** *emergency action plan, sustainable development, educational buildings, emergency management, sustainability.*

Emergency and Emergency Action Plan

For emergencies that occur in an unexpected moment and cause loss of life and property, occur in natural disasters or humanities; Preventive, limiting and interfering methods are specified by defining them with regulations. Disaster and Emergency Management Presidency (AFAD) emergency is defined as “all situations and situations that require urgency, with a large but generally local facility.” (Afet & Başkanlığı, 2014). In business life, according to the “Regulation on Emergency Situations in Workplaces” in which the procedures and principles regarding the things to be done before and after emergencies are arranged; It is evaluated as “events requiring urgent intervention, struggle, first aid or evacuation such as fire, explosion, spreading from hazardous chemical substances, the natural disaster that may occur in all or part of the workplace". (Resmi Gazete, 2013a s.1). Depending on the function and spatial size of the workplace, emergencies and plans vary.

Emergency scenarios before emergencies occur, disasters to be experienced in line with the related estimates; Emergency action plans are also prepared with scenarios and works. Disaster scenarios should be designed according to real conditions as much as possible. AFAD planned the emergency plan "the work and procedures that need to be done in order to get rid of the consequences of extraordinary events with the least loss and harm and during the incident; all activities that require timely, rapid and effective implementation" (Afet & Başkanlığı, 2014 s. 20).

The purpose of preparing an emergency plan; It is determined to be always ready for emergencies, to resolve the emergencies quickly and effectively in order to reduce the impact at the time of emergency and to manage after emergency (Resmi Gazete, 2013a). The emergency arises as a result of the risk analysis made what might be these (Resmi Gazete, 2013b);

- Fires and Explosions
- Natural disasters (Earthquake, Flood, Storm, Tsunami, Landslide, Rockfall etc.)
- First aid and evacuation events,
- Zehirlenme ve Sabotaj
- Tehlikeli kimyasal madde yayılımı gibi acil durum olarak kabul edilmiş ve acil durum planı gerektiren olaylar olmuştur (Resmi Gazete, 2013b).

Emergency Management

Risk analyzes are very important for the detection of possible emergencies. Emergency management is made by analyzing possible situations (ÇSGB, 2017). Emergency management: It consists of four different stages to protect by doing "Mitigation" and "Preparation" before an emergency occurs, and to provide correction by "Response" and "Recovery" after it occurs (Alexander, 2002).

The evacuation method, which is included in the preparation and response methods of emergency management, is one of the best methods to ensure life safety by reducing the hazards with the estimations made. The emergency seen in the buildings should be able to evacuate the users as quickly and effectively as they occur. Accordingly, national regulations and international standards are needed to prepare evacuation plans that are effective in ensuring safe evacuation (Figure 1) (Oymakapu, 2019).

While preparing architectural plans containing evacuation plans, the provisions of the "Regulation on Fire Protection of Buildings (BYKHY)" are mainly used, which contain information about technical rules. The issue of reducing the risk of disasters by making emergency planning in buildings is an important parameter affecting the speed of social and economic development of developing countries. The emergency issue, which is within the scope of sustainable cities, is among the sustainable development targets of the countries.

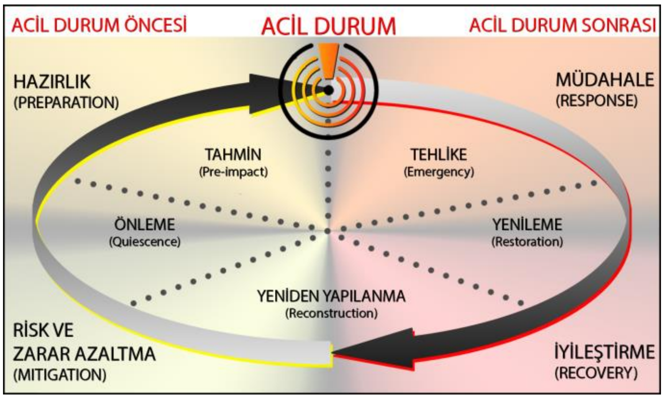

Figure 1: Emergency management phases (Oymakapu, 2019).

Sustainable Development and Emergency Management

Although the concept of sustainable development was first defined in the report prepared by the World Wildlife Fund (WWF) in 1980, when we look at the literature, in the Brundtland Report named "OurCommonFutureBrundtland Report" published in 1987 by the United Nations World Environment and Development Commission (WCED), defined as meeting today's needs, without compromising on the ability to meet (United Nations [UN], 1987). The United Nations Human Settlements Program has been established to create sustainable human settlements and take steps towards providing adequate housing for all (United Nations [UN], 1996). At the UN Housing and Sustainable Urban Development Conference held in Kito in 2016 by this program, an action plan on “Creating adequate housing and sustainable human settlements for everyone in the urbanized world” was adopted. In the United Nations Sustainable Development Summit organized by the United Nations in New York in 2015, they pointed out the necessity of determining sustainable development goals that will solve their existing problems. Seventeen main objectives, including the “Sustainable City and Living Spaces” target, have been adopted (United Nations [UN], 2016).

With the “Sustainable City and Living Spaces” target (Figure 2) set out in 2015, the “Urban Development Report” in 2016 shows that the building sector is the most crucial sector within this concept. Within the scope of the researches, it is determined that the studies on the local scale regarding the sustainability of the building sector are not sufficient. In the literature review conducted in this direction, in the study conducted by Taner (2019), he determined that his stakeholders in the building sector did not comply with the sustainable development goals. At the same time, it has been determined in the literature studies that local studies on the sustainability of the building sector are not sufficient. Earthquake and fire regulations are also included in the regulations, which inform the determining and restrictive rules when building architectural projects in the building sector.

92% of the territory specified in the earthquake zone in Turkey, there are many disasters, mainly earthquakes, likely to happen. Turkey, geological condition, topography and geographical location of frequent disasters due to natural disasters, although a country where there is not enough to prevent or to take actions. Also, the material and moral losses caused by emergencies arising from the human origin such as fire are quite high. Minimizing the economic and social losses of emergencies and reducing risks can be achieved through practical, sustainable development policies and strategies.

Figure 2: Sustainable development goals (United Nations [UN], 2016).

At the World Leaders Conference organized by the UN in South Africa in 2002, it was determined that one of the most important factors preventing sustainable development is natural disasters. As a result of the conference, it was decided that "countries should give importance and priority to the prevention of natural disasters and mitigation". As a result of the World Conference on Disaster Reduction organized by the United Nations Secretariat in Japan in 2005, "Development and strengthening of preparatory activities to respond to disasters on time, quickly and effectively" was requested.

There is both a positive and a negative relationship between disaster and emergency management and sustainable development. The adverse situation will inevitably arise if the balance is disturbed. If disaster and emergency management is not implemented, the rate of development will decrease, it cannot be sustainable, and consequently, negativities increase in case of emergency. If disaster and emergency management can be provided, the rate of development will increase. The result is two situations. In the first case, in development and sustainable cities, building production speed also increases. Awareness increases, disaster risk, can decrease. In the second case, the speed of building products in development and sustainable cities also increases. Unconscious structures increase skewed urbanization and disaster risk (Figure 3) (Ergünay 2009).

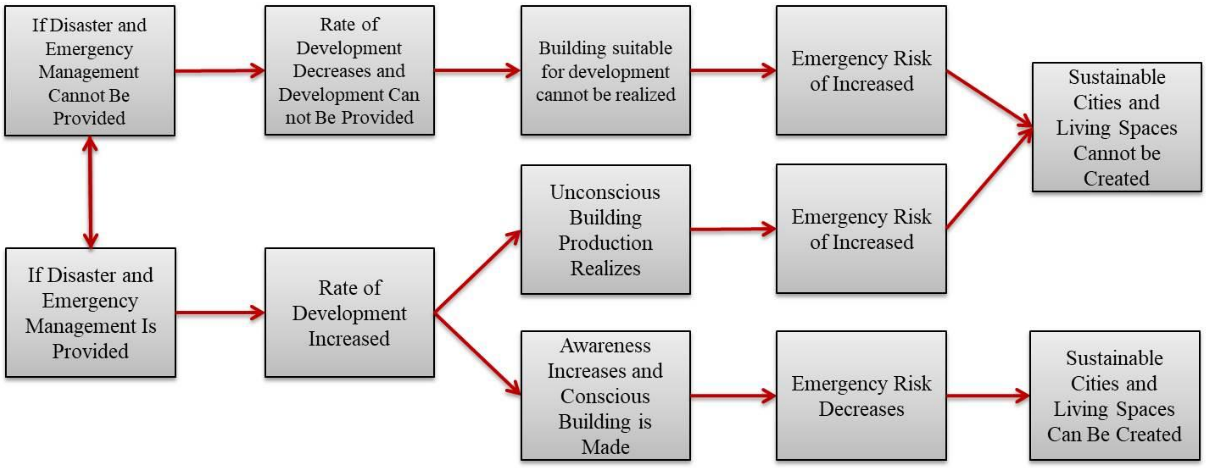

Figure 3: Sustainable development and emergency management relationship.

Sustainable Development and Education Buildings

In the Ninth Five-Year Development Plan in Turkey, targets for converting secondary education and higher education preparation courses to private schools have been determined. In 2014, as of September 1, 2015, the state decided to transform private teaching institutions into private schools. After the decision, many private teaching institutions, which are commercial buildings that were not designed as educational buildings, gained the identity of educational institutions. Transformed buildings are buildings that are compressed between buildings, without a garden area, which can cause problems in case of emergency (Özan et al., 2015). There are not only private teaching institutions within the scope of converted buildings. Buildings of different qualities such as offices, hotels and shopping malls are also converted into educational institutions.

Amendments were made to the "*Regulation on Private Education Institutions*" published in February 2020. Accordingly, private schools; It is defined as "*detached building (s) with a total of at least 500 m² gardens provided that it is at least two m² for each student outside the school area*". Besides, the floor plans should include "the plan of each floor, dimensions of the rooms and corridors and sketches of the fire ladder created following the provisions of the Regulation on Fire Protection of Buildings" (Gazete, 2020). According to the article 151 of the Regulation on the Protection of Buildings from Fire; It is necessary to determine the "emergency assembly area" within the building area to the distance of "an open area at least 15 meters away from the building point not less than the height of the building" from the building point (BYKHY, 2007). These conditions must be met in all transformed educational buildings.

Case Study

According to the official figures, there are 395 Primary Schools, 337 Secondary Schools, 214 Secondary Schools in total, 946 Schools. A total of 275,072 students' study in 11,406 classrooms, and 18,269 teachers work in school buildings (T.C. Kayseri Valiliği, 2018). In intensive use education structures, precautions to be taken against emergencies are very important. Considering that the majority of users are children under the age of 18, it is clear that emergency escape routes should be easily accessible and safe areas. Projects that are not designed as educational buildings and converted from different types of projects into education buildings become places that threaten security in case of emergency.

In the field study, 4 private schools located within the boundaries of central districts Melikgazi, Kocasinan and Talas, on-site observations were made, and their compliance with fire regulations was examined. The first example of the schools selected for the study is a school designed as an educational building on the education parcel. The second school was designed as a residential building and turned into a school after residence permit. While the third school was used as an industrial building, it was transformed into a school structure. The fourth school is an educational building converted from the post-2015 school to school (Table 1).

Table 1. Schools examined in the field study.

SCHOOLS	LOCATION	FIELD QUALITY	FIRST TYPE OF USE OF THE BUILDING	CURRENT EDUCATION PROGRAM
TYPE A SCHOOL	TALAS	FOUR-FLOOR CONCRETE SCHOOL	-	KINDERGARTEN-PRIMARY SCHOOL-SECONDARY SCHOOL-ANATOLİAN HİGH SCHOOL-SCIENCE HİGH SCHOOL
TYPE B SCHOOL	MELİKGAZİ	TEN FLOOR APARTMENT AND LAND	RESIDENTAL	ANATOLİAN HİGH SCHOOL
TYPE C SCHOOL	KOCASİNAN	MASONRY OFFICE BUILDING	COMMECIAL BUILDING	KINDERGARTEN-PRIMARY SCHOOL-SECONDARY SCHOOL
TYPE D SCHOOL	KOCASİNAN	FIVE FLOOR CONCRETE BUILDING	PRİVATE TEACHİNG İNSTİTUTİONS	ANATOLİAN HİGH SCHOOL

Within the framework of sustainable development, education buildings should be ensured to be suitable for emergencies. The research aims to guide local and national administrations, school administrations and designers and contribute to the field in order to create emergency action plans in order to ensure environmental, economic and social sustainability.

Findings

According to the research carried out on educational buildings, TYPE A School was placed on the education parcel. It is a formal educational institution serving in 4 different programs: kindergarten, primary school, secondary school and high school. There is a building for each program. The school consists of 2 basements, ground floor and 1st floor and has a quota of 725 people. The school has a large garden area following the regulations—the locations of the emergency assembly area where deemed appropriate. There is an emergency evacuation plan and plan sketches in the school that are visible to everyone (Figure 4-5-6).

Figure 4: School entrance and garden.

Figure 5: Emergency assembly area.

Figure 6: Emergency evacuation plan.

Fire escape dimensions, corridor dimensions, step width dimensions and fire cabinet height are following the regulation. Although the emergency direction signs used are in the correct position, they are not used numerically at specific distance intervals in the main corridors. It is seen that the handrail is not placed against the railing (Figure 7-8-9-10).

Figure 7: Fire escape.

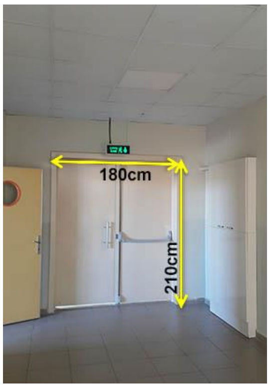

Figure 8: Fire exit.

Figure 9: Fire cabinet.

Figure 10: Corridors of classrooms.

TYPE B School: It was transformed into a school building providing high school education by replacing an existing building on the residential parcel (Figure 11). The structure of the building, which consists of a total of 10 floors, basement, ground floor and eight floors, has 330 students. While the building was transforming into a school, a fire escape was added following the educational building regulations. The new staircase was built too close to the residential building in the north of the building. The floor height of the building is not suitable for the educational building (Figure 12-13-14).

The school does not have a sketch plan showing the emergency action plan, in a location where everyone can be seen. The school has no garden area in the appropriate square meter. For this reason, the emergency assembly area could not be located at the correct distance (Figure 15). While the width of the preserved steel fire stairs added to the building after the conversion to the school is 150cm, the width of the existing staircase is 120cm. It should be at least 180cm according to the school quota. (Figure 16-17). Stair Railing seems appropriate, but there is no handrail at the edge of the wall. Fire cabinet height and fire doors are not selected in appropriate sizes. Corridors and emergency signs were found to be in the correct position and size (Figure 18).

Figure 11: Preschool status of the building.

Figure 12: Added staircase as it turns into a school building.

Figure 13: School's entrance.

Figure 14: School escape gate.

Figure 15: Emergency assembly area.

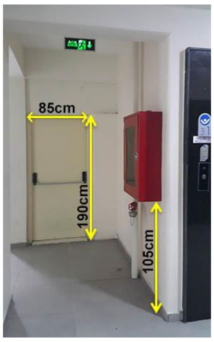

Figure 16: Fire cabinet.

Figure 17: Fire escape.

Figure 18: The main stairs.

TYPE C School: It is a structure consisting of four floors, basement, ground and two floors, which are converted into the school area of the existing workplace. The school, which serves in kindergarten, primary and secondary school programs, has a quota of 400 people (Figure 19-20-21). The school does not have a garden area, so there is no emergency meeting area at the appropriate location. The distances of the main corridors are compatible with the regulation (Figure 22). There is no emergency evacuation plan in the corridors.

Figure 19: Schoolyard.

Figure 20: School's entrance.

Figure 21: Schoolyard.

Figure 22: Corridors of classrooms.

While the building is being converted into a school, escape doors with appropriate dimensions were added. However, it has been determined that fire exit doors have been added to unusable places only in order to comply with the legislation (Figure 23). Step widths and qualities of fire stairs, fire cabinet locations do not comply with the regulation—the presence of a column at the point where the ladder descends further increases the mistake. The stairway width, railing, handrail heights and corridor distances are suitable (Figure 24-25-26).

Figure 23: Fire exit.

Figure 24: The main stairs.

Figure 25: Fire escape.

Figure 26: Fire cabinet.

TYPE D School is located in a busy city centre. The adjacent building has no garden area and emergency assembly area. The school consists of 6 floors, basement, ground floor and four floors and has a quota of 300 people. While the building was used as private teaching institutions, as a result of educational policies, it was transformed into an educational institution providing high school education. A steel fire escape was added to the building during the transformation envelope. However, since the staircase is in the back garden, access to the entrance cannot be provided (Figure 27-28-29). There are sufficient floor corridors in the building (Figure 30).

Figure 27: School's entrance.

Figure 28: Schoolyard.

Figure 29: Added steel staircase.

Figure 30: Corridors of classrooms.

The stairway fire doors have been removed after the dwelling; the door frames remain in place. The fire escape door remains in place (Figure 31-32). The width of the corridor reaching the fire door is not enough. Stairstep widths, balanced stairs, lack of handrails do not comply with the regulation. There is no fire extinguisher on the floors. The floor map is hanging on the wall, but its juxtaposition with the electrical contact increases the risk of emergency (Figure 33-34).

Figure 31: Removed fire door leaf and location.

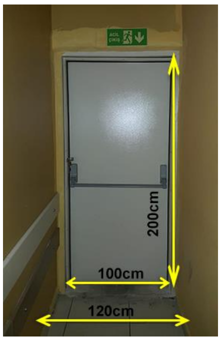

Figure 32: Fire exit and corridors.

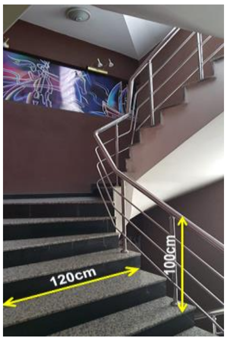

Figure 33: Fire escape.

Figure 34: Emergency evacuation plan.

Conclusion

The data in Table 2 emerge when the researches conducted over 4 special education institutions in Kayseri are evaluated according to the Regulation on Fire Protection of Buildings. Accordingly, it has been determined that problems related to fire regulations are more intense in educational institutions that are converted or changed. Structures that are constructed in a suitable location on the training plot and with few floors in the area may produce positive results in an emergency situation such as fire.

Tablo 2. Evaluation of the determined educational buildings according to the regulation on the protection of buildings from fire.

EVALUATION CRITERIA OF SCHOOLS			TYPE A SCHOOL	TYPE B SCHOOL	TYPE C SCHOOL	TYPE D SCHOOL
REGULATION ON THE PROTECTION OF BUILDINGS FROM FIRE	FIRE ESCAPE STEP WIDTH (150 cm)	<150 cm			✓	✓
		≥150 cm	✓	✓		
	FIRE ESCAPE RAILINGS	RAILING	✓	✓	✓	✓
		HANDRAIL			✓	
	EMERGENCY ASSEMBLY AREA PICTOGRAMS	EXISTING	✓	✓		
		APPROPRIATE LOCATION	✓			
	FIRE EXIT(min 80/200)	<80/200 cm		✓		
		≥80/200 cm	✓		✓	✓
	FIRE EXIT (min 80/200)	OPENING BY HAND (PANIC-BAR)	✓	✓	✓	✓
		LOCKED STAY				✓
	FIRE CABINET HEIGHT (120cm)	=120 cm	✓			
		>120 cm, <120 cm		✓	✓	
	EMERGENCY ESCAPE CORRIDOR SIZE (150cm)	<150 cm				
		≥150 cm,	✓	✓	✓	✓
	EMERGENCY GUIDED LIGHT PICTOGRAMS	H:15cm	✓	✓	✓	✓
		SUITABLE DISTANCE AND NUMBER		✓	✓	✓
	THE CASE OF PLAN SKETCHES, IMPORTANT FOR EMERGENCIES, IN THE CORRIDORS		✓			✓

The increase in the quality and quantity of educational buildings is a result that positively affects development. However, the fact that the increases are implemented in an uncontrolled manner with incorrect strategic plans prepares the ground for negative consequences in case of emergencies. The emergence of risk situations in emergency and disaster management prevents sustainable development. For this reason, structures that comply with the regulations must be produced during the construction and implementation process of educational buildings. The accredited institutions must apply supervision and sanctions.

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An Investigation on Benefit-Cost Analysis of Greenhouse Structures in Antalya

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Abstract

Significant population increase across the world, loss of cultivable land and increasing demand for food put pressure on agriculture. To meet the demand, greenhouses are built, which are, light structures with transparent cladding material in order to provide controlled microclimatic environment proper for plant production. Conceptually, greenhouses are similar with manufacturing buildings where a controlled environment for manufacturing and production have been provided and proper spaces for standardized production processes have been enabled. Parallel with the trends in the world, particularly in southern regions, greenhouse structures have been increasingly constructed and operated in Turkey. A significant number of greenhouses are located at Antalya. The satellite images demonstrated that for over last three decades, there has been a continuous invasion of greenhouses on all cultivable land. There are various researches and attempts for the improvement of greenhouse design and for increasing food production by decreasing required energy consumption. However, the majority of greenhouses in Turkey are very rudimentary structures where capital required for investment is low, but maintenance requirements are high when compared with new generation greenhouse structures. In this research paper, life-long capital requirements for construction and operation of greenhouse buildings in Antalya has been investigated by using benefit-cost analysis study.

Keywords: *solar greenhouse structures, benefit-cost analysis, solar greenhouses in Antalya*

Introduction

Massive increase in world population, shortage of water and loss of cultivable farm lands cause higher demand in food production and need for higher amount of food (Esmaeli & Roshandel, 2020). It has been assumed that by 2050 the world population will be reached to 9.1 billion and to feed this population, it is required to 70% increase current food production (Blakeney, 2019). Together with increasing pressure on need for higher amount of food, it has been revealed that traditional farming techniques cannot fulfil the requirements of market. Solar greenhouses were introduced earlier as a concept proposed for providing a rapid solution by transforming traditional farming lands to transparently covered light structures for enabling more stable and controllable microclimate proper for growth of plants (Choab et al., 2019; Esmaeli &

Roshandel, 2020; Yilmaz et al., 2005) There are various parameters affecting solar greenhouse design. These are climate, plant type, soil, shape of the greenhouse, cladding material and orientation. Crops are continuously harvested in each production cycle (Choab et al., 2019; Yilmaz et al., 2005).

Especially some agricultural lands are transformed into solar greenhouse fields to have an appropriate environment with small investments to construct and operate. These transformation processes within these fields preserve certain problems related with not only environment of the fields but also the quality of the foods (Tüzel et al., 2018). Some of these shortcomings were noticed in literature but these hazards generally focus on healthy of food and earth due to contaminants released by materials used in not only construction of greenhouse but also additives to feed the plants during the crop yield. However, other environmental impacts of these built structures were ignored or put at to the background.

Compared with traditional farming in which there is one season crop, solar greenhouse structures enable two crop yield. One crop yield uses the soil a short time in a year and the remaining time is used for resting of the soil. During this resting time, the soil regains its nutrients in natural ways. However, when second or more crop yields are introduced by greenhouses, it has been experienced that timely the soil within the greenhouse has not regain necessary nutrients from nature. Therefore, additives and fertilizers are introduced to support the soil nutrients. Together with other problems, these additives and fertilizers cause hazardous pest contamination and due to that reason, pesticides are used for these purposes. However, long term use of these pesticides represents hazardous situations for not only soil but also humans fed by these products. Soil includes lots of components and particles necessary for livings. Involvement of these fertilizers and other additives are also negatively affecting other components within the soil.

Regarding the aforementioned limitations on increasing the crop yield by soil, new farming methods are introduced eliminating usage of soil to grow the plants. Although research about soilless farming go backs to 19th century, in the 1990s, it has gained popularity and various greenhouses were constructed to produce crops without using soil. Instead of soil, water or roots of some plants are used. Necessary nutrients for growth of the plants are provided by a water mixture. Together with more efficient irrigation system, soilless food production increases the crop amount collected from unit area. Furthermore, at the following phases of soilless farms, expansion of plantation has gained vertical dimension and called as vertical farming.

Turkey is the 5th fruit and 4th vegetables producer in the world in terms of total production (BÜGEM, 2017). Majority of the production comes from solar greenhouses. The solar greenhouses in Turkey can be divided into two categories regarding their technology involvement and farming concept. These are (i) traditional, short term usage greenhouse structures and (ii) high technology – long term usage greenhouse structures (BÜGEM, 2017). Market of the first category is domestic markets with 80% ratio while market of the second category is totally international markets. This is due to fact that, the foods produced by first category greenhouses cannot fulfil the standards and requirements depicted by other countries. In other words, domestic foods have not proper quality for exportation. On the other hand, foods of second category greenhouses are sustaining certain level of quality by the opportunities of higher amount of technology involved contemporary farming techniques and thus successfully maintaining their exportation. For vulnerable Turkish economy, exportation and foreign currency brought by the exportation is much more valuable than domestic trade.

Considering its life-cycle, a greenhouse can be designed for long-term or short-term investments policies (Benli, 2020; BÜGEM, 2017; Yilmaz et al., 2005). Long-term policies include, smaller operation cost of greenhouses by making higher amount of investment for design and construction. Short-term policies, on the other hand; require small amount of investment for design and construction while relying upon higher amount of operation cost. Furthermore, renovation period of greenhouse cladding materials of short-term policies are also shorter than cladding materials of long-term policy greenhouse projects. Microclimatic conditions inside the greenhouse is controlled by computerized systems in long-term policy greenhouses while farmers manually check and control the microclimatic conditions in short-term policy greenhouses. The literature indicates that the majority of the greenhouses in these Mediterranean regions of Turkey are within short-term policy greenhouses (Benli, 2020; BÜGEM, 2017; Yilmaz et al., 2005). However, these greenhouses are lack of efficient operation system causing not only higher amount of operation cost during heating and cooling the indoor environment of the greenhouses but also environmental impact due to use of fossil-based cooling and heating system (Yilmaz et al., 2005).

Since 1990s, the total solar greenhouses in Turkey has doubled (BÜGEM, 2017). Especially majority of solar greenhouses are located in Antalya by having 40% of the total greenhouses in Turkey (BÜGEM, 2017). Turkey is the second country among Mediterranean countries and fourth country in the world by having 700,000 decare of solar greenhouse area (BÜGEM, 2017). Food production was 7.17 million tones with providing 13.5 billion Turkish Lira economic income in 2016 (BÜGEM, 2017). Southern region of Turkey has proper environment for solar greenhouses due to high amount of annual daylight illumination and having warm climatic conditions in all around the year. Thus Antalya, Mersin and Adana provinces have capacity of more than 70% of total greenhouses in Turkey. Majority of the greenhouses in these regions are short-term greenhouses and 80%-85% of their production are consumed in domestic market. Satellite images presented in Figure 1 demonstrated these massive solar greenhouse transformations between 1980 and 2020 in Antalya. The dense construction of the greenhouse structures changes the built environment at located region.

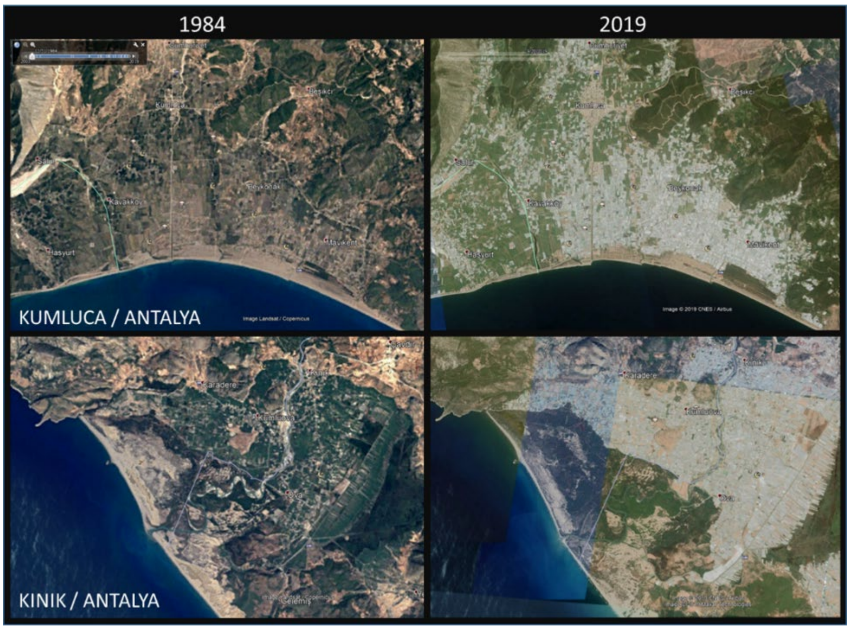

Figure 1: Satellite images illustrating farming land transformation in Kumluca and Kınık.

Problem Statement

Majority of the greenhouses are short-term policy greenhouses in Antalya and neighboring cities. The farmers choose short-term policy greenhouses for their low initial construction cost. However, long-term maintenance cost of short-term policy greenhouses are not clearly stated in literature. This means that existing greenhouse transformation occurs for short-term benefits without knowing neither long-term cost nor environmental impacts. Considering the gap in this field, a benefit-cost assessment study has conducted for sample greenhouse structures located at Antalya in order to unveil both short-term and long-term cost impact of short-term policy greenhouses.

Aim & Objective

The aim of the study is unveiling short term and long term performance of the existing greenhouse structures located at Antalya in order to not only assess cost of the structures but also user benefits and outputs of the structures to environment. The objective of the research is presented as follows:

- Analyzing both construction and operation cost items of the greenhouse structures
- Finding maintenance period of the structures
- Determining short-term and long-term performance of the structures
- Evaluating environmental impact of the structures in short-term and long-term performances

Research Method

There are two methods used for assessing cost performance of a project. Benefit-Cost Analysis (BCA) and Life-Cycle Cost Analysis (LCCA). LCCA is a subset of BCA (U.S. Department of Transportation, 2002). BCA is more comprehensive in terms of evaluating impact of the project to both user and environment while LCCA is focusing on only cost of the project. The primary objective of major ratio of greenhouse farmers to choose short-term policy greenhouse structures is to achieving low initial construction cost. When, farmer objective is considered, LCCA is the proper tool. However, goal of this study, is not only unveiling short-term and long-term cost performance of the greenhouses but also assessing user benefit and various outputs of the greenhouse structures. Thus, Benefit-Cost Analysis (BCA) is the proper analysis method to be used in this research. A research framework has established and implemented for this study as stated at Figure 2. Four greenhouse structures located at Antalya are randomly found and their construction and operation information are collected. After construction and maintenance cost items are described, their cost definitions and expenditures are retrieved from governmental sources. The cost items, definitions and codes are annually published by various governmental institutions. Then, regarding the maintenance period, initial construction cost, ten years, thirty years and fifty years performance costs of the construction items are listed and described. At the last step, the findings of the study are evaluated.

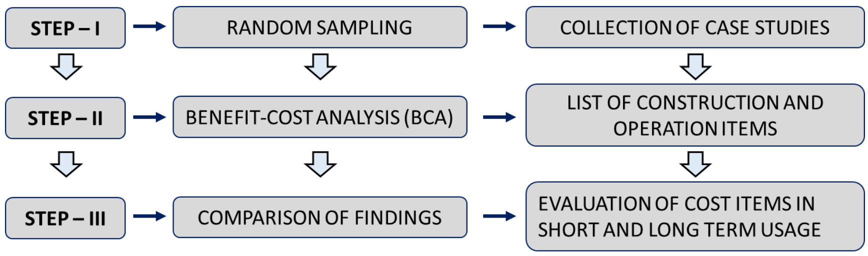

Figure 2: Research framework of the study.

Benefit-Cost Assessment (BCA) versus Life-Cycle Cost Assessment (LCCA)

LCCA is a tool used to compare costs of competing alternatives. LCCA is a subset of BCA, an economic analysis tool that includes the comparison of benefits as well as costs in selecting optimal alternatives. LCCA is used when the project is decided to be undertaken and is looked for most cost-effective means to accomplish the project objective. Use of LCCA is proper only the project implementation alternatives would yield same level of services and benefits to the project user. For example LCCA is an appropriate tool to use when comparing two alternatives to replace a greenhouse structures that has reached the end of its service life, where each design alternative will result in the same level of service to the user. Costs taken into account in LCCA is typically include expenses to the owner such as construction, operation and maintenance costs. Unlike LCCA, BCA considers the benefits of an improvement as well as its costs and, therefore; can be used to compare design alternatives that do not yield identical benefits together with comparing projects that accomplish different objectives. Benefits measured in BCA are typically those associated with the desired results of the projects. From this perspective, LCCA is a cost-centric approach used to select the most cost-effective alternative that accomplishes a preselected project at a specific level of benefits that is assumed to be equal among project alternatives being considered. BCA, on the other hand; is the proper tool to use when design alternatives will not yield equal benefits. The elements typically considered in BCA and LCCA are illustrated at Figure 3. Therefore, BCA considers also user benefits and externalities resulting from project while LCCA is consider only construction, maintenance and operation costs items.

PROJECT ELEMENTS	LCCA	BCA
CONSTRUCTION, REHAILITATION AND MAINTENANCE EXPENDITURES	✓	✓
USER COSTS DURING CONSTRUCTION, REHABILITATION OR MAINTENANCE	✓	✓
USER COSTS DURING NORMAL OPERATIONS	✓	✓
USER BENEFITS RESULTING FROM PROJECT	X	✓
EXTERNALITIES RESULTING FROM PROJECT	X	✓

Figure 3: Comparison of analysis elements of LCCA and BCA. Source: (U.S. Department of Transportation, 2002).

Benefit-Cost Analysis Study

BCA study has implemented regarding the implementation step as demonstrated at Figure 4. These are collection of alternative greenhouse structures, acquire of construction and maintenance costs, computation of life-cycle costs, describe of potential benefits and analyzing the results. The following sample greenhouse structures are studies considering this implementation steps.

BENEFIT-COST ANALYSIS IMPLEMENTATION STEPS:
- ACQUIRE ALTERNATIVE GREENHOUSE STRUCTURES
- DETERMINE CONSTRUCTION, SERVICE & MANITENANCE LIFE OF BUILDING COMPONENTS
- DETERMINE COSTS
- COMPUTE LIFE-CYCLE COSTS
- DETERMINE POTENTIAL BENEFITS
- ANALYZE THE RESULTS

Figure 4: BCA implementation steps. Adopted from: (U.S. Department of Transportation, 2002).

Greenhouse Structure #1

The greenhouse structure of #1 has 22,8 by 50 m area with 2 m tunnel height as illustrated at Figure 5. The structure is made of light steel structure covered with metal paint. The cladding material is plastic sheet. The construction cost items and maintenance period of them are presented at Table 1. Life-cycle costs of construction items with respect to the maintenance period of the construction items of Greenhouse #1 is stated at Table 2. The ten, thirty and fifty year's performance of the cost items are considered for the analysis. As a result of the study, cost of maintenance of construction components of greenhouse #1 is 58,8%, 198,4% and 353,9% of initial construction cost.

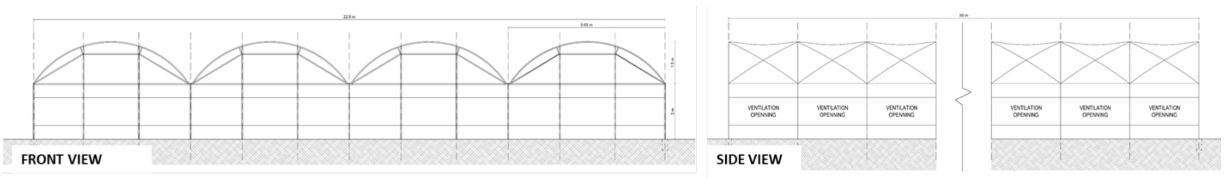

Figure 5: Dimensions of Greenhouse Structure #1.

Table 1. Construction and maintenance cost requirements of Greenhouse #1.

Ministry Code	Explanation	Amount	Unit	Unit Price	Cost	Maintenance Requirement
Special – 1	Plastic Greehnouse Cladding	1800	m2	3.75	**6,750 ₺**	3 years cycle
Special – 2	Greenhouse Gutter	156	mt	30	**4680 ₺**	50 years
15.165.1001	Steel construction of greenhouse structures	1.88	ton	7695.99	**14,468 ₺**	No Maintenance Requirement
15.540.1103	Two layered epoxy paint application to Steel Components	124.53	m2	37.46	**4,665 ₺**	5 years cycle
15.150.1101	C 8/10 type concrete pouring at construction site.	11.68	m3	265.55	**3,101 ₺**	No Maintenance Requirement
15.180.1002	Wood formwork for greenhouse footings	116.8	m2	63.98	**7,472 ₺**	No Maintenance Requirement
15.120.1001	Excavation work for footing of greenhouse structure	226	m3	5.46	**1,234 ₺**	No Maintenance Requirement
Total					**42,370 ₺**	

Table 2. Life-cycle costs of construction items of Greenhouse #1.

Ministry Code	Explanation	Initial Cost	Cost for 10 years	Cost for 30 years	Cost for 50 years
Special – 1	Plastic Greehnouse Cladding	6,750 ₺	20,250 ₺	67,500 ₺	108,000 ₺
Special – 2	Greenhouse Gutter	4680 ₺	No Maintenance	No Maintenance	No Maintenance
15.165.1001	Steel construction of greenhouse structures	14,468 ₺	No Maintenance	No Maintenance	No Maintenance
15.540.1103	Two layered epoxy paint application to Steel Components	4,665 ₺	9,330 ₺	27,990 ₺	46,650 ₺
15.150.1101	C 8/10 type concrete pouring at construction site.	3,101 ₺	No Maintenance	No Maintenance	No Maintenance
15.180.1002	Wood formwork for greenhouse footings	7,472 ₺	No Maintenance	No Maintenance	No Maintenance
15.120.1001	Excavation work for footing of greenhouse structure	1,234 ₺	No Maintenance	No Maintenance	No Maintenance
Total		42,370 ₺	67,285 ₺	126,445 ₺	192,355 ₺
Change Ratio		%0	%58.8	%198.4	%353.9

Greenhouse Structure #2

The greenhouse structure #2 has 27 by 70 m area with 2,5 m tunnel height as illustrated at Figure 6. The structure is made of light steel structure covered with hot-dip galvanized paint. The cladding material is plastic sheet. The construction cost items and maintenance requirement of them are presented at Table 3. Life-cycle costs of construction items with respect to the maintenance period of the construction items of Greenhouse #2 is stated at Table 4. The ten, thirty- and fifty-years performance of the cost items are considered for the analysis. As a result of the study, cost of maintenance of construction components of greenhouse #2 is 4,5%, 18,3% and 38,6% of initial construction cost.

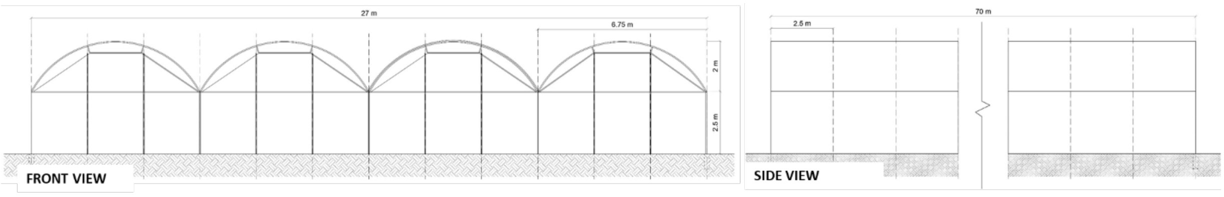

Figure 6: Dimensions of Greenhouse Structure #2.

Table 3. Construction and maintenance cost requirements of Greenhouse #2.

Ministry Code	Explanation	Amount	Unit	Unit Price	Cost	Maintenance Requirements
Special – 1	Plastic Greehnouse Cladding	2694	m2	3.75	10,102 ₺	6 years cycle
Special – 2	Greenhouse Gutter	216	mt	30	6,480 ₺	50 years cycle
15.165.1001	Steel construction of greenhouse structures	13.349	ton	7695.99	102,734 ₺	No Maintentance Requirments
V.0720	Hot-dip galvanizing of steel components	13,349	kg	5.43	72,485 ₺	50 years cycle
15.150.1101	C 8/10 type concrete pouring at construction site.	30	m3	265.55	7,966 ₺	No Maintentance Requirments
15.180.1002	Wood formwork for greenhouse footings	300	m2	63.98	19,194 ₺	No Maintentance Requirments
15.120.1001	Excavation work for footing of greenhouse structure	302	m3	5.46	1,649 ₺	No Maintentance Requirments
Total					220,610 ₺	

Table 4. Life-cycle costs of construction items of Greenhouse #2.

Ministry Code	Explanation	Initial Cost	Cost for 10 years	Cost for 30 years	Cost for 50 years
Special – 1	Plastic Greenhouse Cladding	10,102 ₺	20,204 ₺	50,510 ₺	90,918 ₺
Special – 2	Greenhouse Gutter	6,480 ₺	No Maintenance	No Maintenance	No Maintenance
15.165.1001	Steel construction of greenhouse structures	102,734 ₺	No Maintenance	No Maintenance	No Maintenance
V.0720	Hot-dip galvanizing of steel components	72,485 ₺	No Maintenance	No Maintenance	No Maintenance
15.150.1101	C 8/10 type concrete pouring at construction site.	7,966 ₺	No Maintenance	No Maintenance	No Maintenance
15.180.1002	Wood formwork for greenhouse footings	19,194 ₺	No Maintenance	No Maintenance	No Maintenance
15.120.1001	Excavation work for footing of greenhouse structure	1,649 ₺	No Maintenance	No Maintenance	No Maintenance
Total		220,610 ₺	230,712 ₺	261,018 ₺	301,426 ₺
Change Ratio		%0	%4.5	%18.3	%36.6

Greenhouse Structure #3

The greenhouse structure #3 has 11 by 70 m area with 1,5 m tunnel height as illustrated at Figure 7. The structure is made of light steel structure covered with industrial paint. The cladding material is single pane glass. The construction cost items and maintenance requirements of them are presented at Table 5. Life-cycle costs of construction items with respect to the maintenance period of the construction items of Greenhouse #3 is stated at Table 6. The ten, thirty and fifty year's performance of the cost items are considered for the analysis. As a result of the study, cost of maintenance of construction components of greenhouse structure #3 is 11,8%, 59% and 106,3% of initial construction cost.

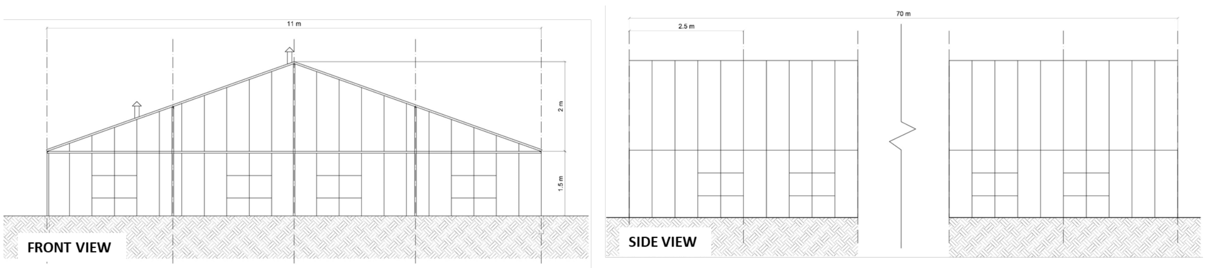

Figure 7: Dimensions of Greenhouse Structure #3.

Table 5. Construction and maintenance cost requirements of Greenhouse #3.

Ministry Code	Explanation	Amount	Unit	Unit Price	Cost	Maintenance Requirements
15.165.1001	Steel construction of greenhouse structures	5.849	ton	7695.99	45,014 ₺	No Maintenance Requirement
15.540.1103	Two layered epoxy paint application to steel components	383.84	m2	37.46	14,379 ₺	5 years cycle
28.063/1	5 mm glazing of steel frames	1075	m2	48.5	52,137 ₺	No Maintenance Requirement
15.150.1101	C 8/10 type concrete pouring at construction site.	6.8	m3	265.55	1,805 ₺	No Maintenance Requirement
15.180.1002	Wood formwork for greenhouse footings	129.76	m2	63.98	8,302 ₺	No Maintenance Requirement
15.120.1001	Excavation work for footing of greenhouse structure	6.65	m3	5.46	36 ₺	No Maintenance Requirement
Total					121,673 ₺	

Table 6. Maintenance requirements of construction items of Greenhouse #3.

Ministry Code	Explanation	Initial Cost	Cost for 10 years	Cost for 30 years	Cost for 50 years
15.165.1001	Steel construction of greenhouse structures	45,014 ₺	45,014 ₺	45,014 ₺	45,014 ₺
15.540.1103	Two layered epoxy paint application to steel components	14,379 ₺	28,758 ₺	86,274 ₺	143,790 ₺
28.063/1	5 mm glazing of steel frames	52,137 ₺	52,137 ₺	52,137 ₺	52,137 ₺
15.150.1101	C 8/10 type concrete pouring at construction site.	1,805 ₺	1,805 ₺	1,805 ₺	1,805 ₺
15.180.1002	Wood formwork for greenhouse footings	8,302 ₺	8,302 ₺	8,302 ₺	8,302 ₺
15.120.1001	Excavation work for footing of greenhouse structure	36 ₺	36 ₺	36 ₺	36 ₺
Total		121,673 ₺	136,052 ₺	193,568 ₺	251,084 ₺
Change Ratio		%0	%11.8	%59	%106.3

Greenhouse Structure #4

The greenhouse structure #4 has 17,2 by 22,5 m area with 1,7 m tunnel height as illustrated at Figure 8. The structure is made of light steel structure covered with industrial paint. The cladding material is single pane glass. The construction cost items and maintenance requirements of them are presented at Table 7. Life-cycle costs of construction items with respect to the maintenance period of the construction items of Greenhouse #3 is stated at Table 8. The ten, thirty and fifty year's performance of the cost items are considered for the analysis. As a result of the study, cost of maintenance of construction components of greenhouse structure #3 is 11,72%, 58,6% and 105,5% of initial construction cost.

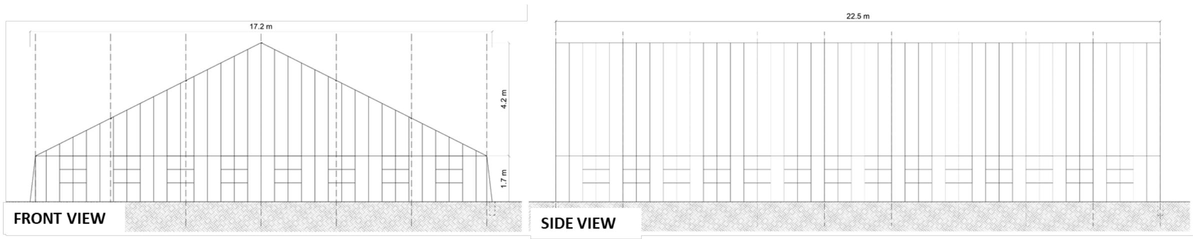

Figure 8: Dimensions of Greenhouse Structure #4.

Table 7. Construction and maintenance cost requirements of Greenhouse #4.

Ministry Code	Explanation	Amount	Unit	Unit Price	Cost	Maintenance Requirements
15.165.1001	Steel construction of greenhouse structures	3.47884	ton	7695.99	26,774 ₺	No Maintenance Requirements
15.540.1103	Two layered epoxy paint application to steel components	229.84	m2	37.46	8,610 ₺	5 years cycle
28.063/1	5 mm glazing of steel frames	632	m2	48.5	30,652 ₺	No Maintenance Requirements
15.150.1101	C 8/10 type concrete pouring at construction site.	7.94	m3	265.55	2,108 ₺	No Maintenance Requirements
15.180.1002	Wood formwork for greenhouse footings	79.4	m2	63.98	5,080 ₺	No Maintenance Requirements
15.120.1001	Excavation work for footing of greenhouse structure	39.4	m3	5.46	215 ₺	No Maintenance Requirements
Total					73,439 ₺	

Table 8. Life-cycle costs of construction items of Greenhouse #4.

Ministry Code	Explanation	Initial Cost	Cost for 10 years	Cost for 30 years	Cost for 50 years
15.165.1001	Steel construction of greenhouse structures	26,774 ₺	26,774 ₺	26,774 ₺	26,774 ₺
15.540.1103	Two layered epoxy paint application to steel components	8,610 ₺	17,220 ₺	51,660 ₺	86,100 ₺
28.063/1	5 mm glazing of steel frames	30,652 ₺	30,652 ₺	30,652 ₺	30,652 ₺
15.150.1101	C 8/10 type concrete pouring at construction site.	2,108 ₺	2,108 ₺	2,108 ₺	2,108 ₺
15.180.1002	Wood formwork for greenhouse footings	5,080 ₺	5,080 ₺	5,080 ₺	5,080 ₺
15.120.1001	Excavation work for footing of greenhouse structure	215 ₺	215 ₺	215 ₺	215 ₺
Total		73,439 ₺	82,049 ₺	116,489 ₺	150,929 ₺
Change Ratio		%0	%11.72	%58.6	%105.5

Findings

The findings of the initial construction costs, 10, 30 and 50 years operation costs of construction items of greenhouse structures are presented and compared at Table 9. It has been revealed that, painting type and cladding material selection are the two components have major impact on operation costs of the greenhouse structures. The greenhouse structure #1 uses plastic sheet covering and metal painting present a performance that after 10 years usage, maintenance cost of the structure doubled its initial construction cost while this ratio is not high even 50 years performance is achieved when steel components are covered with hot-dip galvanizing method. When glass panel covering is used instead of plastic sheet as used in Greenhouse Structure #3 & 4, cost of painting in 50 years performance is more than initial construction cost.

Table 9. Comparison table of greenhouse structures regarding their initial construction costs, 10 years, 30 years and 50 years performance costs.

	Investment Cost of Initial Construction	Investment Cost for 10 years Operation	Investment Cost for 30 years Operation	Investment Cost for 50 years Operation
Greenhouse #1 (Plastic Sheet Cladding)	37.16 TL/m²	59.02 TL/m²	110.91 TL/m²	168.73 TL/m²
	%0	%58.82	%198.4	%353.9
Greenhouse #2 (Plastic Sheet Cladding)	116.72 TL/m²	122.06 TL/m²	138.10 TL/m²	159.48 TL/m²
	%0	%4.57	%18.3	%36.63
Greenhouse #3 (Glass Panel Cladding)	158 TL/m²	176.69 TL/m²	251.38 TL/m²	326.08 TL/m²
	%0	%11.8	%59	%106.3
Greenhouse #4 (Glass Panel Cladding)	189.76 TL/m²	212.01 TL/m²	301 TL/m²	389.99 TL/m²
	%0	%11.72	%58.6	%105.5

Potential Benefits

Low maintenance period of greenhouse construction items not only consume time and effort but also cause waste of the material. In a 50 years' service life, accepting that a plastic sheet service life is 3 years, it is necessary to renew plastic sheet 17 times. This means that there will be 17 m2 waste for each unit area of greenhouse structures. Furthermore, regarding that, service life of metal paint is 5 years, it is necessary to renew the metal paint 10 times in 50 years' service life of a greenhouse structures. Although initial construction cost has decreased by using metal paint and plastic sheet covering in greenhouse structures, both maintenance costs and environmental impact of the greenhouse structures has increased. Nevertheless, regarding the investment cost for 50 years operation, still, plastic sheet covered greenhouse structures are cheaper options than glass panel cladded greenhouse structures as illustrated at Table 13.

Conclusion

As a result of the study, maintenance costs of various types of greenhouse structures located at Antalya has been examined, their initial construction costs and maintenance costs for 10, 30- and 50-years' service life has illustrated. The cost-benefit analysis indicated that although initial construction cost of plastic sheet covering is cheaper option for investors than glass panel cladding, its maintenance costs over initial construction costs and environmental impact has more than plastic sheet cladding options. Accepting that majority of the farmer has capital shortage in Turkey, plastic sheet covered greenhouse structures will be remained cheaper options. In the coming future, regarding the plastic sheet consumption in agricultural greenhouse market, it is likely to confront with environmental impacts of the solar greenhouses. This study can be expanded by including energy requirements of each greenhouse structure types.

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Use of the Design Structure Matrix During the Construction Phase of Building Production Process in Turkey

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Abstract

This paper aims to investigate several process development models and finally focus on the Design Structure Matrix which is one of most up to date methods. It can be seen that the use of the DSM not only benefits the real estate development project in whole, but also enhances the construction phase of the building production by providing clear planning of the process, by defining relationships between actors and tasks, by the ability to see future risks and agility in taking action in unexpected scenarios during construction phase. In order to use the DSM in Turkey during the construction phase of building production process, some adaptations should be made. The construction phase may be considered the most structured phase in the Turkish market. Since the application of the project must have a defined schedule and budget, and all the actors are tied with contracts, there is not much space for disorder. However still compared to the original Design Structure Matrix, the Turkish construction industry lacks some of the formal agreement tasks, has unequal task distribution and should be more inclusive of marketing and sales activities.

Keywords: *construction phase, design structure matrix, process models.*

Introduction

As researchers in the real estate development field started seeing empty spots in the development process, they tried to define them by models. Real estate development models can be grouped as agency, economic, event sequence, structure and systems models. (Healey, 1991; Trevillion, 2002; Sullivan, 2009) Each real estate development model observes the previous model, decides on what is missing and does the appropriate research to create a new viewpoint. When Grasskamp created the Fundamentals of Real Estate Development, he focused on the relationships between the actors and the highest and best use analysis, but did not pay much attention to financial aspects of the real estate development (Grasskamp, 1981). So when Wheaton's Four Quadrant was created, DiPasquale & Wheaton focused on how the four main financial factors in a real estate development project are affected from each other. This model brings together the actors and the financial market together. (DiPasquale & Wheaton, 1996). Then the Miles' Eight Stages came with the idea that the tasks in the development process can be put in a standardized order. This model lists the eight main steps in a real estate development process and tells the developer to evaluate his work at the end of each step and decide if the project should be continued (Miles et al. 2015). Kohlhepp's 56-Cell Development Matrix not only focuses on the actors and the tasks but also considers the exterior factors and how they mıght affect the project and what the developer should do at the each of stage respectively (Kohlhepp, 2012) Finally, this paper looks into Bulloch and Sullivan's Design Structure Matrix which views the real estate development process as a whole system and brings together the actors and the tasks. In addition to that, it gives the developer information about their relationships and the information flow between the tasks. (Bulloch & Sullivan, 2010).

According to Medin, the main problems of the real estate sector in Turkey were "the state of the Turkish economy, the lack of investors, developers and qualified workforce, the inability of the construction companies to get organized properly, the lack of professionalism' education and technology in real estate organizations." (Medin, 2000) After looking into major development projects over the last 10 years, it was realized that there were no process models used in the construction industry. This created a lot of problems where projects were either not completed on time, or on budget, or lacked aimed quality. There is a gap in process models for building production process in Turkey and a model such as DSM in construction projects might improve these problems. By having a holistic view, it is aimed to see the whole process in a single chart, which provides information about what may cause problems and what aspects of the project would be affected. This paper will only focus on the construction phase of the DSM for traditional construction delivery methods.

The purpose of this study is to minimize the problems encountered in the construction phase, which is the most problematic area of the building production cycle and directly affects the duration, cost and quality of the building, the information flow between the people / groups involved, transmission of tasks to the relevant actors and their timeliness is very important. In this paper, a visual tool will be developed with the help of DSM in order to help the production and transfer of information between those involved in the construction phase.

Design Structure Matrix

The Design Structure Matrix aims to provide a process management model and lower the risk by defining the whole process even before the project starts. In order to use the DSM properly, one should have very clearly defined tasks and actors, as well as having standardization in all analysis, permits, and data.

Stages of Development in the Design Structure Matrix: Bulloch & Sullivan has divided the development process into six stages which are: Idea Inception, Feasibility, Preconstruction, Construction, Stabilization, Asset Management and/or Sale (Bulloch & Sullivan, 2010) At the end of each Stage, information is collected, synthesized, and reviewed to determine whether the project should: Move forward and expend further resources, Stop and lose the investment made to date, Go back to an earlier phase and reexamine assumptions and decisions in an effort to create a more viable path. (Bulloch & Sullivan, 2009), or Pause and wait for certain input factors to change. These Decision Gates are crucial steps in the building production process and can assume a variety of forms. (Bulloch & Sullivan, 2010)

Disciplines in the Design Structure Matrix: In order to categorize the numerous tasks in the real estate development model the creators of the DSM have grouped them into five disciplines: Market & Competitive (yellow), Legal & Political(red), Financial (green), Physical & Design(blue), and Project Management (grey) (Bulloch & Sullivan, 2009). Since this paper will only focus on the construction phase, instead of the above-mentioned five, only two disciplines will be used: disciplines that are directly connected to construction (blue) which is a combination of Physical & Design (blue), and Project Management (grey);and disciplines that are not crucial to construction but still relevant to the overall process (orange) which is a combination of Market & Competitive (yellow), Legal & Political(red), and Financial (green) disciplines.

Informational Relationships between Tasks: The tasks in the DSM come in three different relations. Those are;

- Dependent tasks (series); task B needs the information from task A, and thus task B has to follow task A.
- Independent tasks (parallel); task A and task B can be done separately.
- Interdependent tasks (coupled); repetitive because they need feedback from each other.

"Modeling and managing coupled tasks, which describes much of building production process, is much more challenging because this arrangement implies iteration and feedback loops" (Bulloch & Sullivan, 2009). DSM in general is a model trying to categorize and coordinate all the tasks. It shows which tasks are independent, dependent or interdependent and thus, which information should be received from what step and which action should be taken next.

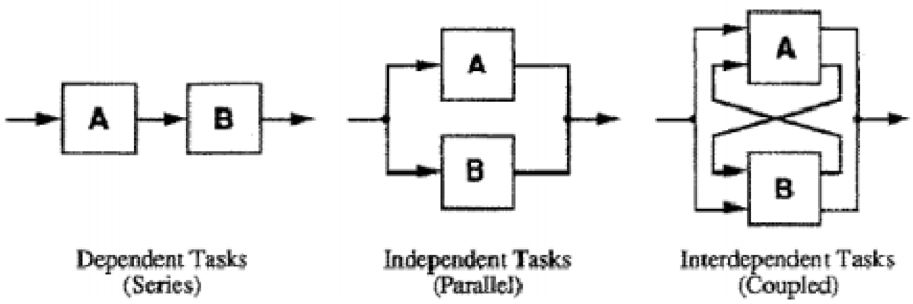

Figure 1: Types of relationships between two tasks (Bulloch & Sullivan, 2009)

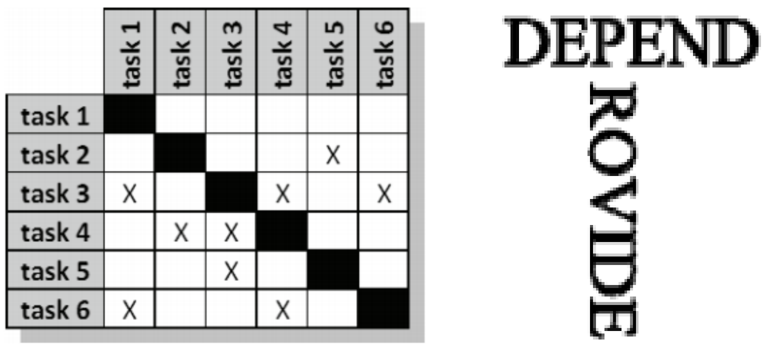

Figure 2: Guide to Reading the Design Structure Matrix (Bulloch & Sullivan, 2009)

DSM lists all tasks in both vertical and horizontal axes of a matrix and shows how each and every task is related to each other once completed. As can be seen in figure 2, where two same tasks intersect a black line is drawn. As we read down a column, we see the outcomes of the task that would be needed for the upcoming tasks. Therefore, it is what the task provides. As we read across the rows, we see the requirements needed to complete the task and which other tasks those requirements come from. Therefore, it is what the task depends on. “In the figure below, Task 5 is dependent on information received from Task 3 for completion. Task 1 sends information to Tasks 3 and 6.” (Bulloch & Sullivan, 7/2010, pg.80) Additionally because all the tasks are placed sequentially on the matrix some of the interdependent tasks are marked by crosses above the black line. This means the marks above the diagonal line are the tasks which require us to go back and rework. For example, Task 2 depends on the information from task 5. Son once task 5 is completed the developer should go back and reconsider / redo task 2.

Applying DSM to Construction phase of building production process: The DSM helps to visualize the whole project in one great chart. It helps the construction phase to see and predict many problems that might occur in the project process and have precautions beforehand. It is also used to sequence tasks in the most efficient way and have a work schedule before the project starts. But apart from all the DSM is most beneficial in “highlight relationships between tasks and identify where rework risk might occur”. It is hoped that in an ideal project all tasks would be sub-sequential and no rework would be needed. That means that all the X’s would be below the black line. However, rework can be beneficial to the project in ways that revising each step with each other makes construction phase crosscheck his estimations / predictions and therefore reduces risk. “The desirable level of rework and iteration is unique for each project, because the information being generated and the associated risks are project specific”. (Bulloch & Sullivan, 7/2010, pg. 82)

Methodology: Using the structure of DSM which is originally developed for real estate; this paper only focuses on the construction phase. In order to do so, categories and list of tasks were fixed according to their actors and their order. Then each task was gone over according to the information it needs and the information it provides. Twenty-five professionals and academicians from the industry with at least 5 years of experience have been consulted at various steps of the adaptation. They were shown the draft of the model in person and asked to make comments on its accuracy according to their experiences. The model was simultaneously revised.

Application of DSM in Turkey to Construction Phase of Building Projects

According to Bulloch & Sullivan, the contractor and the subcontractors are provided building design prepared at the preconstruction stage. Most of the responsibility is on the contractor at this stage because he is bound by the contracts to deliver a quality project in time and in budget. Throughout the construction phase, the constructor should keep updating his budget and financial assumptions. If the construction takes too long the market situation might be very different from the time project started, affecting the costs of materials (Bulloch & Sullivan, 2009, pg. 57). A process model as the DSM allows making educated predictions.
Changes in the categories and order of Tasks: The construction stage may be considered the most structed stage in the Turkish market. Since the application of the project must have a defined schedule and budget, and all the actors are tied with contracts, there is not much space

for disorder. However still compared to the original DSM, the Turkish real estate development lacks some of the formal agreement tasks. List of tasks that can be found in Table 1 was decided upon by combining the original Design Structure Matrix of Bulloch and Sullivan (2009) with the research made in the graduate thesis by Bulgan (2017) and later developed during doctoral studies at Istanbul Technical University.

Table1: Tasks of stage 4 – Construction

	Construction tasks	**Action Taken**
1	Design Development	Continued from PreConstruction
2	Execute "Good Manufacturing Practice" (Quality) Agreement	Moved Construction →PreConstruction
3	Secure Construction Loan	Moved Construction →PreConstruction
4	Obtain Building Permit	Moved up in order
5	Acquire Property	
6	Procure Major Trade Buyouts	Moved Construction →PreConstruction
7	Excavation Works	added
8	Build Project Infrastructure	
9	Build Core and Shell	
10	Rough Construction	added
11	Build MEP systems	added
12	Build Interiors	added
13	Fine Works	added
14	Build Client Requirements	
15	Monitor Schedule	Moved up in order
16	Construction Inspection	
17	Building Turnover	
18	Settlement of Claims	added
19	Update Development Budget	
20	Update Market Conditions	

As can be seen in table 1, some of the changes made are as such: First tasks are divided into two disciplines: disciplines that are directly connected to construction (blue) and disciplines that are not crucial to construction but still relevant to the overall process (orange). Tasks as “secure construction loan” or “update development budget” are not actual construction tasks but they indirectly affect the construction. If the loan is not secured or there is a major change in the budget, then construction cannot continue. By also monitoring indirectly related tasks, the contractor can be prepared for uncertain conditions that might affect the project.

With the commentary received from various professionals on the adaptation of the DSM some tasks have been added and some have been removed. Design Development was a preconstruction task in the original DSM but in today’s world, design process extends into the construction stage to shorten overall project time. For example, interior drawings of a building can be made as the excavation for the land begins. Tasks such as “Execute GMP agreement”, “Procure Major Trade Buyouts”, “Obtain Building Permit” have been moved to the preconstruction stage because the construction cannot start before these steps are completed.

Since DSM is a real estate model, it doesn't go into detail in the construction stage. So, tasks such as "Excavation Works", "Build MEP systems", "Build Interiors", "Settlement of Claims" are added in order to make this stage more detailed. The more detail put into the model, the more certain it gets.

Changes in the relationship of Tasks: After reordering the tasks in the previous section, they are now listed horizontally and vertically to see their relationships with each other. As the table is read from left to right we see what the tasks depend on. As the table is read top to bottom we see what information the tasks provide. For example, as can be seen in table 3, Rough construction depends on information from previous tasks such as Acquire Property, Excavation Works , Build Project Infrastructure, Build Core and Shell and Design Development, which makes sense because the rough construction cannot start before these tasks are complete. They are serial / dependent tasks. Rough construction task also depends on information coming from development budget and market conditions. Although not directly connected the overall financıal situation of the market and the project would affect the construction. When read from top to bottom rough construction provides information for the following steps such as Build MEP systems, Build Interiors, Fine Works, Build Client Requirements, Monitor Schedule, Construction Inspection.

From reading this chart the contractor or the project manager can get to these conclusions:

- If most of the relationships are below the diagonal black line, this means that the risk is lower in the project because the tasks are mostly serially connected. There is no need for rechecking or rework. (Bulloch & Sullivan, 2009) Compared to previous stages the construction stage is mostly straight forward.
- When tasks from two different categories come together, these relationships are more critical than a similar category relationship (Bulloch & Sullivan, 2009). Information flow between two blue tasks would be easier because the professionals speak the same language whereas a relationship between a blue and an orange task might be harder to communicate since the professionals come from different backgrounds.
- This chart helps the contractor to see exactly which tasks would be affected if a problem occurs at a certain part of the project. For example, if there is a problem at the fine works task, then it is visible that there will be problems with the information flow to Build Client Requirements, Monitor Schedule, Construction Inspection, Settlement of Claims tasks. Also interestingly, tasks such as Design Development and Build Interiors which happened before the problematic task have to be revised.
- It is important not just to think about building activities during the construction stage of building production but also constantly be aware of the surrounding factors. The DSM allows the contractor /project manager to integrate these factors into construction planning. As an example in this stage, tasks such as secure construction loan, obtain building permit, development budget, market conditions etc. are integrated into the overall chart allowing us to see their effects on the physical construction.

Table 3: Construction Stage - Relationships between Tasks Matrix

	Design Development	Secure Constrctn Loan	Obtain Building Permit	Acquire Property	Excavation Works	Build Projct Infrastruct.	Build Core and Shell	Rough Construction	Build MEP systems	Build Interiors	Fine Works	Build Client Req.	Monitor Schedule	Construction Inspection	Building Turnover	Settlement of Claims	Update Develpmt Bgt	Update Market Cond.
Design Development	■										x	x						
Secure Construction Loan		■	x															
Obtain Building Permit		x	■															
Acquire Property		x	x	■														
Excavation Works		x	x	x	■												x	x
Build Project Infrastructure	x	x	x	x	x	■											x	x
Build Core and Shell	x		x	x	x	x	■										x	x
Rough Construction	x			x	x	x	x	■									x	x
Build MEP systems	x				x	x	x	x	■								x	x
Build Interiors	x					x	x	x	x	■	x	x					x	x
Fine Works	x					x	x	x	x	x	■	x					x	x
Build Client Requirements	x					x	x	x	x	x	x	■					x	x
Monitor Schedule	x	x	x	x	x	x	x	x	x	x	x	x	■	x	x	x		
Construction Inspection					x	x	x	x	x	x	x	x	x	■	x	x		
Building Turnover														x	■	x	x	x
Settlement of Claims					x	x	x	x	x	x	x	x	x	x	x	■	x	x
Update Development Budget		x	x										x		x	x	■	x
Update Market Conditions		x	x										x		x	x	x	■

Evaluation of the Adaptation of the Design Structure Matrix

1. Unclear task distribution: In Turkey, actors and tasks are not always defined clearly which creates ambiguities in task division. Sometimes, too much work is loaded on the incorrect professionals which increases the amount of risk in construction projects. In order to fix this issue, the construction industry should have very clear job and task definitions. When tasks are done by experts in their fields, the risk is decreased since the decision is made by combining the knowledge of many.

2. Different timing of tasks: Some tasks are done at different times in Turkey compared to the original order of the Design Structure Matrix. This difference sometimes cause the construction to be more risky or for processes to take longer. One of the other issues encountered about the timing of the tasks is that since the Turkish construction industry is less structured and lead by mostly practical knowledge, the order of the tasks are more likely to change during the construction of the project. When this happens the X's on the chart would change and might change into a less stable, more risky scenario.

3. Longer span of tasks: In today's construction industry simultaneous tasks are a must considering that the less time spent on construction means faster return of capital. In order to do so task are not achieved back to back but some continue at the same time. For example the design of a project no longer starts and ends during the preconstruction stage but also extends over the construction stage. In some cases it even continues after the opening of the property.

4. Interdisciplinary tasks: In today's construction industry some tasks are no longer the responsibility of a single professional category. Most tasks require two or more professionals from different fields to come together and work together on a single task. For example, obtaining building permit task is handled by the client or the contractor depending on their agreement. There is no clear definition of who should do it.

In conclusion, it was realized that the Turkish industry is still a bit unorganized compared to the original Design Structure Matrix and most tasks require more re-working or re-checking. However, the adaptation of Design Structure Matrix to the Turkish real estate development industry promises a lot of benefits such as better structural organization, better time management, and more stable budgets. It also solves major problems of the Turkish real estate industry since using the proper development models would encourage standardization and research, thus changing the Turkish real estate development in a more beneficial, efficient and stable state.

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Personality Effect on Developing Resilience and Managing Stress in Architecture Students

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Abstract

Architecture students face increasing stress factors throughout their undergraduate education. Students show positive or negative attitudes to these factors. The attitudes and behaviours students show towards stress during their undergraduate education follow them in their professional careers. Personal resilience is an important factor in managing stress in one's professional and academic careers. In this study, the effect of personality on stress management and resilience development is examined by using the "Enneagram" model, which is one of the approaches used to define personality structures. With the use of the enneagram model as a guide, this study offers suggestions that not only to increase the individual awareness of architectural students, but also to determine the benefits that will guide students, trainers and career consultants.

Keywords: *Stress, Resilience, Personality, Architecture Students, Enneagram*

Introduction

University students face various new and challenging situations (Turner & Simmons, 2019) and increased stress factors throughout their undergraduate studies (Blanco et al., 2008). In college life, architecture students spend more time at school and encounter more stress factors than students in other departments (Lynch, 2016). Architectural education consists of both theoretical and practical challenging subjects (Bachman & Bachman, 2006). Social, physical and emotional difficulties can cause stress in students (Hassim et al., 2012). Stress is the entire process, including the effect of environmental events or forces called stress events on the individual and the results of the individual's response to this effect (Baum et al., 1981). The stress process is any disturbing emotional experience accompanied by predictable changes (APA 2013). The effect of these stress factors on the person depends on how the person perceives the stressors (Elias et al., 2011). The effect of stress can cause a positive response and increase performance, the increase in stress level may be a negative response rather than a positive one (Steptoe et al., 1998). The response to stress is the adaptation response of the body to changes both neurologically and physiologically (Elias et al., 2011). While some people adapt positively to stress, some people experience trouble (Luther et al., 2000). Positive adaptation to stress factors enables students to progress and develop (Turner, 2019). This positive adapt is the resilience occurred by experiencing stress and distress situations (Holdsworth et al., 2017).

Resilience is the positive adaptation to stress factors and "bouncing back" from difficult experiences (APA, 2020). Some researchers define resilience as the ability to survive or resist stressful situations (Walker et al., 2006), while others describe resilience as the ability to return to a stable life situation by favorably adapting to stressors (Hassim et al., 2012). Therefore, there is no universal definition of resilience (Knight, 2007). Resilience is a feature that can be learned, improved and transferred through life experiences (APA, 2020). Learning resilience is based on the experiences gained by exposure of individuals to challenging and stressful situations (APA 2020). Transferring resilience is critical for students to survive and develop in their academic and career lives. (Turner & Simmons, 2019). Improving resilience helps students manage stress and stay healthy (DeRosier et al., 2013). Accordingly, resilience development is beneficial for both academic success and professional development (Groen et al., 2019). It is the responsibility of both students and the university to improve resistance of students to stressors and difficulties (Holdsworth et al., 2019). Universities can offer learning methods that support building resilience behavior (Turner,2017). While encouraging students with these methods, care should be taken not to be overwhelming (APA 2013). Personality traits can be used in the development of resilience and stress management (Vollrath, 2001).

Personality is an important factor on the stress process (Borger & Zuckerman, 1995; Vollrath, 2001). Personality traits affect the choice, reaction and outcome of the stressful condition (de Jong & Emmelkamp, 2000). The response to similar stressors varies according to personality types (Cooper 2005). Personality types can provide resistance to stressors over time, hence these should be considered to manage stress and determine strategies (Dumitru & Cozman, 2012). In this study, the “Enneagram” model, which is one of the tools used in defining personality types, is selected to benefit from personality types in managing stress and improving resilience.

Enneagram Model

The word enneagram consists of the Greek words which are "ennea" meaning "nine" and "gramma" meaning "written" (Sutton, et al., 2013). Enneagram model, which is a framework consisting of 9 personality types, in which no personality type is superior to another, provides understanding of people and attitudes (Riso & Hudson, 2008). Even if individuals have the characteristics of each personality type, only one type is most dominant in the direction of stress and development (Wagner ve Walker, 1983). Enneagram personality types enable individuals to recognize themselves under stress and development conditions by allowing some changes in personality traits to be noticed while under stress and in the direction of development (Riso & Hudson, 2008). The characteristics of enneagram types do not include the information that individuals have learned through experience, but give an idea of personality and potential qualities before experiencing an event (Oraz, et al., 2016). The enneagram is portrayed as a valuable tool for personal development by trainers and practitioners, as it is believed that if people know more about themselves, they will respond more effectively to the challenges they face (Sutton, et al., 2013). Researches on enneagram explained personality typologies differently (Oraz, et al., 2016). In this study, the typology definitions of Riso and Hudson (2008) are used. In the enneagram model, nine personality types are defined so that not only students are offered suggestions for stress management and endurance development but also information is provided to increase the awareness of the advisors about the students.

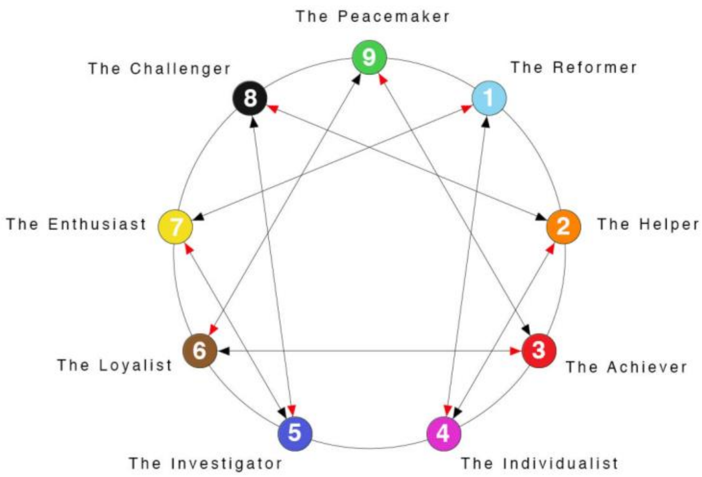

Figure 1: The Enneagram Model (adapted from Riso & Hudson, 2008).

Type 1 - The Reformer
Keywords: Principled, purposeful, self-Controlled, perfectionistic
Basic Desire: To be honest, balanced and good
Basic Fear: To be imperfect, unbalanced and corrupt
Direction of Stress: In the direction of Type 4; pessimistic, guiltiness, self-harm
Direction of Growth: In the direction of Type 7; to decrease anxiety by accepting the facts, being enthusiastic and free by enjoying living, improvement in communication skills
Key defense mechanism: Suppression, response generation, to transfer emotions and reactions to other foci.
Level of Healthy Development: Realistic wise, conscientious and honest, responsible
Level of Average Development: Idealist, regularness obsessed, strident criticism for perfection
Level of Unhealthy Development: Lack of tolerance, obsessed, punisher and vengeful
Strategies to Manage Stress and Develop Resilience: Taking time to rest, to be patient for effective change, accepting the existence of errors instead of feeling uncomfortable all the time, to advice and recede instead of anger and pressure, sharing information instead of telling people what to do, learn more by listening to others even if you have mastered topics, to be open to doing different instead of doing perfectly, dealing with the basic problem without going into details
Mindfulness for Advisors: Type One; makes sagaciously decisions, cares about doing the right things even if conflict with one's interests, behaves impartially and fairly, undertakes all the work in team work because Type One thinks most people are lazy, depends on rules and standards, wants everyone to do everything right

Type 2 - The Helper
Keywords: Generous, demonstrative, people-pleasing, possessive
Basic Desire: To feel loved
Basic Fear: To be unwanted, unworthy of being loved
Direction of Stress: In the direction of Type 8; oversensitiveness, angry, aggressiveness
Direction of Growth: In the direction of Type 4; honest, self-acceptance, be an open book

Key defense mechanism: To give reaction and refuse
Level of Healthy Development: Agapeic, empathy, generous, modest
Level of Average Development: People pleaser, interfering, give oneself up to others
Level of Unhealthy Development: Directing others for their own needs, feel victim, aggression
Strategies to Manage Stress and Develop Resilience: To meet their own needs before meeting others' needs, to help without expecting anything back, not to draw attention to the good things done, to help if there is a request instead of doing something for others all the time, not to praise people unnecessarily in order to be loved, to love and appreciate people as they are
Mindfulness for Advisors: Type Two; capable of empathy and strong communication, cares about helping people even if conflict with one's interests, wants to be loved as they are, likes to advise and guide, afraid to be criticized, expresses own needs indirectly, has the ability to persuade

Type 3 - The Achiever
Keywords: Adaptable, excelling, driven, image-conscious
Basic Desire: To feel estimable and worthwhile
Basic Fear: To be worthless
Direction of Stress: In the direction of Type 9; passiveness, self-effacing
Direction of Growth: In the direction of Type 6; cooperation, committed to others
Key defense mechanism: Suppression, to transfer emotions and reactions to other foci
Level of Healthy Development: Self-accepting, adaptable, self-confident, admirable
Level of Average Development: Competitive, image enthusiast, self-righteous
Level of Unhealthy Development: Dishonest, malicious opportunist, vindictive
Strategies to Manage Stress and Develop Resilience: Act honestly for sincere feelings and needs, to be helpful and cooperative, relax to widen one's viewpoint, appreciate others and support them for their development, not to hesitate to ask questions to understand, accepting yourself instead of comparing yourself to others
Mindfulness for Advisors: Type Three; cares about development and success, pays attention to appearance, focuses on success and goal, cares about team management, acts against the rules and compromises on quality if necessary to reach the goal

Type 4 - The Individualist
Keywords: Expressive, dramatic, self-absorbed, temperamental
Basic Desire: To find oneself
Basic Fear: To be unidentified and insignificant
Direction of Stress: In the direction of Type 2; variable mood, imbalance, needing care
Direction of Growth: In the direction of Type 1; self-discipline, sensible, intuitive creative
Key defense mechanism: Introversion, to transfer emotions and reactions to other foci
Level of Healthy Development: Embracing life, self-aware, sentient, creative
Level of Average Development: Imaginative, variable temperament, self indulgence
Level of Unhealthy Development: Introversion, hateful, self destruction
Strategies to Manage Stress and Develop Resilience: Not to act constantly according to emotions, bringing order to life by applying self-discipline, not waiting for the best moment to act, talk to a trusted person instead of soliloquize, participating in voluntary relief activities, be at peace with oneself rather than self-criticize
Mindfulness for Advisors: Type Four; tries to understand the feelings, questions everything, prefers to work individually, evaluates experiences, cares about being original, unique and creative with wide imagination, may has problems in reconciliation situations, makes original

contributions to projects

Type 5 - The Investigator
Keywords: Perceptive, innovative, secretive, isolated
Basic Desire: To be sufficient and capable
Basic Fear: To be useless, helpless, inadequate
Direction of Stress: In the direction of Type 7; isolated life or excessive sociability, impulsive behavior, drug addiction
Direction of Growth: In the direction of Type 8; to feel their intuitive power, to trust their information, to benefit the world by leading
Key defense mechanism: Attributing their thoughts to others, self-abstraction
Level of Healthy Development: Comprehensive understanding, intuitive observation,innovator
Level of Average Development: Specialization, concentration on concepts, extremism
Level of Unhealthy Development: Getting away from reality, introversion, distorted thoughts, self-aggression
Strategies to Manage Stress and Develop Resilience: To think without estranging oneself from social life, to exercise instead of using substance to relax, to get support from others instead of being dwelled on subject, identifying priorities by reviewing ideas, managing conflicts instead of running away from problems, to learn by exchanging ideas with each other, using information to benefit rather than contempt, controlling self-behavior when others are estranged
Mindfulness for Advisors: Type Five; concentrates deeply on the subject of interest, prefers to work individually, attaches importance to long-term studies and expertise, shares information only if necessary, avoids physical activities

Type 6 - The Loyalist
Keywords: Engaging, responsible, anxious, and suspicious
Basic Desire: To have security and support
Basic Fear: Being unsupported and alone
Direction of Stress: In the direction of Type 3; become introverted, opportunist, vindictive
Direction of Growth: In the direction of Type 9; feeling comfortable, even-tempered, extrovert, supportive, peaceful
Key defense mechanism: To transfer emotions to other foci, attributing their thoughts to others
Level of Healthy Development: Self-assured, engaging, brave, collaborationist and equitable
Level of Average Development: Self-doubt, anxiety, passive-aggressive, accusing, strict
Level of Unhealthy Development: Inferiority complex, extremely skeptical, self destruction
Strategies to Manage Stress and Develop Resilience: To Live the moment instead of constantly thinking about the future, trusting and collaborating with others, to focus on solving the problem rather than blaming others, avoiding excessive anxiety and terrible thoughts, taking responsibility instead of accusing someone else in the face of an error, contact the body and calm your anxious mind, expressing emotions openly rather than being complex and defensive, to trust and believe in yourself
Mindfulness for Advisors: Type Six; cares about trust and loyalty, needs guidance and authority, constantly thinks and worries about possible problems, identifies problems that may occur and produces long-term solutions, works hard for a safe environment

Type 7 - The Enthusiast
Keywords: Spontaneous, versatile, distractible, and scattered

Basic Desire: To be satisfied and happy, to have their needs fulfilled
Basic Fear: Of being deprived and in pain
Direction of Stress: In the direction of Type 1; lack of tolerance, obsessed, punisher and vengeful behaviors
Direction of Growth: In the direction of the Type 5; comprehensive understanding, mental calmness, original innovation
Key defense mechanism: Suppression, externalization, revealing previously suppressed emotions
Level of Healthy Development: Grateful, enthusiastic, free spirited, practical productive
Level of Average Development: The desire to try everything, acting with impulses, insatiateness, excessive consumption
Level of Unhealthy Development: Distractibility, spiritual breakdown, conniption
Strategies to Manage Stress and Develop Resilience: Act by thinking instead of acting with sudden urges, believing in oneself by reducing the tendency to external factors, preferring quality rather than quantity in experiences, thinking of long-term results of requests, think rather than react instantly to impress others, not afraid to be sad, to be grateful, learning to listen to others, to appreciate silence and loneliness
Mindfulness for Advisors: Type Seven; attaches importance to short-term studies and change, open to innovation and experience, wants more than needed, starts with enthusiasm and gets bored quickly, aims to be versatile, cares about being free rather than following plans and rules, thinks fast and acts fast under pressure

Type 8 - The Challenger
Keywords: Self-confident, decisive, willful, and confrontational
Basic Desire: To protect oneself, to be independent
Basic Fear: Of being damaged or controlled by others
Direction of Stress: In the direction of Type 5; introversion, insecurity, getting away from reality
Direction of Growth: In the direction of Type 2; compassionate, generous, cordial
Key defense mechanism: Suppression, to transfer emotions to other foci, denying
Level of Healthy Development: Compassionate, self-assuredness, generous, protective leader
Level of Average Development: Entrepreneur, pragmatic, impressive, coercive, defiant
Level of Unhealthy Development: Relentless, megalomania, vindictive, disruptive
Strategies to Manage Stress and Develop Resilience: To show the glory of the heart instead of pressure, to help by handling the administration in times of crisis, not to be intrusive to others, approaching people's attitudes with compassion rather than reaction, learning to trust not only yourself but also others, to care about spiritual development, asking someone else for help if needed, when bad feelings arise both believing goodness and being open to change
Mindfulness for Advisors: Type Eight; is confident and brave, cares about power and status, takes the leadership and responsibility, gathers people under one roof, adopts authoritarian leadership characteristics, solution-oriented in times of crisis, has self-rules and sense of justice, takes risks and compete.

Type 9 - The Peacemaker
Keywords: Receptive, reassuring, complacent, and resigned
Basic Desire: Inner peace, integrity
Basic Fear: To lose something, separation
Direction of Stress: In the direction of Type 6; reject, anxious, sudden reactive, isolate oneself
Direction of Growth: In the direction of Type 3; sociable, self-accepting, self-confident

Key defense mechanism: Suppression, parsing and denial
Level of Healthy Development: Personal freedom, open to innovation, supportive
Level of Average Development: Actor that adapts to the environment, passive, determinist
Level of Unhealthy Development: Negligent, disconnection, denial, self-surrender
*Strategies to Manage Stress and Develop Resilience***:** Focus on the surrounding events to be effective, not to prioritize someone else's wishes, to be aware of feelings and express clearly, exercise and be aware of the body, listening and understanding people carefully, to share anger and fears, not to be afraid to get help if panic attacks and agoraphobia are encountered,confronting instead of escaping from conflict
Mindfulness for Advisors: Type Nine; avoids competition and conflicts, creates peaceful environments, remains calm during a crisis, allows everyone to contribute, prioritizes the wishes of others, leaves problems to time instead of solving them, takes long-term decisions, ignores discomfort to avoid problems, shares success with others, exhibits positive and supportive attitudes

Using the Enneagram

The enneagram model is used in therapy, spiritual work, coaching and work (Delvo, 2015). The fact that the enneagram model can explain both the potential of doing business and changing behaviors in stress and relaxation situations can facilitate the use of the model as a practical tool (Oraz, et al., 2016). Thanks to the practical use of the enneagram model not only students can gain individual awareness but also supervisors and mentors who do not have enough time to get to know the students can offer faster solutions to support student development.

Architecture education consist of uncertainties where there are no exact solutions (Bachman & Bachman, 2006). For Type 1, who cares about doing the right things and depends on the rules and standards, these uncertainties can cause negative stress. Being open to doing different instead of doing it perfectly and correctly, taking time to relax can be effective for Type 1 students to cope with these uncertainties. Advisors who want to help Type 1 gain resilience against uncertainties can use methods that use different methods without rules and standards, conduct short-term and instant studies, encourage students to achieve superficial results.

Students are faced with non-academic stress factors due to factors such as socioeconomic status, race, gender, and culture. Due to these differences, students may experience social isolation during their transition to university (Groen et al., 2019). For example, Type 9, who does not want the peaceful environment to change, can become introverted against change. In such a case, Type 9 should be aware of their feelings and express their feelings clearly, share anger and fears, and should not be afraid of getting help. Advisors who know that Type 9 students refrain from seeking help and tend to isolate themselves can support students to express their feelings, advise them to exercise to socialize and get to know themselves.

In undergraduate education, students who encounter overlapping assignments, exams and projects (DeRosier et al., 2013). For example, Type 5 students who value long-term studies, in-depth focus and expertise can get support in matters that they rely on, determine their priorities by reviewing their ideas, manage their time. Supervisors can increase practicality by giving students short term projects, support their time management by following the working process, direct students who focus on negative points by exchanging ideas to see the big picture.

Group work can be a source of stress due to differences in the way students work (Michaelsen et al., 1997). Group work can be difficult for Type 5 students who prefer to work individually and trust their own knowledge. Type 5 students can learn by exchanging ideas with others, getting support from missing issues by relying on others and using their knowledge to benefit others. Advisors that encourage students to participate in group work, can improve their knowledge sharing skills, help them learn to work with others and trust others' knowledge. In this way, it can be ensured that students do not see group work as negative stress and increase group efficiency.

Some students may not like to be leaders because they feel stressed in group work, however they feel more comfortable as a group member who does not want high responsibility and may be more beneficial to the group (APA 2013). For instance, it is safer to be a member of the group rather than a leader for Type 6 who needs authority. Type 6 students who are leaders in group work should take responsibility, avoid excessive worries, and rely on their own decisions. Advisors can encourage, motivate, support and assist to avoid bad thoughts students who need guidance.

Students who think that activities and hobbies other than academic studies will increase their responsibilities perceive them as a source of stress. However, these activities and hobbies can help to increase resilience and reduce stress factors (Groen et al., 2019). Type 6 students may be afraid and worried about spending some of its time on hobbies and activities instead of the things it needs to do to achieve a safe environment. These students who focus on academic and business life and are not interested in other activities can improve themselves with methods such as living the moment instead of constantly thinking about the future, not to act with extreme anxiety of the future, calming the mind by contacting the body. For the development of Type 6 students, advisors can help them manage stress by promoting their participation in activities and hobbies.

Some students start to postpone their studies when they face stress (Turner & Simmons, 2019). Scheduling is important to facilitate excessive workloads in architectural education and increase student success (Bachman & Bachman, 2006). Students can overcome their procrastination behaviors with time management methods such as creating reminder notes, managing complex targets by cutting them into small pieces (Owens et al., 2008). To illustrate, Type 4 who expects the best moment to act, tends to procrastination. Students who want to eliminate the tendency to delay can use methods such as not acting according to emotions constantly, work in a self-disciplined schedule, self-motivating avoiding negative self-criticism, getting support when things get worse. Supervisors can enable students to progress by requesting short-term presentations, creating a study program and encouraging planned studies by observing previous experiences and academic success. Thus, they can support students to reduce their tendency to procrastination, provide time management and fulfill their responsibilities.

Conclusion

Given the high level of mental distress experienced by architecture students, the ability to manage stress factors has become critical. Preventive strategies can be applied by both students and advisors before a negative reaction of stress occurs. Thanks to university support, students can get advice from mentors and supervisors who have more life experience than themselves. Personality is an important factor in identifying, responding and approaching stress events. It is significant to be aware of personality traits for stress management and resilience development. The enneagram model is a guide that will help both students get to know themselves and university advisors understand students. Using the tactics in this guide, students and the university can contribute to students' positive adaptation to stress factors, to improve their resilience and to their personal and professional development beyond their undergraduate careers.

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Evaluation of Compliance and Applicability of Safety Nets Used in Construction Workplaces

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Abstract

As in other developed countries, the majority of fatal work accidents occur in the construction sector in our country. When the reasons for the occurrence of these accidents are analyzed, it is seen that most of them are due to falling from height. It is known that the use of unsafe work equipment that is not suitable for the standards and the work has an important place among the sub-causes of these falls. Within the scope of the Regulation on Occupational Health and Safety in Construction Works published in the Official Gazette dated 5/10/2013 and numbered 28786, in terms of material properties and installation conditions of safety nets, it has been compulsory to comply with TS EN 1263-1 and TS EN 1263-2 standards to prevent the use of work equipment that does not comply with the standards. In addition, the minimum health and safety requirements for safety nets have been extensively included in the Regulation on Occupational Health and Safety in Construction Works, which was amended on 31/12/2018 to improve work equipment that is widely used in the sector. Within the scope of this study, suggestions were made to expand the use of safety net in compliance with the legislation and standards by examining what should be considered in the installation and use of safety nets, which types of safety nets are frequently used in Ankara province and to what extent they are suitable, and the troubles and difficulties experienced in its installation and usage.

Keywords: *occupational health and safety in construction works, safety nets, TS EN 1263-1, TS EN 1263-2.*

Introduction

The construction industry, which has a huge share in the economic growth of countries, serves as a driving force in the development of Turkey with the demand for goods and services for many sub-sectors. However, in Turkey as well as all over the world one of the biggest problems of the construction industry are work accidents. The reason for this is that the job groups that have the highest risk in terms of fatal work accidents serve in the sector. In Turkey, construction industry is the sector with the most deaths with a rate of approximately

35% among the fatal work accidents in all sectors. In 2018, 591 fatal accidents occurred in the construction industry (SGK, 2018; Erdal et.al, 2018).

Research studies conducted worldwide reveal that most of the work accidents occurring in the construction industry are due to falling from height (OSHA, 2018). 40-45% of fatal accidents in the sector in Turkey is known to occur because of same reason. A large part of these accidents occurs in the form of falling from the edges of the floors, scaffolds, elevator shaft or other spaces in the building.

In Turkey's national legislation, work at height in construction works are comprehensively handled and detailed arrangements regarding measures and equipment are included. Within the scope of these regulations, many fall prevent and fall arrest measures are implemented to prevent the employees from falling at the construction sites. One of the most frequently used among these equipment is safety net. Safety net is an equipment designed to catch people falling from a height and supported by a rope or supporting elements. It is required to comply with the Occupational Health and Safety Regulations in Construction Works and TS EN 1263-1, TS EN 1263-2 standards in the installation, dismantling, use and controls of safety nets.

In order to prevent falls from height in Turkey, use of safety net has begun to become widespread, however, it has been observed that there are serious deficiencies in issues such as compliance of safety nets to standards, knowledge levels of occupational safety specialists and other employees on safety net and awareness of employers (Dursun, 2016). In our country, some incompatibilities are frequently encountered in the installation and use of safety nets especially the use of safety net not in compliance with the standards.

In this study, in order to increase both the level of technical knowledge and awareness in the sector about safety net, it has been tried to determine to what extent the safety net systems in compliance with the legislation and the matters in TS EN 1253-1 and TS EN 1253-2 standards by examining the condition of the safety net systems used in the constructions in Ankara province.

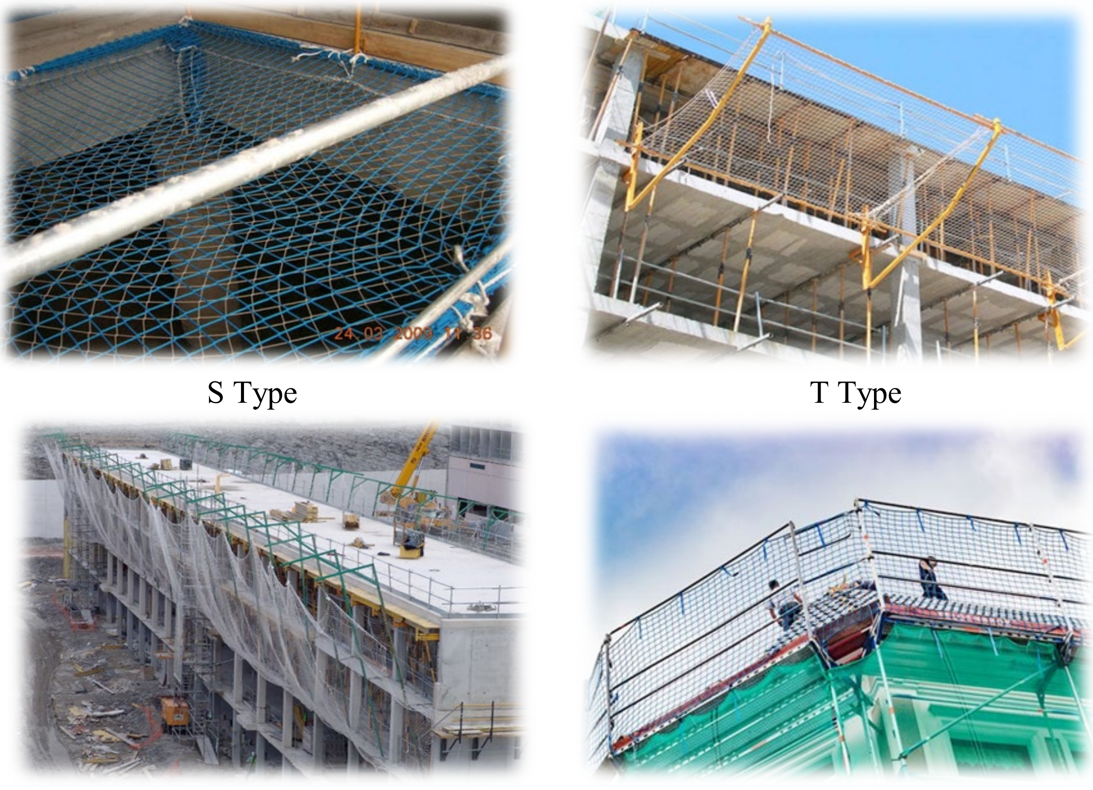
Safety Nets

Safety nets, which are collective protective measures, are a fall arrest system and provide passive protection against falls. Safety nets reduce the fall distance of employees and prevent undesired consequences such as injury and death by mitigate the impact of falling (DGOSH, 2018).

In the hierarchy of work at height measures, fall prevention systems that prevent employees from falling provide higher precautions than the fall arrest systems designed to reduce the severity of injury in case of an employee falling from height. Therefore, while taking precautions when working at heights, it is necessary to examine the applicability of fall prevention systems such as edge protection system and cover systems before safety nets which are a fall arrest system. Because safety nets which limit the falling distance, do not prevent the employee to fall, unlike edge protection systems (Celik & Aydinli, 2019).

Safety net is a collective protective measure and is preferred by employers as they provide protection for more than one employee at the construction sites. In addition, it is stated in the Occupational Health and Safety Regulation on Construction Works that the safety of the employees in the workplaces should be ensured primarily by collective protection measures instead of the personal fall arrest systems.

Another advantage of safety nets are that they are passive systems. Passive systems are fall protection systems that are sufficient to be mounted once or do not require any other adjustment, any changes or operations by the employee to perform their activities. In active systems, the intervention and control of the employee comes into prominence as the employee needs to be equipped with a seat belt, keeps himself connected to a solid anchorage point or lifeline and comprehensive training for employees is required for these systems. For this reason, safety nets, which are passive systems, are more common in construction sites than active systems.



S Type | T Type

V Type | U Type

Figure 1: Types of safety nets.

Considering the current working conditions and the features of the installation area, it is necessary to choose the most suitable safety net system among the four system types in the TS EN 1263-1 standard (DGOSH, 2013). Safety nets have four system types: S type, T type, U type, and V type. S type safety nets are supported with edge rope and are generally used in the form of completely closing gaps that cause discontinuity in floors such as elevators, stairs, chimneys, shafts, lighting spaces. S type safety nets should be surrounded by edge ropes. TS EN 1263-1 standard does not cover small S type safety nets (less than 35 m2 and 5.0 m on the shortest side). T type safety nets are the type of net that are supported by connecting the net to the console and usually used along the perimeter of flooring edges. T type safety nets are for horizontal use and the support structure should be positioned in such a way that in the event of a fall, the worker is not harmed. U type safety nets are attached to supporting framework for vertical use. It is generally used as a Class C edge protection system on sloping surfaces such as roofs. TS EN 13374 standard should be considered in the establishment of U type safety nets. V type safety nets, on the other hand, are a net type with border rope attached to a gallows type support. V type safety nets should be placed with the top edge at least 1 meter above the work area. The distance between supports should not exceed 5 m and the distance between anchorages used to connect the net to the building should not exceed 50 cm. The most commonly used types of safety net in our country are S type and T type.

Safety Nets in Legislation

With the amendment made in the Occupational Health and Safety Regulation on Construction Works on 31/12/2018, very comprehensive provisions regarding the safety nets were added. The provisions on safety nets in the legislation are generally based on TS EN 1263-1 and TS EN 1263-2 standards. In addition, it is stated in the Regulation that safety nets with a certificate of conformity to TS EN 1263-1 standard should be used in construction works and the safety net to be used should be established in accordance with TS EN 1263-2 standard. TS EN 1263-1 standard includes the classification and components of safety nets, test mesh, rope properties and requirements, and static and dynamic strength tests for each type of safety nets. In the TS EN 1263-2 standard, the safety requirements of the nets are generally determined and the standard includes instruction manual, fall height, catching width, linkage, installation, and fixing issues.

In accordance with the provisions of the aforesaid legislation, the primary and most important issue in the procurement and use of safety nets is that this safety nets must have a certificate of compliance with TS EN 1263-1 standard. The use of safety nets that do not meet the qualifications specified in the standard may cause the employee not to be held by the safety net in a possible fall and the employee to fall/crash to the ground or lower levels (DGOSH, 2018). In addition, in a study conducted by HSE in 2011 to determine the capacity of safety nets to prevent falling from height, it was revealed that the performance of safety nets that do not comply with the standards was very low (HSE, 2011).

Another important point in the legislation and TS EN 1263-2 standard related to safety nets is the issues to be considered during the installation of safety nets. First of all, the installation of safety nets should be performed by employees trained on safe working methods and in accordance with the manufacturer's instructions (DGOSH, 2013). However, the fall distance between the work platform and the safety net should be kept under maximum limits and at the minimum distance as far as possible. Because the bigger the fall height, the greater the effect will occur when the fall occurs. Another issue is the clearance distance under the safety net. When a worker falls, there must be sufficient clearance distance under the safety net so that the safety net can stretch and not hit any obstacles and not cause serious injury. In addition, it is necessary to carry out the installation in accordance with many more detailed issues in the legislation and standards.

Controls to be carried out after installation in the safety nets are also vital. In use of safety nets, primarily, it should be checked whether the current installation is correct, immediately after the installation. During the use of the safety nets that are installed correctly, it is necessary to make controls both visually and by testing the test meshes. Visual checks include wear or cuts in the safety nets and visual inspection of deformations in the supporting structure and fasteners at regular intervals or in case of adverse weather conditions. The test meshes provided by the manufacturer with the safety nets and exposed to the same conditions as the safety net during use are determined to test once a year. Deteriorations due to aging are determined and it is confirmed that the minimum energy absorption capacity is met. In case of regular checks are not made, it is very likely that safety nets will not protect against falls, and therefore vital consequences met.

Findings

In order to determine the current condition of safety nets in Ankara province, investigations have been carried out in the constructions. For this purpose, due diligence has been made in 26 building constructions in different parts of the city. It was observed that 10 of these constructions were used only S type, 6 of them were used only T type, and 10 of them were used both types of safety net (S type and T type). In total, 36 safety nets (16 T-type and 20 S-type) were examined at the visited sites. In the construction sites visited in Ankara province, the type of safety net except S and T type was not found. Information about the checklist used for determining the condition of safety nets and their compliance status are given in Table 1.

Table 1. Findings on construction sites related to safety nets.

Criteria	Number of Construction Sites			
	T tipi		S Tipi	
	App.	Not App.	App.	Not App.
Does the safety net comply with the standards?	6	10	15	5
Has the safety net been set up by employees with sufficient knowledge?	11	5	12	8
Is the fall height of the safety net suitable? (Is it installed less than 6 meters away from the working area?)	7	9	11	9
Are S type safety nets installed in the appropriate area? (Areas with an area of more than 35 square meters or a short edge of more than 5 meters)	X	X	10	10
Is there sufficient clearance under the safety net?	16	0	15	5
Is the safety net regularly checked for deformation and corrosion?	8	8	9	11
Is there a test mesh with the safety net? If the period of use has exceeded 12 months, have the test eyes been tested?	2	14	4	16
Is it paid attention not to waste material or garbage on safety nets?	8	8	11	9

As a result of the examination made in a total of 36 safety nets found in construction sites, it was observed that the use of the S type safety net was more common than the T type safety net. While S type safety nets can be used in buildings of any height, T type safety nets are generally preferred in high-rise buildings. It is known that the S type safety net is more cost-effective than T type safety net since structure of S type safety net does not require a supporting console. In addition, the fact that T type safety nets have some difficulties because they require relocation to maintain the fall height as the building rises, can be listed as the reasons for the use of S type safety nets more common.

In the examinations conducted, it was determined that 21 safety nets comply with the standards, and 15 of them did not comply with the standards. In S-type safety nets, access to standards-compliant safety net is higher due to both low cost and widespread nature. In some construction sites, it has been determined that in T-type safety nets, only the net is in compliance with the standard, but T-type safety nets do not have a certificate of conformity as a system with the steel console. It was realized that there is a lack of information about the need for standardization of safety nets according to the types at the construction sites, and it was concluded that construction sites need to be raised awareness of this issue.

There are also huge risks to the installation of safety nets. It is known that the installer should work in the most dangerous area in terms of fall risk. For this, it is of great importance to give special training to the installers. It has been declared that 23 of the safety nets examined within the scope of this study have been established by suppliers who have knowledge and experience in installation. It has been observed that the other 13 safety nets that do not comply with this criterion do not comply with the standards and were established by employees with different areas of expertise on the construction site.

Falling height of safety nets is very important especially in T type safety nets. As the building rises, the T type safety nets installed on the exterior must be moved to the closest possible distance to the working floor or closer than 6 meters. In the examinations, it has been observed that only 7 of the 16 T type safety nets were at a suitable distance. In S type safety nets, it has been observed that as the building rises, it is preferred to establish a new safety net by leaving sufficient clearance distance to the existing net and 9 S type safety nets do not meet the falling height criteria. It has been determined that the falling height is not suitable in half of the safety nets and there is a lack of information that safety nets do not provide protection at a falling distance of more than 6 meters and even cause serious injuries on sites with unsuitable safety nets installed.

Another important issue in S type safety nets is the size of the space where the safety net will be installed. If the employee falls into a net that is less than 35 square meters, it may cause serious injury or loss of employee due to less stretching and more limited energy damping of the smaller net area compared to the net with larger area. In the examinations conducted, it was determined that there was a low awareness in this issue and there were 10 out of 20 S type safety nets that did not meet this criterion.

It has been determined that 31 safety nets are suitable for leaving sufficient clearance distance under the safety net and there is no possibility of collision of the employee falling during the possible stretch of the safety net. It has been observed that the clearance distance is insufficient only under the 5 S type safety nets. Since the insufficient clearance distance creates a risk in S type safety nets installed in large areas, the clearance distance calculation is only given for S type safety nets in the legislation and in the TS EN 1263-2 standard.

Another important issue in safety nets is that the safety nets should be periodically checked and tested using the test mesh. In the examinations carried out, it was observed that 19 safety nets did not have visual controls and it was seen that there is an opinion at the workplaces that these equipment can be used for a long time without any control after the establishment of safety nets by suppliers. However, visual control is of great importance as safety nets can wear out in a very short time due to exposure to sun rays, weather conditions, sharp objects and similar reasons. Safety nets should also be tested once a year to have sufficient strength using test mesh. However, it was observed in the field visits that even many of the safety nets complying with the standards did not have a test mesh. Firms were told that the test mesh was offered as an option by the suppliers and it was stated that the issue of where the firms would perform the test of the test mesh was not explicitly stated in the legislation and it was stated that there is ambiguity in this regard. It was observed that the institutional companies visited renewed their safety nets annually without the need for testing and remained on the safe side without the need for a test mesh.

Finally, safety nets should not be used for waste material or garbage collection and storage, as it is an equipment designed to reduce damage in the fall of employees only. In this regard, it was observed that 19 safety nets out of 36 safety nets were appropriate and it was concluded that there is a need to inform employees more and the controls should be further increased at the construction sites to prevent waste materials from being thrown over the safety nets.

Results

In the current legislation in our country, there are detailed regulations regarding safety nets. However, the use of a safety nets that does not comply with the standards is frequently encountered at the construction sites. The sale of safety nets that do not comply with the standards need to be prevented from selling and being used as there will be ambiguity about their protection and this will lead to vital risks. In addition, as a result of the observations, it has been observed that the necessary measures against fall from height are not taken adequately in the gaps and the edges of the floor and there are some deficiencies in the safety nets installation, usage and control stages. In addition to this, it has been determined that there are no test meshes in safety nets in general, and it is believed that improvements should be made in this regard and the ambiguity related to testing of test meshes in legislation should be eliminated. Accordingly, it has been observed that it is necessary to increase the competencies of the people who will carry out the use and control works of safety nets that are in accordance with the relevant standard. Improvement in this regard will only be possible only if the technical personnel on site are trained more. Finally, before the safety nets are preferred, the availability of fall prevent measures such as edge protection systems that prevent employees from approaching unprotected edges or points should be considered. It should not be forgotten that safety nets should be used as an additional measure to other measures or in work areas where fall prevention is not possible with other measures.

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Examining of One of the Agile Project Management Practices: Scrum in Turkish Construction Industry

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Abstract

Agile project management is a business philosophy that provides constant respond to changing expectations and demands in an uncertain business world. It increases adaptation and efficiency. In order to continuously improve the project product and process, tasks are divided into phases. Its primary purpose is to add value to ensure customer satisfaction. Projects with high uncertainty, complexity and risk are suitable for implementing agile project management. Considering these definitions, it is seen that it is beneficial to implement agile project management in the construction industry. However, this issue is a new concept for the sector. As it is required to clarify this issue, the applicability of one of the agile project management's method scrum, which is the most frequently used process framework, in the construction industry examined by reviewing the literature and conducting a survey. Literature analyzed in the following categories; customer satisfaction and feedback, transparency-inspection-adaptation, lean and agile comparison and integration, the applicability of the building production process. A survey was conducted with 42 professionals about agile project management, scrum and its applicability in the construction industry. As a result of this work, it has been determined that the sector needs these applications and efficiency can be increased by adding new business understanding in the construction industry.

Keywords: *agile construction management, agile project management, scrum.*

Introduction

Agile Project Management

The etymology of the "agile" is based on Latin. The term "agere" with the word root "-ag"; it means going forward and changing directions quickly and easily (URL1). In the informatics industry, where agile methodology was born, agile is defined as a perspective and business philosophy (Yitmen, 2017). Agility is the ability to both make changes and respond quickly and continuously in order to make a profit in the business environment with high uncertainty (Ghani et al., 2016; Highsmith, 2002). In the informatics sector, where uncertainty is high, by dividing the tasks into stages, the project product and process are continuously improved, scope flexibility and production of products suitable for customer needs are provided (Cobb, 2015; Layton, 2011). Values defining agile mentality, guiding principles and revealing are different practices (Agile Practice Guide, 2017). In agile project management, planning and execution cycles are done with short iterations. In this way, the needs mature over time. Main stakeholders are also involved in this process, so quick feedback is provided by responding quickly to requests for changes. At the end of the process, it is beneficial to increase the quality while decreasing the risk and cost (PMBOK, 2016). The first principle in agile project management is to create value by providing customer satisfaction. Thanks to fast and transparent customer feedback, customer demands are responded more quickly (Agile Practice Guide, 2017).

The fact that the project work is identifiable or has high uncertainty is one of the features that affect working approaches. Identifiable studies are described as studies with proven success and open procedures in similar projects conducted in the past. The production area and processes of interest are generally well understood and overall there is a low level of executive uncertainty and risk. In studies with high uncertainty, the rate of change is high, complex and involves risk. For this reason, it is difficult to anticipate all requirements and to keep control of possible changes. Instead of these methods, there is a need to investigate, evaluate and provide feedback by controlling with short cycles. This has been effective in the emergence of agile approaches (Agile Practice Guide, 2017).

The basis of agile management comes from Deming's management science, which has achieved great success in the Japanese industry. Agile management focuses on constant change and adaptation to the uncertain environment. To achieve this situation, it is necessary to ensure win-win, well-explained and sustained communication between the customer, supplier, and manufacturer, which is emphasized in the 14 principles of Deming (Chen et al., 2007). In addition; Koskela and Owen (2006) mentioned that agile management has evolved from the time of post-World War II reconstruction in the Japanese industry.

The agile approaches are based on the values and principles of the Agile Software Development Manifesto published in 2001 by thought leaders in the software industry. The four values of Agile Manifesto are stated by Beck et al. (2001) as follows. The items on the left are more valuable than those on the right:

1. “Individuals and interactions over processes and tools
2. Working software over comprehensive documentation
3. Customer collaboration over contract negotiation
4. Responding to change over following a plan”

Scrum

Scrum, XP (Extreme Programming), Crystal Methods, FDD (Feature Driven Development), DSDM (Dynamic Systems Development Method), Scrumban are agile project management methodology implementation methods (Agile Practice Guide, 2017). In this study, scrum, which is the most frequently used process frame according to Agile Practice Guide (2017), was examined. It was created in 2017 by Ken Schwaber and Jeff Sutherland. Schwaber and Sutherland (2017) defined the scrum as a framework in which people can address complex problems, as well as produce products of the highest possible value productively and creatively. Scrum consists of scrum roles, activities and products (Streule et al., 2016).

Scrum roles consist of product owner, development team and scrum master. This triple group is called the scrum team. The scrum team is a self-organized and cross-functional team. With the scrum team being able to organize itself, it can decide how best to direct their business and does not receive support from outside the team. Thanks to being a cross-functional team, it has the necessary qualifications to complete the job. (Schwaber & Sutherland, 2017). If the number of people in the team is three or fewer, interaction and productivity will be less. Coordination problems will occur in the team of nine or more people. This causes complexity (Schwaber & Sutherland, 2017). Streule et al. (2016) said that if the number of members in the scrum team is 7, the best result occurs. The two members are more or less missing is the situation where the team works effectively. In this way, the Scrum team becomes the team that can take an active role during the project's success, and the process continues with the activities implemented (Agile Practice Guide, 2017).

During the scrum process, kick-off meeting, sprint planning, daily scrum, sprint, sprint review, sprint retrospective activities are applied (Streule et al., 2016). At the kickoff meeting, the scrum development team completes the necessary preparations for the first run. At the sprint planning meeting, the scrum team plans the work they will do in the sprint in front of them and develops a strategy to accomplish these tasks. In the sprint, the team works within the specified time and daily sprint meetings are held during this process. With daily scrum meetings, the team comes together to synchronize and evaluate their progress towards the goal they set at the sprint planning meeting. It is effective to hold daily scrum meetings in the morning in the same place every day, in a short time of 15 minutes before the team starts work. In this way, a sprint review meeting is held after the sprint, which lasts about 1 month. The product owner also attends this meeting and the work done by the team in one month is discussed in the meeting with all transparency. Then a retrospective meeting is held and the team expresses the problems they have experienced during the sprint process, what they have done well, and if there is something to improve before starting the next sprint, the certain action is determined. With these events and meetings, the scrum process is continued (Yitmen, 2017).

During the scrum events, products called product backlog, sprint backlog and increment are revealed. The product backlog is prepared during the kickoff meeting and requests of at least 3-4 sprints are created (Yitmen, 2017). Each item is divided into tasks and represents a simple and detailed explanation of what the development team should do. Sprint backlog is created after the sprint planning meeting. Contains a number of items selected from the product backlog by the product owner and development team. This list contains items that the development team believes can achieve completion during a sprint. Scrum team makes the definition of "Done". When an item is evaluated as completed in the sprint backlog, it is removed from the backlog and included in increments. Thus, the total of all the works considered to be completed constitute increments (Streule et al., 2016).

It is possible to apply the Agile Manifesto principles in all projects with a high level of uncertainty and risk, an end goal difficult to define, requiring research and development, such as the IT sector where it was born (URL2; Agile Practice Guide, 2017). Construction industry is one of these sectors that has this same requirements and it has a lot of waste. Agile in the construction sector, focuses on adapting to uncertain and constantly changing environment and responding quickly to create value (Chen et al., 2007). Since the business environment is uncertain, a proactive approach, not a reactive approach, is adopted (Owen et al., 2006). With agile methods, comprehensive jobs are divided into manageable work packages and jobs are completed in short stages (Jin, 2017). Two types of plans are required for this; long-term planning is completed for the completion of the project, and short-term planning for iterations (Kalinichuk & Tomek, 2015). With this method, the communication in the team increases, the lower ranks are given responsibility and thus the motivation of the employees is increased, they become members of the team who can think independently (Pareliya, 2018).

Literature Review

Within the scope of this study, recent literature research has been made to investigate the applicability and benefits of scrum, which is one of the agile project management implementation methods, in the construction industry. The literature study was researched with the keywords agile project management, scrum, and agile construction management. Considering these studies, it is determined that literature studies focus more on case study and survey studies. When the literature is analyzed, it is determined that these studies focus on customer satisfaction and feedback, agile and lean comparison or integration, uncertainty and adaptability, and usability in building production processes within the scope of agile construction management.

Customer Satisfaction and Feedback

Agile Practice Guide (2017) states that the first principle of agility is customer satisfaction and focus should be on the customer. Accordingly, fast and transparent customer feedback is essential. Thanks to the iterative and incremental life cycles, the customer's change requests are determined in the early phase of the project, and the project is matured and customer satisfaction is increased in the later stages. PMBOK (2017) mentions that frequent feedback increases quality; Ghani et al. (2016) mentioned that the ability to constantly respond to changing expectations and demands in the variable business world increases creativity.

Transparency, Inspection, Adaptation

Scrum has three supporting pillars; transparency, inspection and adaptation. These three pillars help build trust among stakeholders (Scrum Guide, 2017). Saini et al. (2018) and Gopinath et al. (2016) talk about trust between parties and construction organizations to achieve significant success. Transparency ensures that the resulting product means the same thing by all stakeholders, shares a common language, and defines a common “Definition of Done". The inspection is often provided not to prevent the scrum team from doing its job, and errors are detected early. Adaptation helps to correct the errors and failures detected by observation without delay (Scrum Guide, 2017).

Chen et al. (2007), Koskela and Owen (2006)'s articles on changes in agile project management are articles about responding to changes. Jalali et al. (2016) talked about minimizing change requests, while Owen et al. (2006) talked about responding to the chaos caused by constant changes. Chen et al. (2007) and Koskela and Owen (2006) emphasized that adaptability is important to respond to changes. In order for requests for change to be manageable, communication between the participants must be increased. Sohi et al. (2016) say that detailed specifications should be developed with the cooperation of customers, designers and suppliers. Chen et al. (2007) stated that there should be a well-defined and sustained communication between these people, and Jalali et al. (2016) said that the customer should be involved. It is stated that the team doing the job needs the organization's ability to adapt to constant change and an uncertain business environment (Koskela & Owen, 2006). Communication within the team should be increased and the team should be able to think and decide on its own (Pareliya, 2018), be trusted and strengthened (Jalali, 2016). Chen et al. (2007) stated that the team should be versatile except for these features.

Agile-Lean

In the construction sector literature, articles that compare agile and lean were found. Agile Practice Guide (2017) considers agile as the grandson of the lean. Accordingly, lean thinking is a supercluster that shares the same characteristics as agile. Both focus on delivering value, reducing waste as much as possible, respecting people, being transparent, adapting to changes, and continual improvement. Blom et al. (2016) state that lean construction contributes to the management of the construction process and to achieve the goal of the project by reducing waste. Agile project management increases relationship, flexibility and quality. The combination of lean and agile methods cope with project complexity and is the key solution to success. Saini et al. (2018) say that applying lean and agile together will yield good results. According to Chen et al. (2007), lean construction and agile project management both include project complexity. Unlike lean production, agile project management has the ability to respond to continuous changes and adapt to an uncertain business environment. Sohi et al. (2016) stated that the complexity of the project has become manageable with agile and lean methods.

Applicability in Building Production Processes

It is determined that there are differences of opinion about the applicability of agile methods in the construction industry. While Koskela and Owen (2006), Owen et al (2006), Kashikar et al. (2016), Soto et al. (2016) have the opinion that agile methods can be used in the design and planning stages of construction projects; Pareliya (2018) said that it is also useful during the construction phase. According to Pareliya (2018), by using agile methods during the construction phase, the participation of the project development team increases, the customer is included in the process, the delay, uncertainty and risk decreases, and the project process is well followed through regular meetings. The reason why Koskela and Owen (2006) say that the environment is efficient in the design and planning stages is because these stages have similar features to informatics. Owen et al. (2006) mentioned that it will be difficult to apply agile methods during construction. There is a serious cultural difference between employees and employers during the construction phase. It is very difficult at this stage to form a self-managing team that is one of the agile management philosophies. Also, many subcontractors work in the construction phase. It is not easy to instill loyalty to workers in this complexity. Applying agile methods requires major changes early in the construction phase. However, wages taken against the labor force put forward cannot cover each other. Independent work item is excessive, early and continuous delivery cannot fulfill the requirement of the construction phase. In short, he mentions that it is difficult to implement agile project management without ensuring cultural change in the sector.

Dasika et al. (2016) stated that agile methods are effective at the design stage and lean methods at the construction stage as a result of the examinations on the basis of India. Soto et al. (2016) say that scrum should be used in the design and planning stages of the construction, while Pareliya (2018) says that it provides benefits during the construction phase.

Survey on Determination of Agile Project Management Need in Turkish Construction Sector

A survey was conducted to investigate the awareness, applicability and application conditions of agile project management, which is a new concept for the construction industry, in the Turkish construction sector. In this survey, the participation of the employees in the construction sector, regardless of their occupation and experience, is ensured. The scope of the survey application area, the target audience was kept wide. It was aimed that the participants are actively working in the construction industry.

Data Collection Process and Method

While preparing the survey questions, the principles explained above and agile project management and scrum implementation principles were taken as basis. The questionnaire was prepared on the Survey monkey online survey site. It was communicated to the construction sector employees with the link providing sharing. There are 2 question groups in the survey. Identity information of the participants in the first question group; in the second question group, questions were asked about agile project management and thoughts about scrum.

Since the Survey monkey application was run on a trial version, Excel could not be obtained as a test. The "Question Abstracts" and "Individual Answers" tabs search and analyze the questionnaire. A graphical representation of the responses of the participants was obtained from the "Question Abstracts" section. Survey responses of the participants are included in the "Individual answers" section. The features of the participants and responses of the participants to the questions were written on the Excel table and comparisons were made.

Findings

The survey was conducted with 42 employees from the construction industry. Of these persons, 18 are architects, 15 are civil engineers, 5 are electrical / mechanical engineers, and 4 are technicians. The survey was answered by 10 people with 1-3 year experience, 3 people with 4-6 year experience, 2 people with 7-9 year experience, and 27 people with 10 years and above experience. When the types of companies studied, it was seen that the highest rate of answers came from the project management firm. 17 people from the project management company, 11 from the contractor company, 10 from the design firm, 3 from the subcontractor and 1 from the public sector participated in the survey.

In the questionnaire, the fourth question includes items related to agile project management and scrum, which is one of the application methods. These items were evaluated under 4 main headings during the evaluation of the results; customer satisfaction and feedback, adaptation, transparency and openness, organization and business culture.

Table 1. Demonstration of the application methods of agile project management asked in the survey under main headings.

	Customer Satisfaction and Feedback	Adaptation	Transparency and Openness	Organization & Business Culture
Primary purpose: Customer satisfaction	X			
Respond quickly to changing demands		X		
Active stakeholder communication			X	
Extensive documentation				X

BIM instead of extensive documentation				X
Minimum change request		X		
Changes in organizational culture				X
Self-organizing and cross-functional team				X
Iterative planning				X
Pre-determined meetings				X
Coordination with team meetings			X	
Feedback to ensure continuous improvement	X			
Organizational learning				X
Ensuring trust in communication with transparency			X	

Customer Satisfaction and Feedback

In the questions about customer satisfaction and feedback, it was seen that most of the participants thought in line with the agile project management principles. The percentage of people who think that ensuring customer satisfaction should be a primary goal is 80.96%. It is determined that experienced professionals and those working in design firms make up a large part of this percentage. 8 out of 10 people working in the design firm said that customer feedback is important. The rate of those who think that continuous improvement should be provided with both internal and external customer feedback is 90.24%. It is understood by the participation of 9 out of 10 designers in this article that design firms are more open to customer feedback.

Adaptation

It is seen that all participants support the ability to respond quickly to changing demands in adaptation. Those who think that change requests should not be ignored in order not to exceed cost and time are 59.52%. A large part of this rate consists of the participants working in the project management company. 76.47% of the project managers who responded think that implementing the required change requests is more important than cost overrun and timeout. Half of the participants support the plan throughout the project and try to minimize the demands for changes. Comparing the adaptation abilities, it is understood that the ratio of experienced employees with less than 10 years is higher, in this case, young people respond more quickly to the changes.

Transparency and Openness

When the issue of transparency and openness is examined, the rate of employees who agree with the idea that communication between stakeholders should be actively is 95.24%. 61.9% of the participants think that active stakeholder participation benefits clarity rather than complexity. Looking at the group that thinks it will cause complexity, it is seen that the employees of the design firm are more than the others. Short-term meetings held on a daily basis to ensure coordination within and outside the team are actually one of the scrum implementation steps. Agile business model is put into practice thanks to the meetings held on a daily basis and planned. The percentile that thinks these meetings are necessary is 78.57%. 82.3% of the employees in the project management firm, responsible for ensuring coordination, stated that these meetings are necessary. 97.56% of the participants participated in the idea that trust would increase among stakeholders by ensuring transparency in communication. It has been observed that the opinions about the transparency in communication in the construction sector are almost equally distributed. With a percentage of 38.09%, it is seen that the number of people who are hopeless to ensure transparency in communication is more than the others.

Organization and Business Culture

When the subject of business and organizational culture is examined, it is seen that 88.09% of the participants participated in the issue that comprehensive documentation is beneficial in increasing the project success. According to the agile project management manifesto, it is written that this item is less important than producing software that works. However, it has been understood that the comprehensive documentation understanding of the construction industry professionals is different from the IT sector. Thanks to technological developments such as BIM and artificial intelligence related to this article, the participation rate to the opinion that there will be no need for documentation is 45.24%. While the rate of participants who think that the current organizational culture of companies is changeable is 42.85%, the rate of people who think not to be changed is 40.48%. The majority of the group, who think that the organizational culture can be developed in order to adapt to changing conditions, is made up of the employees of the project management company. It was seen that 95.23% of the participants approved the change of culture in order to adapt to the changing business world. Being a self-organizing and multidisciplinary team is one of the agile project management application features. It has been observed that the rate of responses given to these items supports agile methods. It was answered by the participants in accordance with the agile project management application method, in other words, with the 90.47% rate, in which the recurring short and long term planning will lead to productive results and the efficiency of the meetings whose predetermined period and duration are determined will increase the efficiency. Finally, the idea that organizational learning is necessary for firm employees and firm success has been confirmed by 95.24% of the participants. A person working in the public sector took part in the survey and thinks it will be useful to apply agile methods under this heading. 84% of those working in the project management office, 81% of those working in the design firm, and 81% of those working in the contractor or subcontractor firm think that it will be beneficial for the construction industry in terms of organizational culture and business model. It is understood that the project management office supports this issue more than other fields and the sector needs agility in terms of organizational culture.

Conclusion

When the uncertainty is high, the rate of change is high and it causes risk. In order to reduce this risk, it is necessary to anticipate the requirements and keep the changes under control. This situation reveals the need for agile project management. Agile project management ensures adaptation to changes in an uncertain business environment, creating value and increasing customer satisfaction.

Scrum, which is one of the methods of agile project management, divides the team into 3 groups as product owner, scrum master and development team. Defines the interaction and tasks between them. In order to respond to the changes, daily, monthly meetings are held and the team can easily adapt to the change requests thanks to its multidisciplinary and cross-functional features.

Agile project management and one of its application methods, scrum's literature studies on the basis of construction sector are examined. It has been observed that studies have been carried out in order to ensure customer satisfaction by creating value from the most important features of the business environment, the importance of transparency to ensure trust between the stakeholders, the advantages of adapting to the uncertain business world, applicability in building production processes and comparison with lean. It is determined to be a new concept for the construction industry.

As a result of the survey conducted to 42 employees from construction industry, it was determined that the construction sector needs agile project management. When the questionnaire study is examined in titles, the prioritization is made for agile project management and scrum, the order of importance according to the results is as follows:

1. Adaptation: It is considered important to be able to respond quickly to changing demands and to make decisions.
2. Transparency and Openness: Communication between stakeholders should be actively provided. In addition, ensuring transparency in communication will increase trust among stakeholders.
3. Organization / Business Culture: If necessary, changes can be made in the organizational culture in order to adapt to the changing business world. In addition, organizational learning is thought to be essential for company employees and success.
4. Customer satisfaction and feedback: Providing both internal and external customer feedback will contribute to the increase of lessons learned and continuous improvement.

To conclude, the construction sector needs agile project management and methods. The value will only be increased in this way. The responses of professionals in the industry during today's pandemic reveal that traditional methods are not suitable for doing business and how agile we should be in the face of this great uncertainty and variability affecting our health.

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Towards a Better Understanding of Construction Disputes: A Literature Review

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Abstract

The complexity of the construction projects and involvement of the thousands of details require many different participants from various disciplines to work together in the construction project process. This multidisciplinary nature of construction projects makes disputes inevitable. It is of great importance to understand the nature of the factors causing disputes, which can negatively affect the relationships and prevent completion of projects successfully. For this reason, determining these factors and taking precautions against them will protect the project participants from many losses. In this regard, this paper aims to analyze the factors causing disputes which occur in the construction industry. In order to reach this aim, a comprehensive literature review was undertaken. The disputes derived from the literature, were classified into seven broad categories depending on their nature and mode of occurrence. The dispute categories are organized as: owner related, contractor related, design related, contract related, human behavior related, project related and external factors. Finally, the main factors are identified for each dispute category by analyzing them in detail.

Keywords: *causes of disputes, construction disputes, construction management, dispute factors.*

Introduction

Nowadays, construction projects change considerably with the effect of growing globalization and competition. Construction systems are developing, projects are growing, increasing and becoming more complex with the development of technology and innovation. The construction industry incorporates many interrelationships, including owners, architects, engineers, contractors, subcontractors, manufacturers, material suppliers, public institutions and organizations. The increasing intertwinement of the parties involved in handling construction projects is one of the major factors contributing to the emergence of disputes (Cheung & Yiu, 2006).

In this complex environment involving participants from different specialties, each has different goals and needs according to their own positions. Therefore, the existence of disputes in a project team is considered normal. The increase in the number of participants of different cultural background in the construction value chain means more business interactions and arguments, whether contractual or social, resulting in an increase in the number of construction disputes (Kumaraswamy & Yogeswaran, 1998).

Disputes are one of the main factors which prevent the successfully completion of the construction project. Thus, it is important to be aware of the causes of disputes in order to complete the construction project in the desired time, budget and quality (Cakmak & Cakmak, 2013). It is observed that the dispute rate has increased in many countries and the development and construction processes in these countries have affected the performance negatively. There are many sources in the literature that disputes generally cause cost increases, project delays, and negative relationships among project participants. Regarding this, Cheung and Suen (2002) concluded in their study that "If disputes are not properly managed, they may cause project delays, undermine team spirit, increase project costs, and, above all, damage business relationships". Also, Lowe and Leiringer (2007) describe disputes as being the source of possible time and cost overrun and possible adversarial relationships between the different parties.

It is vital to understand the nature of these causes which can negatively influence the quality of relationships and ultimately serve as an obstacle to sustainability of construction relationships (Jelodar et al., 2013). For this reason, determining these factors and taking precautions against them will protect the project participants from many losses. Therefore, understanding the underlying causes of disputes in construction projects in many countries has been the subject of an ongoing research among academics, consultants, lawyers and other research professionals.

In this context, this paper aims to analyze the factors causing disputes which occur in the construction industry. In order to reach this aim, a comprehensive literature review was undertaken, disputes in construction projects in different countries and the factors that cause these disputes are examined. It has been observed that the studies examined within the scope of the literature review, the disputes that arise in the construction projects conducted in different countries and the factors that cause these disputes vary depending on the socio-economic, cultural, demographic structure and geographical conditions in the respective countries.

Relationships between Conflicts, Claims and Disputes

There is confusion among construction professionals about the differences between conflict and dispute, and these terms have been used interchangeably especially in the construction industry (Acharya et al., 2006). If the definitions of each concept made by different people in different periods are briefly mentioned, it is necessary to start with the notion of "claim", which often causes conflicts and disputes.

Powell-Smith and Stephenson (1993) also described a "claim" as a general term for the assertion of a right to money, property or a remedy. Once a claim has been presented, the owner and contractor can come to an agreement concerning the claim and, thereby, create a change order or a modification, or they may disagree and create a dispute (Zaneldin, 2018). It is thought that unsolved claims will lead to disputes. However, it should be noted that, not all conflicts do necessary lead to claims, and as well as not all claims result in disputes (Narh et al., 2015).

However, conflict and dispute are two distinct notions (Fenn et al., 1997). Conflict has been defined as a serious difference or disagreement between two or more beliefs, ideas or interests (Kumaraswamy, 1997). Disputes in the construction industry often entail a variety of definitions. It is common for the words dispute and conflict to be used interchangeably, although conflicts may not necessarily evolve into disputes. The phenomenon of conflict, observed in all walks of life, arises from an incompatibility of ideas, interests, values, or actions between individuals or factions (Love et al., 2011). The meaning and the conceptual distinction between the terms conflict and conflict are illustrated graphically in Fig. 1.

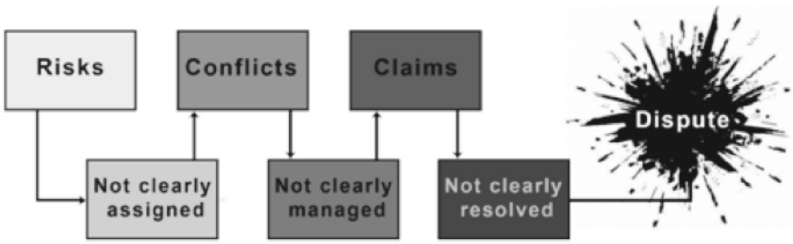

Figure 1: Risk, conflict, claim and dispute continuum model (Acharya & Lee, 2006).

Due to differences in perception and conflicting goals among the participants in a project, conflicts in the construction project environment are inevitable (Cheung & Suen, 2002). If not properly managed, these conflicts can quickly turn into disputes. Thus conflicts, claims, and disputes could be considered an unavoidable consequence of the construction process (Fawzy & El-adaway, 2012; Ogburn & El-adaway, 2013).

Analysis of Literature Review on Dispute Factors

There has been considerable research undertaken to determine the causes of disputes in the construction industry. Within the scope of the paper, a comprehensive literature review has been conducted in order to overview the factors causing construction disputes. The review focused mainly on searching relevant academic papers towards the research objective. The following databases were utilized: Emerald Insight, American Society of Civil Engineers (ASCE), Elsevier and Taylor & Francis. The search rule employed in the Title/Abstract/Keyword (T/A/K) field of the selected databases was (“dispute”) AND (“factors”) AND (“construction”) with no time restriction. Eventually, 58 ones were considered as most relevant to the research aim and were subject to a detailed review.

Although care has been taken to select the studies examined within the scope of the research to represent different countries; it is seen that many studies are the studies that include general results regarding the construction sector not limited to a country. While 19 of the studies reviewed included general results at the international level; in studies conducted in some countries, the United States and Turkey is in first place with four studies. Three studies from the UK, the United Arab Emirates and Australia; Two studies from Saudi Arabia, Sri Lanka, Pakistan, the Middle East, Canada and Hong Kong; One study from New Zealand, Thailand, Egypt, Malaysia, Korea, Ireland, Ghana, Palestine, Indonesia and China were examined. Table 1 summarizes the causes of disputes which are determined by several researchers from different countries.

Table 1. Dispute factors in literature (Adapted from Kumaraswamy, 1997).

Researchers	Country	Disputes Factors
Assaf et al. (2019)	Saudi Arabia	**Causes to be the most significant contributors to claims and disputes:** (1) Change or variation orders due to new requirements from client, (2) Variations in quantities due to new requirements from client, (3) Delay caused by contractor, (4) Design errors or omissions, (5) Inconsistencies in the drawings and specifications
Illankoon et al. (2019)	Sri Lanka	**Causes for disputes:** (1) Failure to properly administer the contract, (2) Error omissions in contract documents, (3) Incomplete design information or Employer requirement, (4) Failure to understand and/or comply with its contractual obligations by either party, (5) Poorly managed construction process leading to shortage of resources and quality issues, (6) Diverse interpretation of contract terms, (7) Lack of interpersonal skills among professionals, (8) Opportunistic behavior of project parties, (9) Lack of experience in construction practices and management, (10) Lack of corporation and trust among parties, (11) Conflicting goals and objectives of project parties, (12) Reluctance of project participants to deal with changes, (13) Inadequate risk identification/allocation, (14) External changes such as changes in market conditions and environmental regulations, (15) External uncertain factors such as weather conditions or environmental regulations
Mishmish and El-Sayegh (2018)	UAE	**Causes of claims:** (1) Variations, (2) Contractor's delay, (3) Inadequate site investigation, (4) Inadequate documentation, (5) Unforeseen conditions, (6) Delay in granting possession of site, (7) Specifications and drawings inconsistencies, (8) Different perception in assessment (9) Poorly written contract, (10) Third-party interference, (11) Late issue of instruction, (12) Payment-related issues, (13) Defects in works, (14) Termination / suspension of works, (15) Acceleration, (16) Measurement-related issues
Zaneldin (2018)	UAE	**Frequent cause of claims:** (1) Change/variation orders, (2) Delay caused by owner, (3) Owner personality
Barman and Charoenngam (2017)	UK	**Core reasons for construction disputes:** (1) Contracts with adequate provisions, (2) Contract misinterpretation, (3) Evasion of contractual commitments, (4) Inefficient collaboration in association with institutional uncertainty, (5) Contracts with inadequate provisions, (6) Incompleteness of information, (7) Opportunistic behavior guided by strategic uncertainty, (8) Behavioral conflict over incomplete contracts
Awwad et al. (2016)	Middle East	**Disputes root causes:** (1) Opportunistic behavior of contract parties, (2) Incomplete and contradictory contract documents, (3) Ill-defined scope of work, (4) Unfair risk apportionment
Yildizel et al. (2016)	Turkey	**Main five dispute causes:** (1) Low quality of completed works, (2) Late payment by the owner, (3) Poor site management by the project management company, (4) Poorly prepared contracts, (5) Design mistakes
Jelodar et al. (2015)	New Zeland	**Common causes of conflict and dispute:** (1) Project uncertainties, (2) Contract and processes, (3) People and behavior
Narh et al. (2015)	Ghana	**Various causes of conflicts:** (1) Failure of clients to honor payments, (2) Delays in time for project completion, (3) Type of procurement method adopted, (4) Breakdown in communication, (5) Conflicting commitment of project managers, (6) Absence of qualified personnel in key positions, (7) Unclear and incomplete description of items in the bills of quantities, (8) Differences in views among stakeholders, (9) Errors, defects or omissions in contract documents, (10) Inaction on the part of contractors, (11) Deficiencies in designs, (12) Uncomplimentary behavior of clients, (13) Unrealistic expectations from clients, (14) Behavior of sub-contractors, (15) Unforeseen site problems, (16) Dissatisfaction of work progress of main contractor by

		Architect/Engineer, (17) Contract awards to incapable contractors, (18) Lack of team spirit among project team members
Treacy et al. (2015)	Ireland	**Seven core critical factors of construction disputes:** (1) Payment and extras, (2) Physical work conditions, (3) Poor financial/legal practice, (4) Changes to the agreed scope of works, (5) Time overrun, (6) Defects, (7) Requests for increase in speed of project and long-term defects
Farooqui et al. (2014)	Pakistani	**Causes of disputes:** (1) Unrealistic tender pricing, (2) Poor supervision, (3) Rising value of dollar, (4) Delay in payments, (5) Inappropriate contract type, (6) Absence of construction management, (7) Breaches of contract by the project participants, (8) Inadequate design documentation, (9) Exaggerated claims
Khahro and Ali (2014)	Pakistani	**Main causes of conflict:** (1) Delay in payment, (2) Contractual claims (on extension of time and financial claims), (3) Public interruption, (4) Poor communication, (5) Differing site conditions
Mahamid (2014)	Saudi Arabia	**Top five direct dispute causes are:** (1) Delay in progress payment by owner, (2) Unrealistic contract duration, (3) Change orders, (4) Poor quality of completed works, (5) Labor inefficiencies **Top five indirect dispute causes are:** (1) Inadequate contractor's experience, (2) Lack of communication between construction parties, (3) Ineffective planning and scheduling of project by contractor, (4) Cash problems during construction, (5) Poor estimation practices
Mitkus and Mitkus (2014)	General	**Main causes of conflicts:** (1) Unclear agreement of contractual terms and conditions, (2) Poor communication process, (3) Unsuccessful communication process, (4) Unfair behavior, (5) Effects of psychological defenses
Cakmak and Cakmak (2013)	General	**Main causes of dispute causes:** (1) Owner related, (2) Contractor related, (3) Design related, (4) Contract related, (5) Human behavior related, (6) Project related, (7) External factors
Cheung and Pang (2013)	General	**Task factor** (1) Collaborative conflict, (2) Risk and uncertainty **People factor** (1) Opportunistic behavior, (2) Affective conflict **Contract incompleteness** (1) Ambiguity, (2) Deficiency, (3) Inconsistency, (4) Defectiveness
Erdis and Ozdemir (2013)	Turkey	**Reasons of technical specification-based disputes:** (1) Project characteristics, (2) Human-origin factors, (3) Planning-origin, (4) Construction process origin, (5) External factors
Ilter (2012)	Turkey	**Dispute factors:** (1) Variations, (2) Late instructions by the employer, (3) Inadequate/incomplete specifications, (4) Unclear contractual terms, (5) Adversarial approach in handling conflicts, (6) Unclear scope definition, (7) Poor communication, (8) Unfamiliarity with local conditions and (9) Technical inadequacy of the contractor
Ayudhya (2011)	Thailand	**Top five disputes factors domestic funded projects:** (1) Violating condition of the contract, (2) Insufficient working drawing details, (3) Delay in progress payment by owner, (4) Evaluation of completed works, (5) Poorly written contract **Top five disputes factors international funded projects:** (1) Insufficient working drawing details, (2) Violating condition of the contract, (3) Delay in progress payment by owner, (4) Inaccurate bill of quantities, (5) Unrealistic contract durations
Jaffar et al. (2011)	Malaysia	**Three main conflict factors:** (1) Behavioral problems (poor communication among project team, multicultural team problem and reluctant to check for constructability, clarity and completeness of project), (2) Contractual problems (late giving of possession, delay interim payment from client and unclear of contractual terms), (3) Technical problems (contractor fails to proceed in a competent manner and late instructions from architect or engineer)
Gad et al. (2010)	General	**Significant disputes:** (1) Different contractual factors, (2) Cultural backgrounds, (3) Legal and economic factors, (4) Languages, (5) Technical standards,, (6) Procedures, (7) Currencies, (8) Trade customs

Love et al. (2010)	Australia	**Underlying pathogens contributing to disputes:** (1) Nature of the task being performed (failure to detect and correct errors), (2) People's deliberate practices (failure to oblige by contractual requirements), (3) Circumstances arising from the situation or environment the project was operating in (unforeseen scope changes)
Enshassi et al. (2009)	Palestine	**Main causes of claims:** (1) Awarding bid to the lower bidder, (2) Border closures, (3) Residents' interference during project implementation, (4) Road blockage and difficulties in passing between cities and governorate
Abeynayake (2008)	Sri Lanka	**Main reasons for disputes in Sri Lanka:** (1) Breaches of contract by any party to the contract, (2) Inadequate administration of responsibilities by the owner or contractor or subcontractors, (3) Some plans and specifications that contain errors, omissions and ambiguities, (4) Sudden tax and cost increase
Cheung and Yiu (2007)	Hong Kong	**Dispute sources:** (1) Construction related, (2) Human behavior related
Abd El-Razek et al. (2007)	Egypt	**Three most important causes:** (1) Variations initiated by owner / consultant, (2) Inferior quality of design, drawings and/or specifications, (3) Delays of approval of shop drawings, instructions and decision making
Soekirno, (2007)	Indenosia	**Grouped the causes of disputes:** (1) External conditions, (2) Change of drawings document, (3) Condition of the field, (4) Change of technical specifications, (5) Others (e.g., cost estimates, professional ethics and licensing)
Yiu and Cheung (2007)	General	**Significant sources:** (1) Construction related: variation and delay in work progress, (2) Human behavior parties: expectations and inter parties' problems
Acharya et al. (2006)	Korea	**These factors with importance weighting are:** (1) Differing site condition, (2) Public interruption, (3) Differences in change order evaluation, (4) Design errors, (5) Excessive contract quantities variation, (6) Double meaning of specifications
Cheung and Yiu (2006)	General	**Three root causes of disputes:** (1) Conflict - Task interdependency, differentiations, communication obstacles, tensions, personality traits, (2) Triggering events - Nonperformance, payment, time, (3) Contract provision
Waldron (2006)	Australia	**Key causes in disputes:** (1) Variations to scope, (2) Contract interpretation, (3) EOT claims, (4) Site conditions, (5) Late, incomplete or substandard information, (6) Obtaining approvals, (7) Site access, (8) Quality of design and (9) Availability of resources
Zaneldin (2006)	UAE	**Most common causes of claims:** (1) Change orders, (2) Delay caused by owner, (3) Planning errors
Adriaanse (2005)	General	**Causes of disputes:** (1) Material/workmanship quality, (2) Delays, (3) Variations, (4) Cost increase and (5) Different interpretations of the contract provisions
Ashworth (2005)	General	**Causes of disputes:** (1) General (contracts, communication, fragmented structure of the sector, tendering practices), (2) Employer (scope, variations, changes made in standard contracts, interventions to the PM, payment delays), (3) Consultants (design errors, inexperience, late/inadequate instructions, lack of coordination, inadequate responsibility descriptions), (4) Contractors (insufficient site management, inadequate planning, quality, problems with subcontractors, delay in paying subcontractors, insufficient coordination of subcontractors), (5) Subcontractors (failure to oblige by contractual requirements, quality) and (6) Suppliers (low performance products)
Chan and Suen (2005)	China	**Problem areas of dispute:** (1) Payments, (2) Variations, (3) Extension of time, (4) Quality of works, (5) Project scope definition, (6) Risk allocation, (7) Technical specifications, (8) Management, (9) Unrealistic client expectations, (10) Availability of information, (11) Unclear contractual terms, (12) Unfamiliarity with local conditions, (13) Difference in way of doing things, (14) Poor communication, (15) Adversarial approach in handling conflicts, (16) Lack of team spirit, (17) Previous working relationships, (18) Lack of knowledge of local legal system, (19) Conflict of laws and (20) Jurisdictional problems

Fryer et al. (2004)	General	**Situations that are prone to disputes:** (1) Inception/briefing/tendering, (2) Design, (3) Construction operations and (4) Project management
Killian (2003)	USA	**Causes of disputes:** (1) Project management procedure (change order, pre-award design review, pre-construction conference proceedings, and quality assurance), (2) Design errors (errors in drawings and defective specifications), (3) Contracting officer (knowledge of local statues, faulty negotiation procedure, scheduling, bid review contracting practices: contract familiarity/client contracting procedures), (4) Site management (scheduling, project management procedures, quality control, and financial packages) and (5) Bid development errors (estimating error)
Sheridan (2003)	General	**Causes of disputes:** (1) Valuation of variations, (2) Valuation of final account and (3) Failure to comply with payment provisions
Brooker (2002)	General	**Causes of disputes:** (1) Payment, (2) Delay, (3) Defect / quality and (4) Professional negligence
Birgonul and Gunay (2001)	Turkey	**Causes of disputes:** (1) Ambiguities in contract documents, (2) Payment, (3) Ineffective planning, (4) project deficiencies, (5) legal factors, (6) Technical inadequacy, (7) poor workmanship, (8) Quality of materials
Mitropoulos and Howell (2001)	USA	**Factors that drive the development of a dispute:** (1) Project uncertainty, (2) Contractual problems, (3) Opportunistic behavior
Daoud and Azzam (1999)	Middle East	**Causes of disputes:** (1) Employer's interference in contracts, (2) Misunderstanding of contractual obligations, (3) Legislation changes and subsequent regulations, (4) Poor design documents, (5) Impact of local culture and social environment
Kumaraswamy and Yogeswaran (1998)	General	**Sources of construction disputes are:** (1) Contractual matters, (2) Including variation, (3) Extension of time, (4) Payment, (5) Quality of technical specifications, (6) Availability of information, (7) Administration and management, (8) Unrealistic client expectation and determination
Yates (1998)	General	**Causes of disputes:** (1) Variations, (2) Ambiguities in contract documents, (3) Inclement weather, (4) Late issue of design information / drawings, (5) Delayed possession of site, (6) Delay by other contractors employed by the client and (7) Postponement of part of the project
Kumaraswamy (1997)	Hong Kong	**Common top ten cause of disputes:** (1) variations due to site conditions, (2) Variations due to client changes, (3) Variations due to design errors, (4) Unforeseen ground conditions, (5) Ambiguities in contract documents, (6) Variations due to external events, (7) Interferences with utility lines, (8) Exceptional inclement weather, (9) Delayed design information and (10) Delayed site possession
Conlin et al. (1996)	UK	**Six key dispute areas:** (1) Payment and budget, (2) Performance, (3) Delay and time, (4) Negligence, (5) Quality, (6) Administration
Sykes (1996)	General	**Two major groupings of claims and disputes:** (1) Misunderstandings, (2) Unpredictability
Bristow and Vasilopoulous (1995)	Canada	**Five primary causes of claims:** (1) Unrealistic expectations by parties, (2) Ambiguous contract documents, (3) Poor communications between project participants, (4) Lack of team spirit, (5) Failure of participants to deal promptly with changes and unexpected outcomes
Diekmann and Girard (1995)	General	**Root causes of disputes:** (1) People, (2) Process, (3) Product
Heath et al. (1994)	UK	**Seven main types of disputes:** (1) Contract terms, (2) Payments, (3) Variations, (4) Extensions of time, (5) Nomination, (6) Re-nomination, (7) Availability of information
Rhys-Jones (1994)	General	**Ten factors in the development of disputes:** (1) Poor management, (2) Adversarial culture, (3) Poor communications, (4) Inadequate design, (5) Economic environment, (6) Unrealistic tendering, (7) Influence of lawyers, (8) Unrealistic client expectations, (9) Inadequate contract drafting, (10) Poor workmanship

Semple et al. (1994)	Canada	**Four common causes of claims:** (1) Acceleration, (2) Restricted access, (3) Weather/cold, (4) Increase in scope
O'Connor et al. (1993)	USA	**Critical causes:** (1) Contractor's lack of planning and scheduling, (2) Owner's reliance on exculpatory clauses, (3) Erroneous plans, (4) General nature of rehabilitation projects
Spittler and Jentzen (1992)	General	**Causes of disputes:** (1) Ambiguous contract documents, (2) Competitive / adversarial attitude, (3) Dissimilar perceptions of fairness by the participants
Watts and Scrivener (1992)	Australia	**Most frequent sources include claims arising from:** (1) Variations, (2) Negligence in tort, (3) Delays
Hewit (1991)	General	**Six areas:** (1) Change of scope, (2) Change conditions, (3) Delay, (4) Disruption, (5) Acceleration, (6) Termination
Diekmann and Nelson (1985)	USA	**Specific claim types:** (1) Design errors, (2) Discretionary or mandatory changes, (3) Differing site conditions, (4) Weather, (5) Strikes, (6) Value engineering
Hohns (1979)	General	**Five primary sources of construction disputes:** (1) Existence of errors, (2) Defects or omissions in the contract documents, (3) Failure of someone to count the cost of an undertaking at the beginning, (4) Changed condition, (5) Consumer reaction and people

Table 1 presents a synopsis of disputes factors in the relevant literature. A review of the table reveals that despite the fact that researchers have concentrated on various causes of disputes, there is a certain level of commonality in the factors that lead to disputes throughout the construction industry. Accordingly, the common dispute factors are classified into seven broad categories depending on their nature and mode of occurrence. The main dispute categories are identified as (1) owner related factors, (2) contractor related factors, (3) design related factors, (4) contract related factors, (5) human-behavior related factors, (6) project related factors, and (7) external factors. Consequently, common dispute factors by categories are identified and presented in Table 2.

Table 2. Common dispute factors by categories.

Category of Disputes	Causes of Disputes
Owner related factors	• Variations • Payment delays • Administration and management • Late giving of possession • Unrealistic expectations • Delays of approval • Accelerations • Poor cost estimation
Contractor related factors	• Delays in work progress and extension of time • Quality of works • Technical inadequacy of the contractor • Negligence and defect from the contractor • Financial failure of the contractor • Ineffective planning and scheduling
Design related factors	• Design errors • Inadequate/incomplete specifications • Availability of information • Quality of design
Contract related factors	• Ambiguities and deficiencies in contract documents • Contractual problems • Different interpretations of the contract provisions • Risk allocation

Human behavior related factors	• Lack of communication • Opportunistic behavior • Lack of team spirit • Adversarial / controversial culture
Project related factors	• Site conditions • Unforeseen changes • Project characteristics
External factors	• Legal and economic factors • Weather • Culture

The mode of occurrence of dispute factors examined in the literature is also given by their frequencies in Fig. 2.

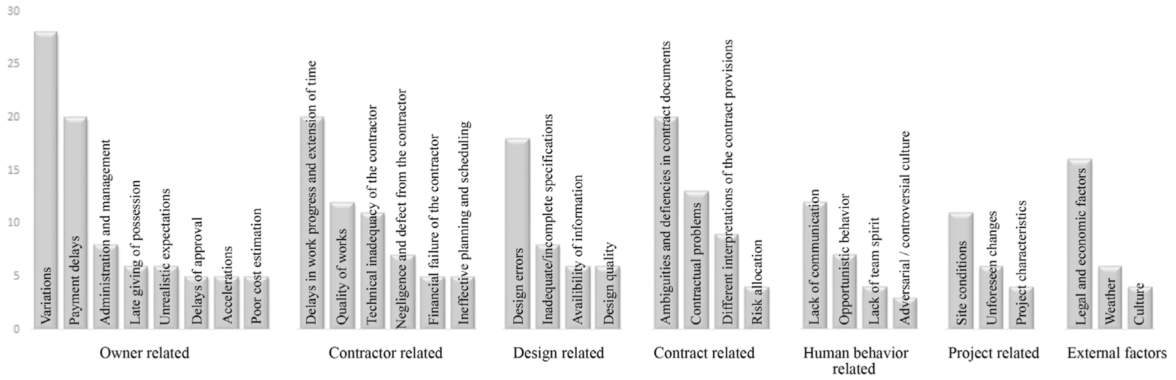

Figure 2: Frequency of factors causing disputes in literature review.

Subsequent to the analysis of the reviewed literature, a questionnaire was developed to assess the relative importance of identified dispute factors. The questionnaire was directed towards experts and practitioners who engaged in construction disputes within the Turkish construction industry. The results will be presented and discussed in a further study.

Conclusion

Disputes prevent successful construction projects from being successfully completed within the budgeted cost, planned time and accepted quality limits. For this reason, determining the factors that cause disputes in construction projects and taking precautions regarding them will protect the project and the project participants from many negative effects and will make important contributions to the successful completion of the project.

In this paper, the main dispute factors in the construction industry were analyzed with the help of a comprehensive literature review. Through the literature review, a total of 32 different dispute factors were identified and categorized into seven broad categories namely, owner related disputes, contractor related disputes, design related disputes, contract related disputes, human behavior related disputes, project related disputes, and external factors. All these dispute categories are presented with their associated dispute factors. Therefore, the paper helps to reveal the most common dispute factors in the construction industry. The findings of the paper can be helpful for project managers or other participants to identify and mitigate causes of disputes factors in construction projects. In the light of the findings revealed as a result of the study, potential problem areas that may cause dispute before starting a construction project can be identified in advance and necessary measures can be taken to prevent disputes among the project participants.

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Comparing the Benefits of CPM and PERT for the Project Manager in Terms of Different Construction Projects

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Abstract

With the increase in the world population, the need for industrialization due to urbanization increases the demand for planning. In fact, the investigations to increase national developments after the Second World War led to the development of the concept of "planning" around the world. The increase of the complex projects and the uniqueness of each project enables planning as a vital parameter. Optimization of time, cost and quality parameters is the most indispensable mission of modern project management. The impact of time delays in projects on planning and budgeting is a significant problem for project stakeholders and especially the project manager. However, the work program, which is mandatory at the contract stage in the Turkish public construction sector, has not reached the desired level in the private sector. Besides, national scientific studies on scheduling tools are limited. In this study, the scheduling of the productions selected from the residential and school projects in Kayseri province was performed using CPM and PERT. Thus, the benefits of different projects, as well as the methods used, for the project manager can be compared. The findings obtained from the study are expected to guide the project stakeholders and contribute to the field.

Keywords: *construction management, scheduling, CPM, PERT*

Introduction

The most significant share in the growth of the country's economies belongs to sectors such as agriculture, industry, trade, and construction. The construction sector has the most significant share among these sectors. The percentage of the construction sector in the Gross Domestic Product is approximately a 30% level (KPMG, 2018). It is possible to complete the projects produced in the construction sector within the desired time, quality, and cost, with coordinated work. This coordinated work is provided by the concept of 'project management'.

Project management is the art and science of coordinating people, equipment, materials, budget, and programs to complete a specific project on time and at the desired cost (Oberlender, 2000). Project management covers all phases of the project, allowing the organization of the investor to be organized and followed up with the project management team (Sorguc, 2005). The American Construction Management Association of America (CMAA) defines project management as controlling time, cost, profit, and quality by applying professional management methods in all phases of a project (Tulubas Gokuc, 2006). Heldman et al. (2001), defined project management as the whole system to achieve the desired goal by planning, executing, and controlling the resources required for a job (Heldman et al., 2001). Oberlender (2000) on the other hand defined project management as balance management between scope, budget, and planning and stated that quality is an indispensable element in this balance, shown in Figure 1. Scope means the amount and quality of the job, the budget is the cost that can be measured, and the program is the logical sequence and timing of the job (Oberlender, 2000).

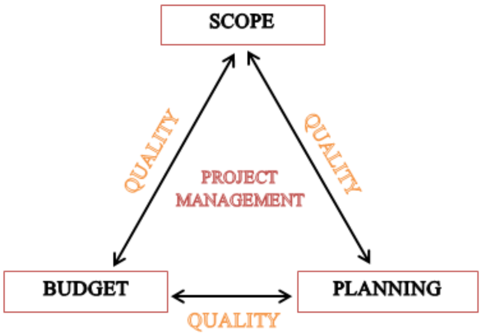

Figure 1: Balance in Project Management (Oberlender, 2000).

Due to the combination of different disciplines in the projects, the specificity of the projects and the growth of the project volumes, the importance of project management currently has increased and has become a milestone of competition among companies. In today's economic conditions, it has become essential to evaluate projects in terms of time and cost, and it has become an essential goal to produce the best quality work at the most appropriate time and cost. The concept that forms the appropriate method and strategy system to achieve this purpose is project planning. Project planning is the establishment of a method and strategy system in line with the project objectives (Taner, 2019), from the beginning of the project to its closure, as shown in Figure 2.

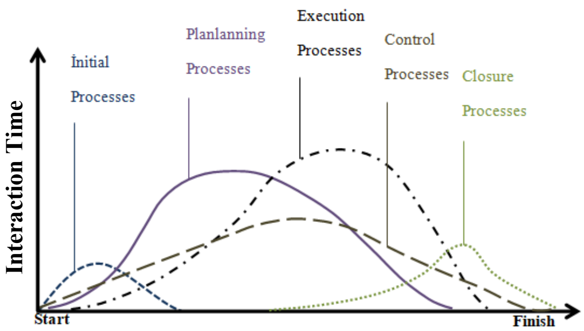

Figure 2: Project management process interaction (Taner, 2019).

Planning in Project Management

Project planning is of great importance in the construction sector with the increase in both technology and complexity of projects in recent years. Project planning is the process of determining the actions required to achieve the project management objective (Gultekin, 2005). Inceoglu (1980) defined planning as 'bringing together tools and directing actions to achieve goals'. Oberlender (2000) stated that planning is the creation of an action plan to guide the completion of a project. It is a dynamic process that includes questions about why, how, when, and for whom the project planning will be done, as shown in Figure 3. In this dynamic process, the actions of the works are controlled, and revisions are performed according to the possible deviations.

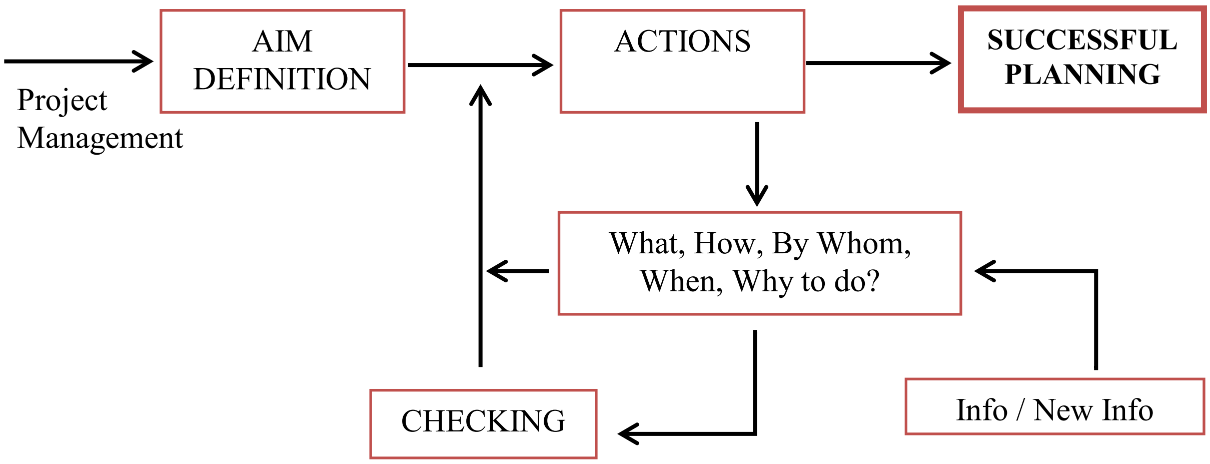

Figure 3: Project planning process cycle (Gultekin, 2005).

For the planning to be successful, it is essential for all parties involved in the project to participate in the planning process and to determine restrictions and critical activities (Oberlender, 2000). Project planning provides the opportunity to take the necessary measures for the opportunities and dangers in the project process by making the right decisions and carrying out and following the appropriate activities (Barutcugil, 1984). While some of these activities are independent of each other, the realization of some activities takes place due to the successful completion of another activity (Durucasu, 2015). It is ensured by project planning techniques to determine the relationships and durations of these activities and to rank them in line with the priority relationship and to control them during and after implementation. Towards the end of the 1950's, studies on the development of project planning and programming techniques started to be carried out and reached today. Project planning techniques include Gantt diagrams, Critical Path Method (CPM), Program Evaluation, and Review Technique (PERT), Equation Bar Method, and Saddle Method (Gunaydin, 2001). PERT and CPM diagrams are used to observe critical information such as the order of activities in the project, the effect and priority of activities to each other, the effects of problems affecting the functioning between activities (Seker, 2015).

Material and Method

Since project management is a competitive criterion today, project planning, a unique way to make the project management successful, has gained importance. The work program, which is mandatory at the contract stage in the Turkish public construction sector, has not reached the desired level in the private sector. Besides, academic studies related to work program tools such as CPM and PERT are limited. In this study, the scheduling of the productions selected from the housing and school projects in Kayseri province was performed using CPM and PERT. Thus, the benefits of different projects, as well as the methods used, for the project manager can be compared. The obtained data were examined and the effect of quality, duration, and cost problems that may arise with the changes in scheduling, have been investigated and the suggestions have been made to the stakeholders.

Application

Currently, people's needs for housing, education, public, health, and sports structures have increased in line with the growth of cities. Due to the population density is directly proportional to the human needs, the structures selected within the study area were selected from the central districts with the highest population density. Within the scope of the study, two schools (A-B) and two residential buildings (C-D) in the central districts of Kayseri were examined, as presented in Figure 4.

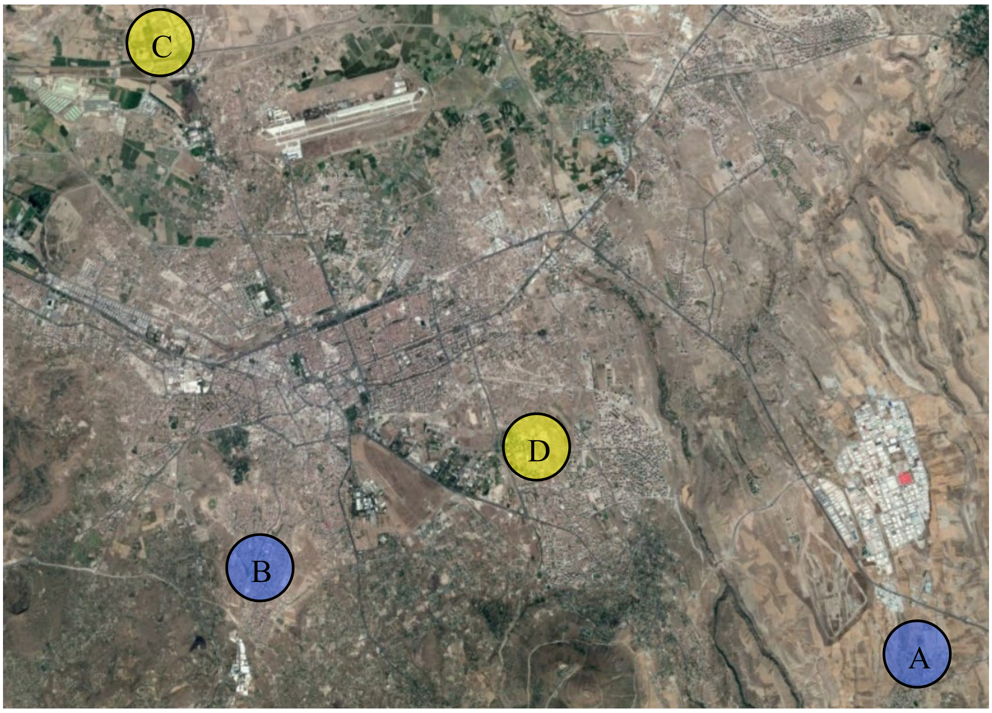

Figure 4: Location of the projects (https://earth.google.com, 2020).

The school (A) with 15 classrooms located in Talas district, which has a closed area of 1,820.00 m². (A) consists of three floors: basement, ground floor, and one normal floor, as seen in Figure 5. Another school (B) that is being examined is in the Melikgazi district and consists of 43 classrooms. (B) consists of two floors, the ground floor, and one normal floor, and has a closed area of 3,750.00 m² as seen in Figure 6. The main data of schools (A) and (B) are presented in Table 1.

Table 1. Data of schools examined.

Schools	A	B
Location (District)	Talas	Melikgazi
Indoor Area (m²)	1,820.00 m²	3,750.00 m²
Number of Floors	3	2
Number of Classrooms	15	43

Figure 5. School (A) (http://www.meb.k12.tr/,2020).

Figure 6. School (B) (https://www.mynet.com/, 2020).

Within the scope of the study, the residential building (C) examined in Kocasinan district, consists of 34 flats and four shops. (C) consists of 10 floors including basement, ground floor, seven normal floors, and attic, which has a closed area of 3,800.00 m² as shown in Figure 7. Another residential building (D) is in the Melikgazi district and consists of 27 flats and a shop. (D) consists of 16 floors including basement, ground floor, 13 normal floors, and attic, which has a closed area of 5,335.00 m² as shown in Figure 8. The main data of residential buildings (C) and (D) are presented in Table 2.

Table 2. Data of Residential buildings examined.

Residences	C	D
Location (District)	Kocasinan	Melikgazi
Indoor Area (m²)	3,800.00 m²	5,335.00 m²
Number of Floors	10	16
Number of Flats	34	27
Number of Shops	4	1

Figure 7. Residential building (C) (https://earth.google.com, 2020).

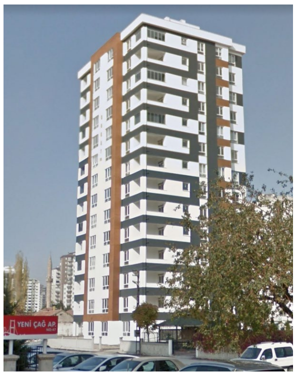

Figure 8. Residential building (D) (https://earth.google.com, 2020).

Findings

All activities carried out within the examined projects are carried out by separate groups of workers. Among the activities to be carried out in a project; "Formwork Activities (I), Reinforcement Steel Activities (II), Concrete Activities (III), Brick Wall Activities (IV)" were selected. Quantity takeoff of these activities were performed for each project. Afterwards, a resource analysis was performed according to the unit price list prepared by the Turkish Ministry of Environment and Urbanization. In line with these data, duration analysis of the activities was carried out, as presented in Table 3.

Table 3. Quantity takeoff summary and duration analysis of the activities.

Project	No	Exposure Number	Work	Quantity	Time of Completion with Unit Team (Days)	Number of Teams	Number of Shifts	Number of People in the Teams	Time to Completion with Increased Team (Days)
A	I	Y.21.001/03	Formwork	4.530,57 m²	664	3	2	6	110
	II	Y.23.014	R. Steel	112.834,00 t	280	10	1	5	28
	III	Y.16.050/16	Concrete	1.278,00 m³	37	4	1	2	9
	IV	Y.18.001 /C12	Wall	1.181.19 m²	34	3	1	4	11
B	I	Y.21.001/03	Formwork	13.446,48 m²	1644	10	2	3	83
	II	Y.23.014	R. Steel	231.446 t	235	6	2	7	19
	III	Y.16.050/16	Concrete	2.226,76 m³	38	4	2	5	5
	IV	Y.18.001/C12	Wall	6.735,14 m²	504	4	1	6	126
C	I	Y.21.001/03	Formwork	10.181,17 m²	1120	6	2	6	93
	II	Y.23.014	R. Steel	119.524 t	198	3	1	3	66
	III	Y.16.050/16	Concrete	2.018,13 m³	31	2	1	5	16
	IV	Y.18.001/C12	Wall	3.004,68 m²	334	2	2	6	83
D	I	Y.21.001/03	Formwork	12.221,77 m²	1494	10	2	3	75
	II	Y.23.014	R. Steel	121.638 t	157	2	1	13	79
	III	Y.16.050/16	Concrete	2.177,10 m³	37	3	1	5	12,3
	IV	Y.18.001/C12	Wall	704,22 m²	56	2	1	3	28

In line with the data obtained, five parameters were calculated for each activity, including the earliest start (ES), the earliest finish time (EF), the latest start (LS), the latest finish time (LF) and total abundance, in order to plan each project with the CPM method. Following, a CPM diagram was created according to the duration of each activity and the interdependence of the activities. The CPM diagram of the activities selected from the school project (A) consisting of 15 classrooms was initially created, and it was determined that it could be completed in a period of 129 days, as seen in Figure 9. Afterwards, a CPM diagram was created for the school project (B) consisting of 43 classrooms, and it was seen that it could be completed in 104 days, as seen in Figure 10.

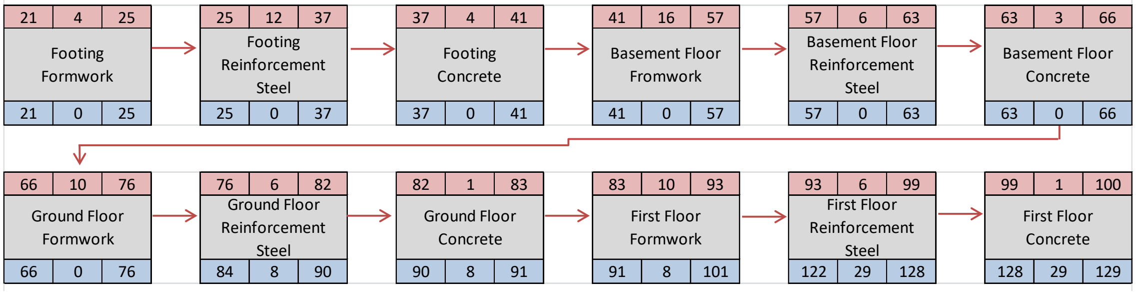

Figure 9: CPM diagram of school project (A).

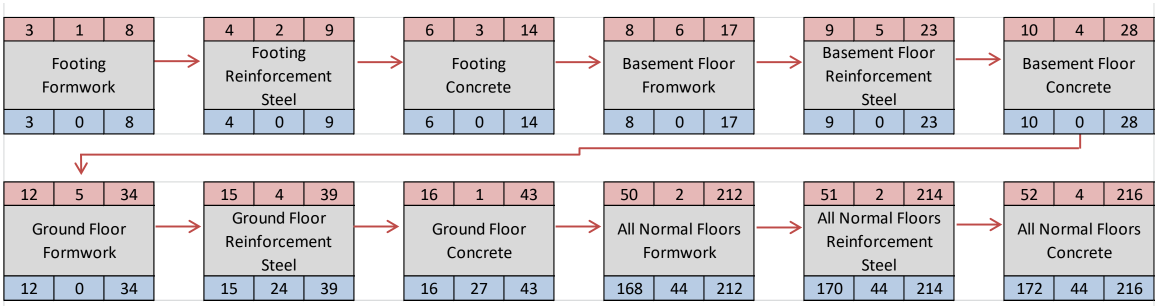

Figure 10: CPM diagram of school project (B).

At the second stage, A CPM diagram was created for the residential building project (C) consisting of 34 apartments and four shops, and it was determined that it could be completed in 216 days as seen in Figure 11. Afterwards, a CPM diagram was created for the residential building project (D) consisting of 27 apartments and a shop, and it was seen that it could be completed in 243 days as seen in Figure 12.

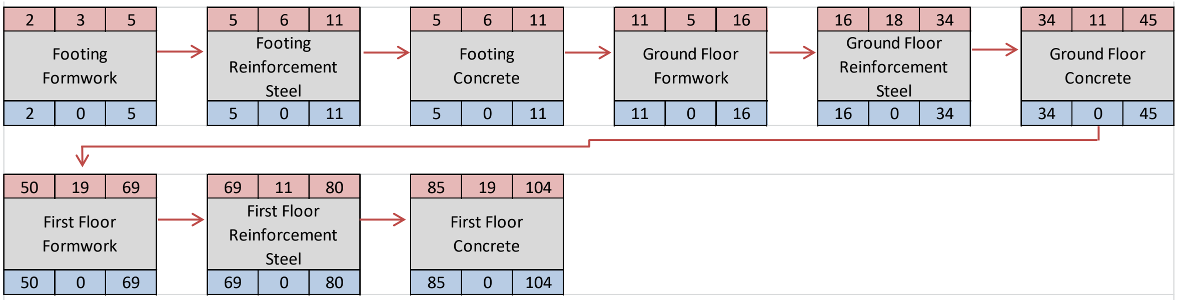

Figure 11: CPM diagram of residential building project (C).

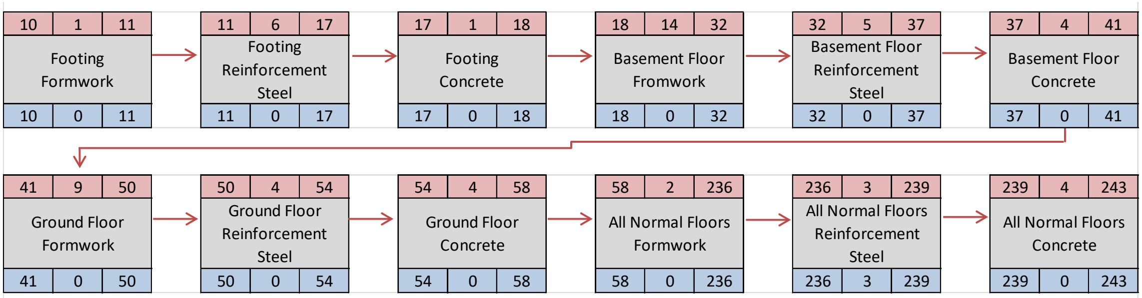

Figure 12: CPM diagram of residential building project (D).

Delphi method was used to plan each project using PERT at the last stage. Within the scope of Delphi method, a five-person estimator group consisting of technical staff (architect, civil engineer, and technician) was determined for the activities selected in the projects. PERT diagrams were created by making calculations with the data from estimators. Initially, it was determined that the activities selected from the school project (A) consisting of 15 classrooms could be completed in 67-85 days in a PERT diagram as seen in Figure 13. Then a PERT diagram was created for the school project (B) consisting of 43 classrooms, and it was seen that it could be completed in a period of 115-143 days as seen in Figure 14.

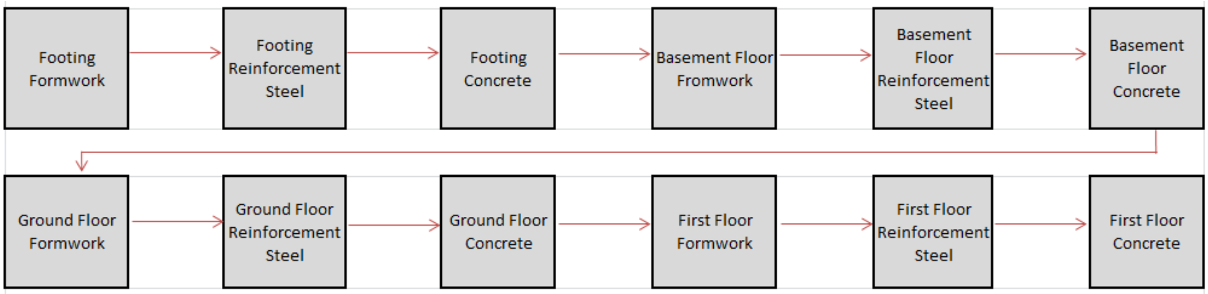

Figure 13: PERT diagram of school project (A).

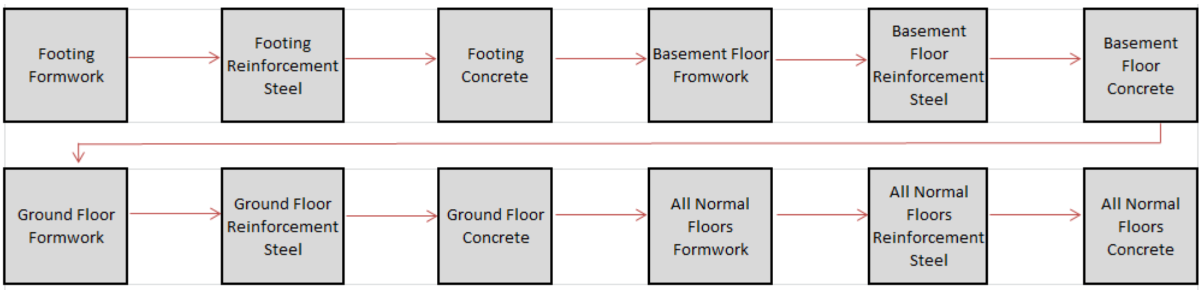

Figure 14: PERT diagram of school project (B).

Similarly, for the residential building project (C) consisting of 34 flats and four shops, a PERT diagram has been established, and it can be completed within a period of 164-202 days as seen in Figure 15. Finally, for the residential building project (D) consisting of 27 flats and a shop, a PERT diagram was created, and it can be completed in a period of 218-266 days as seen in Figure 16.

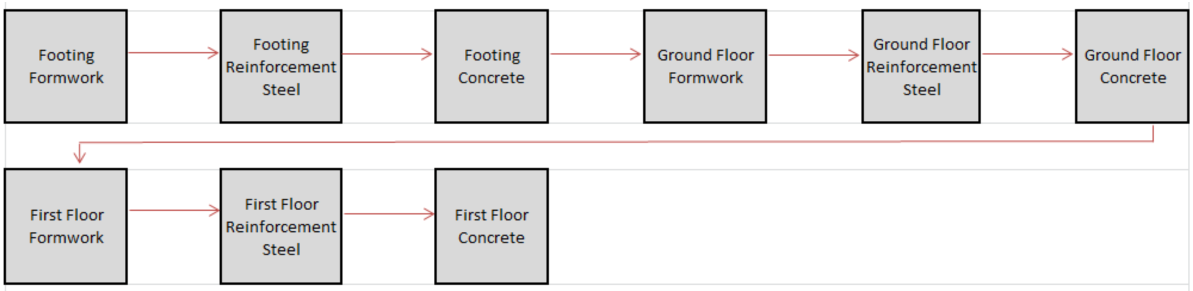

Figure 15: PERT diagram of residential building project (C).

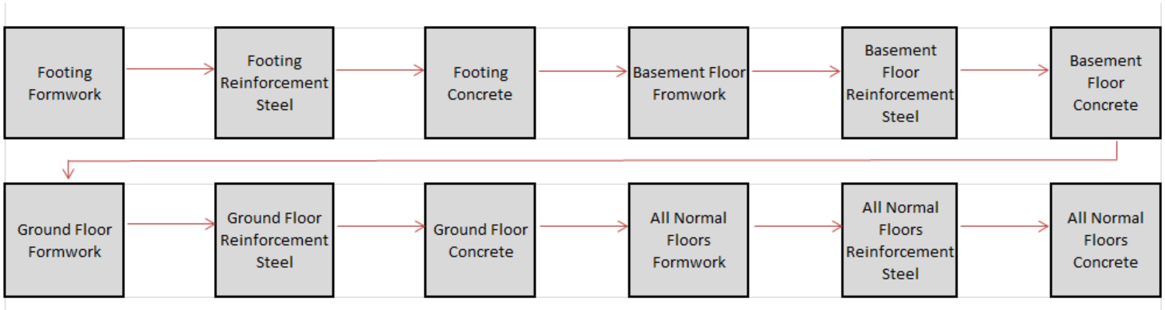

Figure 16: PERT diagram of residential building project (D).

Results

In this study, the CPM and PERT diagrams of the selected activities were created, and the completion times of the activities were determined for two schools and two residential buildings in Kayseri province of Turkey, as presented in Figure 17.

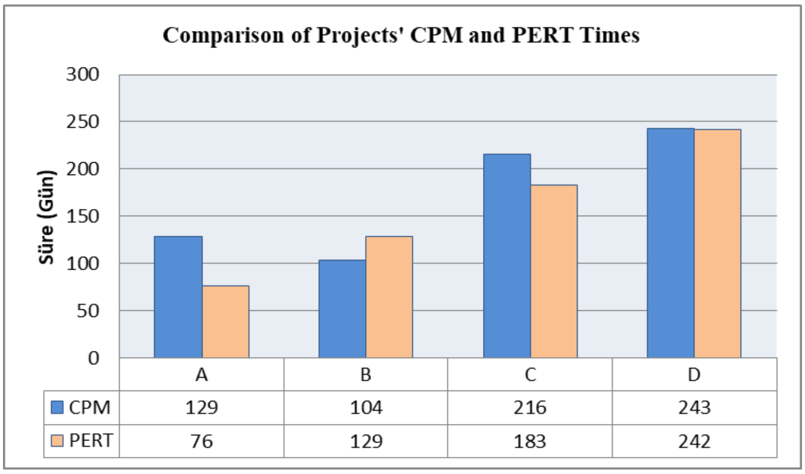

Figure 17: Comparison of projects' CPM and PERT times.

Based on the data obtained, it was determined that the main difference between the CPM and PERT diagrams was in the time estimates. Since the projects have different functions, different volumes, and different floor heights, this allows project managers to choose the optimum or near optimum alternatives by comparing different time combinations of the projects. It has also been determined that planning the projects separately with CPM and PERT techniques provides project managers with different perspectives and facilitation in building the problem structure. Thus, the necessity of the project manager to manage the project planning process by observing which activities, duration, and costs can be accelerated in the projects. With this type of analysis, which is trusted to be accurate, the project management will be able to succeed by making time analysis of the project stakeholders in the planning process of projects in public and private investments. This study will contribute to future academic studies and stakeholders in the building industry.

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A Framework for BIM-Based Accurate Formwork Quantification

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Abstract

Although Building Information Modeling (BIM) has been paving the way for faster and more reliable quantity take-off processes, there are still some problems while obtaining the formwork area from information-rich 3D models. These issues are usually due to the overlaps between different components and the wrong modeling of structural elements. Generally, modelers should create models by following appropriate guidelines to represent the actual construction sequence of structural elements for obtaining the proper area quantities. However, models mostly contain an excess amount of modeling mistakes, and they do not provide correct geometry for the extraction of formwork areas, because of the limited time available for modeling during the design stage and human errors caused by misinterpretations. This study proposes a framework for extracting formwork quantities using Autodesk Revit Dynamo to acquire relevant area information from 3D models. Therefore, an example model is created in Autodesk Revit, from which accurate formwork quantities can be extracted, and then traditional hand calculations are used as a benchmark to validate model correctness. As a result, a framework is presented in this paper, which can be followed to obtain the required structural surface areas correctly. This framework can be used as a guideline for modeling structural elements and can be a baseline for developing a dynamo code to extract structural surface areas automatically.

Keywords: *automation, building information modeling (BIM), formwork, quantity take-off*

Introduction

Collaboration in the architecture, engineering, and construction (AEC) industry advances with the adoption of Building Information Modeling (BIM), which brings increased profits and reduced costs (Azhar, 2011). This is because BIM creates a single repository of data enabling to share information throughout the project lifecycle, which is significantly different from the conventional approach that forces project participants to work predominantly in their field with less understanding of the overall design and construction process (Cheung et al., 2012). Therefore, BIM provides a smart platform for the exchange of building information between different stakeholders, and thereby it creates an environment for extracting cost information (Firat et al., 2010). The models include essential information to extract bills of materials, geometric sizes of components, material costs, and other related inputs for cost estimation, which can also be linked or updated in the course of the projects (Ashcraft, 2008). Hence, BIM-based quantity take-off (QTO) has gained importance over the years and has proven its superiority over the conventional quantification process which is based on measuring and counting from 2D drawings.

Even though BIM-based QTO plays a prominent role in the construction industry, there are some obstacles resulting from the application of BIM. The main drawback is that information about the construction phase required to perform QTO is still not fully included in building information models (Olsen & Taylor, 2017). This is due to the 3D modeling process or limitations in software features. For example, placing construction joints in the wrong places and modeling a building component with different family types are some of the reasons for deviations in BIM-based QTO (Bečvarovská & Matějka, 2014). Moreover, composite building components such as walls and floors are difficult to manage in BIM tools; even though section details represent the original configuration, the wall and floor components in the 3D model are still single elements with the same dimensions for every layer of that component (Monteiro & Martins, 2012). Therefore, QTO and detailed cost estimation in construction companies are eventually carried out using traditional 2D drawings since estimators cannot adequately rely on building information models (Aram et al., 2014).

This study aims to reveal the limitations of BIM-based QTO for structural formwork and propose a framework to increase the accuracy of formwork area calculations from BIM models. Moreover, a simple reinforced concrete (RC) building is investigated to verify the proposed framework and to demonstrate several limitations of an existing BIM software's features.

BIM-Based Quantity Take-Off

Quantity take-off (QTO) is the measurement and interpretation of various design drawings, including plans, elevations, sections, and details (Monteiro & Martins, 2013). Traditionally, estimators draw up an organized list of materials based on their measurements over construction drawings, and then these measurements are used for cost estimation. For this reason, estimators need to carefully examine each drawing and perform the calculations accordingly to avoid double-counting or omissions from the drawing sets (Olsen & Taylor, 2017). Eventually, this process gets tedious and time-consuming since designs are always changing, and details are increasing throughout the project lifecycle. Shen and Issa (2010) made a categorization of time spent on paper-based QTO, including identification of items and their relations, investigating drawings for relevant dimensions, converting these dimensions into units of measurements such as area and volumes for different materials. Although this categorization may seem straightforward and easy, revisions in the design process entail the need to reinvestigate each drawing over time. Hence, traditional QTO becomes iterative and ineffective since design feedbacks between different stakeholders create time-lags during reviews, and consequently, cost estimation and QTO process slow down (Cheung et al., 2012).

At this point, BIM-based QTO facilitates the quantification process as the models include essential geometric information for quantity extraction. In this way, construction practitioners can access material quantities in various formats to examine and group information whenever it is essential (Masood et al., 2014). It also helps surveyors to concentrate on more important tasks other than counting and measuring recurrently, which adds more value to the projects (Sabol, 2008).

However, the quality of BIM models, which requires comprehensive and structured information, is the main disadvantage in the BIM-based QTO (Smith, 2014). Therefore, construction practitioners find BIM-based QTO unreliable owing to the limited and misleading information available in building models and due to the amount of time required for checking the model correctness (Olsen & Taylor, 2017). Several researchers have proposed different solutions for these issues over the years, some of which are presented in Table 1.

Table 1. BIM-based QTO in literature for various building components.

Author (s)	Building Components	The Focus of the Study
Khosakitchalert et al. (2020)	Architectural walls and floors	Proposed an algorithm to automatically modify Autodesk Revit models for the quantification of finish materials by using Dynamo and Revit API.
Khosakitchalert et al. (2019)	Architectural walls and floors	Developed an algorithm to extract surface area information from Autodesk Revit models by using Dynamo.
Kim et al. (2019)	Interior building components such as masonry, wood, thermal and moisture protection, insulation, and finishes.	Addressing quantity discrepancies in interior materials due to model representation and unnecessary modeling and providing suggestions for the BIM modeling process to reduce inconsistencies in model components for interior building material quantification.
Liu et al. (2016)	Light frame walls	Proposed a construction-oriented QTO system with an ontology-based semantic approach and developed an Autodesk Revit add-on with a semantic search user interface to visualize the query results for better communication among parties.
Choi et al. (2015)	Concrete structural components Steel structural columns and beams	Suggested a process for schematic QTO for the early design stage by developing a model in Autodesk Revit, checking model quality in Solibri Model Checker, and performing QTO in InSightBIM using IFC models.
Monteiro and Poças Martins (2013)	Earthwork, coatings, concrete components, masonry walls, doors, windows, and MEP elements	Investigated QTO features of Graphisoft ArchiCAD to reveal problems on quantification of distinct building components and suggested different solutions to overcome software and modeling limitations.
Cheung et al. (2012)	Walls, floors, roofs, stairs, ramps, doors, and windows	Represented the cost module of LIDX (Low Impact Design Explorer) for early design cost estimation in Google SketchUp environment as the design progresses.
Firat et al. (2010)	Architectural, structural and HVAC components	Performed case studies to investigate model-based QTO at the construction site by using Tekla Structures and VicoControl.

According to the studies in Table 1, various building components were investigated to increase the accuracy of BIM-based quantification. Some studies mainly focused on implementing modeling guidelines and visual programming tools to increase the efficiency of the quantification process. Others conducted case studies and proposed distinguished frameworks to test and enhance the estimation capacity of BIM tools. Moreover, studies are mainly emphasized architectural walls and floors, which are composite elements requiring detailed QTO process.

In the case of formwork, Meadati et al. (2011) conducted a study creating a concrete formwork knowledge repository for students, which can be used for design checks, material take-off, constructability analysis, and automatic shop drawing preparation. Lee et al. (2009) proposed a formwork layout planning system by making priority analysis among cost, constructability, safety, quality, and site characteristics. Kannan & Santhi (2013) studied the advantages of climbing formworks over conventional formwork systems in terms of constructability in the BIM environment. Cho & Chun (2015) created a cost estimation system extracting physical shape information from 3D models for formwork quantification and assigned the unit price to formwork quantities to find the construction cost of total formwork. Khosakitchalert et al. (2019) introduced a visual programming algorithm to calculate concrete formwork areas.

Considering the endeavors to increase the efficiency of BIM-based QTO process and relevant studies conducted on formwork quantification in the literature, this research proposes a framework for formwork area quantification of core RC components in Autodesk Revit. The main idea is to identify common modeling mistakes and software limitations and then to propose a framework to retrieve area information correctly from BIM models.

Proposed Framework For Bim-Based Formwork Qto

Monteiro and Martins (2013) states that BIM software does not allow modelers to create formwork elements directly from structural models. Therefore, formwork models need to be created with other categories such as walls and floors, and this requires significant time. Other than modeling, accurate formwork area calculation in BIM tools is not also possible when different elements intersect (Monteiro & Martins, 2013). For example, BIM software remains incapable of deducting the formwork area where beams intersect with structural walls and slabs, and formwork is eventually overestimated (see Figure 1).

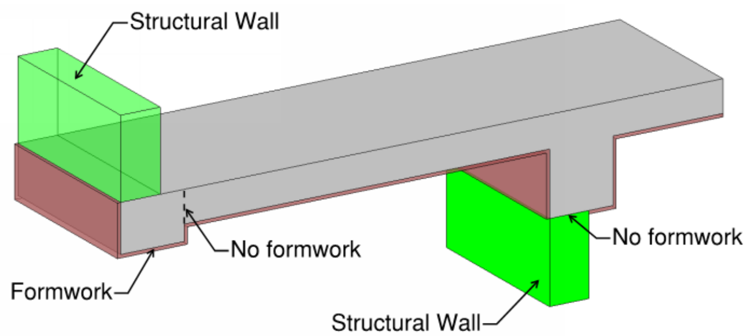

Figure 1: Typical formwork application for a structural floor section.

Furthermore, modeling mistakes also reduce the accuracy of BIM-based QTO. To exemplify, Autodesk Revit accurately calculates wall surface areas, without openings, for correctly modeled structural elements, and these areas can also be used as formwork area. If wall elements are modeled wrongly and intersect with columns and beams, then the area information deviates significantly (see Figure 2a and 2b).

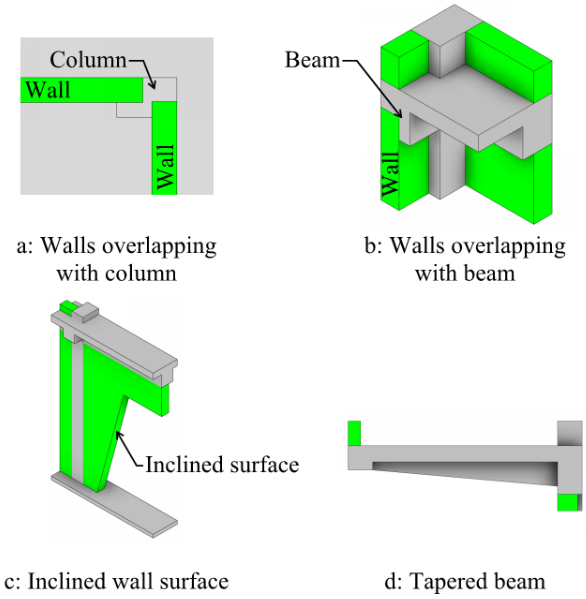

Figure 2: Typical challenges in formwork calculations.

Although overlapping areas create problems for formwork quantification, they can be corrected manually. On the other hand, wall opening surfaces, inclined surfaces, elimination of intersected areas, and stair surfaces cannot be extracted with the current capability of Autodesk Revit. Hence, an external tool, such as Revit Dynamo, needs to be utilized to obtain formwork area information from BIM models.

For this reason, a framework that defines significant steps to calculate formwork areas of common structural elements is presented in Figure 3. Accordingly, building element surfaces are obtained from the BIM model, and firstly the elimination of overlapping parts is done for all structural components. Then element surfaces connecting to the formwork area of other elements are removed for all structural elements except for foundations. It is because top surfaces of foundations, which other elements are connecting, are separately removed together with the bottom surfaces since they do not require formwork material.

After that, door and window opening surfaces and inclined surfaces are included for wall formwork area. Slanted column and tapered beam surfaces are also extracted and included in the quantification process. For slabs, deductions at slab penetrations and openings are made, and formwork for slab edges is included in the calculation process. Besides, stair surfaces are extracted for formwork calculations.

After all, all formwork surfaces are gathered, and the formwork area is calculated. Finally, the formwork model is created.

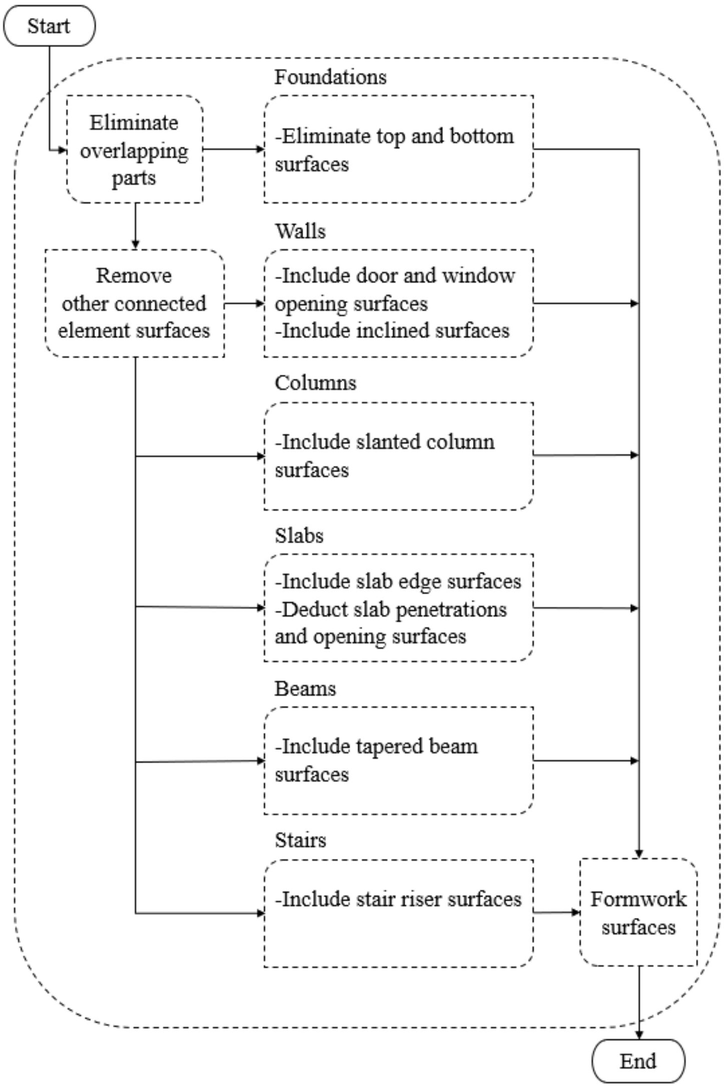

Figure 3: The proposed framework to calculate formwork areas accurately.

Results and Discussions

As an example, a simple RC structure is created in Autodesk Revit 2021 environment (see Figure 4a), and the proposed framework is modeled in Revit Dynamo to calculate and create structural formworks, as shown in Figure 4b & 4c.

Furthermore, quantities are extracted by using *Schedules/Quantities* and *Material Take-off* features of the Revit software. According to Autodesk Knowledge Network, the *Material Take-off* option schedules all the materials assigned to a component or subcomponent, but *Schedules/Quantities* option only provides general properties of components. For example, a wall element can be scheduled with both methods, but in the case of individual material take-off in the wall layers, the *Material Take-off* option needs to be used. In addition, formwork areas extracted from the Revit model are compared with manual calculations. It is also important to note that the material *paint option* is used to paint formwork requiring surfaces in the case study so that the *Material Take-off* option can be utilized for structural elements' formwork area.

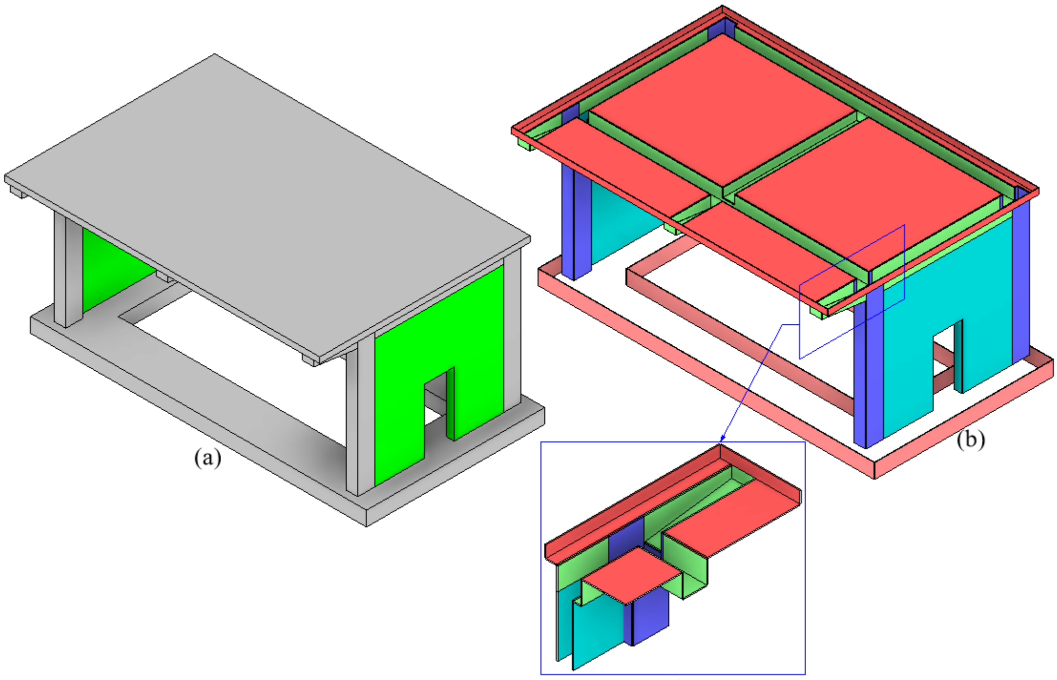

Figure 4: (a) RC structure for the case study. (b) Formwork view for the entire structure created by Revit Dynamo. (c) Formwork view for beam, column, and wall intersection

Consequently, a comparison of formwork quantities obtained from manual calculations, Dynamo, and Revit are presented in Table 2. According to results in the table, *Schedules/Quantities* and *Material Take-off* options in Autodesk Revit do not always accurately provide formwork area information for main structural elements. The reasons for deviations are listed below.

- Foundation formwork areas are calculated by adding a calculated schedule parameter using automatically assigned foundation perimeter and thickness parameters in *Schedules/Quantities* option. Since the perimeter parameter is not deducted when two foundations join with each other, formwork is overestimated. In the case of *Material Take-off* option, formwork surfaces are painted with a specific material, and the *Split Face* option is used to separate formwork requiring surfaces from joined surfaces. For this reason, the *Material Take-off* option is more reliable than *Schedules/Quantities,* but it requires additional time and further modeling effort for splitting formwork surfaces.

- Wall formwork area is first calculated with *Schedules/Quantities* option and then *Material Take-off* option. Deviations between manual calculations and these methods are negligible for this case, but it is interpreted that as the number of openings in walls increases, deviations increase; hence the QTO becomes unreliable in *Schedules/Quantities* option since it does not account for opening faces.

- Column formwork is the most problematic one for formwork quantification in Revit. It is because the *Split face* cannot be applied in the *Material Take-off* option, and wall and beam areas connecting to columns cannot be deducted from the overall formwork area. Similarly, *Schedules/Quantities* option does not work at column-wall and beam-column connections. Hence, deviations between manual calculations and Revit calculations are the highest for this case study.

- Beam formwork calculation is more accurate in *Schedules/Quantities* option than *Material Take-off* option because of the implementation of calculated schedule parameters by using predefined beam parameters such as volume and beam thickness. The *Material Take-off* option provides less accuracy than the *Schedules/Quantities* option because it does not work for beams as it does for columns.

- Slab formwork area can be extracted precisely the same as manual calculations if the *Material Take-off* option is applied. Hence, the *Split face* option needs to be used to eliminate beam areas. *Schedules/Quantities* option provides inaccurate results since it does not account for beam-slab intersections.

For these reasons, Revit schedules for formwork quantification are not always trustworthy, and it can mislead the estimators. On the other hand, the quantity results obtained by Dynamo are precise as the same values as the manual calculations are obtained for all structural components. It is also noted that stair elements are included in the framework but exempt from the case study since it requires a more detailed approach while coding in Dynamo.

Table 2. Formwork quantity comparison among manual, Dynamo, and Revit Schedule Results.

Structural Element	Manual Results (m^2)	Dynamo Results (m^2)	Revit Schedule (m^2)	Revit Material Take-Off (m^2)	Deviations Between Manual Results and Revit Schedule (%)	Deviations Between Manual Results and Revit Material Take-Off (%)
Foundations	29.20	29.20	37.70	32.20	29.11	10.27
Walls	74.39	74.39	73.04	74.39	-1.81	0.00
Columns	32.40	32.40	40.00	38.40	23.46	18.52
Beams	40.46	40.46	40.62	43.06	0.40	6.43
Slabs	69.12	69.12	84.96	84.96	22.92	22.92
Total	**245.57**	**245.57**	**276.32**	**273.01**	**12.52**	**11.17**

Conclusion

BIM provides smooth and fast solutions for many tasks in the construction industry. However, studies indicate that there are significant limitations of BIM-based QTO, and further improvements are required in this field for better cost calculations. Thus, this study draws up studies in the literature for BIM-based quantification and discusses studies on formwork quantification to reveal the limitations of BIM-based formwork estimation. A simple case study is conducted to demonstrate the capability and limitations of Autodesk Revit for formwork estimation, and a framework, which is going to be improved further in the future, is proposed for more reliable area information extraction from building information models. Consequently, the use of Revit Dynamo facilitates the extraction of accurate geometric information from BIM, and it surpasses the other in-house methods of Revit as per the case study results.

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Identification of Causes of Delay Factors in Construction Projects

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Abstract

Delays generally occur in every construction projects and effect project success negatively. For a successful implementation of construction projects; projects must be completed on time and within the defined budget to meet the project targets. Therefore, it is important that all participants in construction projects must pay attention to time, cost, quality criteria which have direct effects on project success. In this context, this research is concentrated on time criterion and aims to identify and classify the factors of causing delay in construction projects. Within the scope of the study, a comprehensive literature review was conducted and previous researches were examined. As a result, most important delay factors were determined and classified. Through assessing a detailed literature review, a total of 70 different delay factors were identified and categorized into nine broad categories namely, owner, project manager, design / designer, contractor, project and contract, material, equipment, labor and external related project factors. The findings of this research can be helpful for project managers or other participants to identify and mitigate causes of delay factors in construction projects.

Keywords: *causes of delay, construction delays, construction projects, delay factors, delay in construction, project management.*

Introduction

Successful construction projects are the ones that are completed on time, within the predetermined budget, and by fulfilling the project requirements. A successful project means that the project has accomplished its technical performance, maintained its schedule, and remained within budgetary costs (Frimpong et al., 2002). Therefore, it is important that all participants in construction projects need to pay attention to time, cost, quality criteria which have direct effects on project success.

Construction delay is defined as the time overrun either beyond the contract date or beyond the date that the parties agreed upon for delivery of a project (Assaf & Al-Hejji, 2006). Generally, delays are divided into three major types, namely: excusable and non-excusable, compensable and non-compensable, concurrent (Alaghbari et al., 2007). An excusable delay is a delay that is due to an unforeseeable event beyond the contractor's or the subcontractor's control. Labor strikes, fires, floods, Acts of God, errors and omissions in the plans, and specifications are examples of excusable delays. Non-excusable delays are events that are within the contractor's control or that are foreseeable. Some examples of non-excusable delays are late performance of sub-contractors and untimely performance by suppliers. Compensable delays are those that are generally caused by the owner or its agents. The most common form of a compensable delay is inadequate drawings and specifications (Alaghbari et al., 2007). Concurrent delays are one in which more than one factor delays the project at the same time or in overlapping periods of time.

Delays are common problems in construction projects and cause important losses to project parties. The major negative effects of delays in construction projects are: legal problems between owner, contractor and consultant, decrease of productivity, termination of contracts, time overruns, cost overruns, and total abandonment (Alavifar & Motamedi, 2014; Pourrostam & İsmail, 2011). Delays cause late completion of the project, disruption of work, cash flow problems, claims, and disputes as well. Briefly, delays in construction projects give rise to dissatisfaction to all parties. Therefore, it is of great importance to identify factors causing delay in order to prevent delays or minimize negative consequences caused by delays before it happens.

In this context, this paper aims to identify and classify the major factors causing delay in construction projects. In order to reach this aim, a comprehensive literature review was conducted and previously conducted researches were examined in detail.

Literature Review on Delay Factors in Construction Projects

Considerable amount of research has been done on the issue of delay and identified main delay factors according to country, project type and project participant perspectives (Alaghbari et al., 2007; Pourrostam & Ismail, 2011; Doloi et al., 2012; Gunduz et al., 2013; Jarkas & Younes, 2014; Oyegoke & Al Kiyumi, 2017; Wang et al., 2018). These existing studies has been reviewed on the purpose of presenting what was previously mentioned in the literature throughout a specific period of time (Durdyev & Hosseini, 2019). Similarly, the results of a comprehensive literature review was presented in this study in order to identify the key delay factors occurred in construction projects.

The literature review concentrated on searching relevant research papers towards the research objective. Research papers in English were searched in academic databases, namely, Emerald Insight, American Society of Civil Engineers (ASCE), Elsevier and Taylor & Francis. The search rule employed in the Title/Abstract/Keyword (T/A/K) field of the selected databases was ("delay") AND ("factors") AND ("construction projects"). To obtain the most recent research, the study was limited to a 15-year period (2005-2019) of publication. Each research paper was reviewed to determine its relevance, and non-relevant ones were eliminated. Eventually, 52 research papers were considered as most relevant to the research aim and were subject to a detailed review. Table 1 summarizes the findings of the literature review by presenting major factors causing construction delays, as referenced in a number of major relevant studies.

Table 1. Delay factors in construction projects.

Researchers	Country	Delay Factors
Wang et al. (2018)	China	(1) Delay in progress payments, (2) Variations /change of scope, (3) Exceptionally low bids, (4) Delay caused by nominated subcontractor, (5) Delay caused by domestic subcontractor, (6) Client interference, (7) Difficulty in claiming indemnity, (8) Short original contract duration, (9) Inadequate resources due to contractor/lack of capital, (10) Unreasonable upfront capital demanded by client
Zidane and Andersen (2018)	Norway	(1) Design changes during construction/change orders, (2) Delays in payment of contractors, (3) Poor planning and scheduling, (4) Poor site management (5) Improper design, (6) Inadequate contractor experience/building methods, (7) Contractors' financial difficulties, (8) Sponsor/owner/client's financial difficulties, (9) Resources shortage (human resources, machinery, and equipment), (10) Poor labor productivity and shortage of skills
Oyegoke and Al Kiyumi (2017)	Oman	(1) Selecting the lowest not the best bidder by the client, (2) Main contractor poor financial condition, (3) Delay in decision making by the client, (4) Poor construction planning of the project by the main contractor, (5) Changes in design by the client, (6) Lack of skilled management team, (7) Slow response by the consultant to contractor's inquiries, (8) Changes in the scope of the work by the client, (9) Delay in settlement of main contractor's claims by the client, (10) Delay in paying the main contractors by the client.
Larsen et al. (2016)	Denmark	(1) unsettled or lack of project funding, (2) delayed or long process times by other authorities, (3) Unsettled or lack of project planning, (4) Errors or omissions in construction work, (5) Lack of identification of needs
Kim et al. (2016)	Vietnam	(1) Financial difficulties to owner, (2) Lack of supervisor's responsibilities, (3) Change design by owner, (4) Incompetence contractor, (5) Inadequate contractor experience, (6) Delay in subcontractors' work, (7) Change function from owner, (8) Lack of consultant's experience, (9) Incompetence owner, (10) Obsolete equipment
Islam et al. (2015)	Bangladesh	(1) Lack of experience construction manager, (2) Lowest bidder selection, (3) Fund shortage by owner, (4) Project site constraints, (5) Improper planning and scheduling, (6) Contractor's excessive workload, (7) Lack of proper management by both owner/contractor especially poor site management by contractor, (8) Lack of skilled workers, (9) Site constraints, contractor's cash flow problem during construction, (10) Escalation of resources price, contractor's excessive workload
Amoatey et al. (2015)	Ghana	(1) Delay in payment to contractor/supplier, (2) Inflation /price fluctuation, (3) Price increases in materials, (4) Funding from sponsor/client, (5) Variation orders, (6) Poor financial /capital market, (7) Excessive bureaucracy in operations, (8) Design changes by consultant/owner, (9) Organization, coordination and control by consultant, (10) Competence of consultants and contractors
McCord et al. (2015)	Northern Ireland	(1) Project financing, (2) Contractor financing, (3) Mistakes and discrepancies in design documents/drawings, (4) Owners slow decision making, (5) Delay in providing services from utilities (water), (6) Delay in obtaining permits from municipality, (7) Poor communication and coordination with other parties, (8) Late in revising/approving design documents, (9) Delays in producing design documents, (10) Design changes during construction
Jarkas and Younes (2014)	Qatar	(1) Unavailability or shortage in materials, (2) Delay in payment process by the employer, (3) Frequent change /variation orders issued by the employer, (4) Lack of coordination among design disciplines, (5) Difficulties in financing the project by the contractor, (6) Late materials procurement, (7) Delay in responding to requests for information (RFI), (8) Clarity of drawings and technical specifications, (9) Slow decision making process by the employer, (10) Unavailability or shortage of skilled labor and technical staff
Shehu et al. (2014)	Malaysia	(1) Cash flow problems faced by the contractor, (2) Late payment from contractor to sub-contractor or suppliers, (3) Problems between the contractor

		and his sub-contractors with regards to payments, (4) Difficulties in financing the project by the contractor, (5) Ineffective control of the project progress by the contractor, (6) Ineffective planning and scheduling of the project by the contractor, (7) Slow decision making by the client, (8) Late payment from client to the contractor, (9) Improper technical study by the contractor during the bidding stage, (10) Contractors poor coordination with the parties involved in the project
Marzouk and El-Rasas (2014)	Egypt	(1) Finance and payments of completed work by owner, (2) Variation orders of scope by owner during construction, (3) Effects of subsurface conditions, (4) Low productivity level of labors, (5) Ineffective planning and scheduling of project, (6) Difficulties in financing project by contractor, (7) Type of project bidding and award, (8) Shortage of construction materials in market, (9) Late in revising and approving design documents by owner, (10) Unqualified workforce
Owolabi et al. (2014)	Nigeria	(1) Lack of fund to finance the project to completion, (2) Changes in drawings, (3) Lack of effective communication among the parties involved, (4) Lack of adequate information from consultants, (5) Slow decision making, (6) Contractor's insolvency, (7) Variations, (8) Project management problem, (9) Mistake and discrepancies in contract document, (10) Equipment availability and failure
Gardezi et al. (2014)	Pakistan	(1) Law and order situation, (2) Design changes, (3) Improper availability of funds with client, (4) War and terrorism, (5) Poor site management, (6) Discrepancies drawings and specifications, (7) Payment delays, (8) Inflation of local currency, (9) Unrealistic time durations, (10) Political / bureaucratic influences
Gunduz et al. (2013)	Turkey	(1) inadequate contractor experience, (2) ineffective project planning and scheduling, (3) poor site management and supervision, (4) design changes by owner or agent during construction, (5) late delivery of materials, (6) unreliable subcontractors, (7) delay in performing inspection and testing, (8) unqualified/inexperienced workers, (9) change orders, (10) delay in site delivery, (11) delay in approving design documents, (12) delay in progress payments, (13) slowness in decision making, (14) poor communication and coordination with other parties, (15) unexpected surface and subsurface conditions
Akogbe et al. (2013)	Benin	(1) Financial capability by contractor, (2) Financial difficulties by owner, (3) Poor subcontractor performance, (4) Materials procurement of contractor, (5) Changes in drawings of architect, (6) Inadequate planning and scheduling of contractor, (7) Slow inspection of completed works by the consultant, (8) Equipment availability of contractor, (9) Preparation and approval of drawings by consultant, (10) Acceptance of inadequate design drawings
Doloi et al. (2012)	India	(1) Delay in material delivery by vendors, (2) Non availability of drawing/design on time, (3) Financial constraints of contractor, (4) Increase in scope of work, (5) Obtaining permissions from local authorities, (6) Delay in material to be supplied by the owner, (7) Slow decision from owner, (8) Poor site management and supervision, (9) Delay in material procurement (action by the contractor), (10) Unrealistic time schedule imposed in contract
Pourrostam and İsmail (2011)	Iran	(1) Poor site management, (2) Delay in progress payment by client, (3) Change orders by client during construction, (4) Ineffective planning and scheduling of project by contractor, (5) Financial difficulties by contractors, (6) Slowness in decision making process by client, (7) Delay in processing design documents, (8) Late in reviewing and approving design documents by client, (9) Poor contract management, (10) Problems with subcontractors.
Motaleb and Kishk (2010)	UAE	(1) Change orders, (2) Lack of capability of client representative, (3) Slow decision making by client, (4) Lack of experience of client in construction, (5) Poor site management and supervision, (6) Incompetent project team, (7) Inflation/prices fluctuation, (8) Inaccurate time estimating, (9) Late delivery of materials, (10) Improper project planning / scheduling
Toor and	Thailand	(1) Lack of standardization in design, (2) Lack of contractor's experience and

Ogunlana (2008)		control over project, (3) Inadequate experience of staff, (4) Lack of competent subcontractors/suppliers, (5) Unrealistic project schedule, (6) Lack or responsibility, (7) Contractor's financial difficulties, (8) Poor contract management, (9) Poor site access or availability, (10) Poor efficiency of supervisor or foreman
Sweis et al. (2008)	Jordan	(1) Financial difficulties faced by the contractor, (2) Too many change orders by the owner, (3) Poor planning and scheduling of the project by the contractor, (4) Shortage of manpower (skilled, semi-skilled, unskilled labor), (5) Shortage of technical professionals in the contractor's organization, (6) Incompetent technical staff assigned to the project, (7) Improper technical study by the contractor during the bidding stage, (8) Ineffective quality control by the contractor, (9) Slow decision making from owner, (10) Insufficient coordination among the parties by the contractor
Lo et al. (2006)	Hong Kong	(1) Inadequate resources due to contractor/lack of capital, (2) Unforeseen ground conditions, (3) Exceptionally low bids, (4) Inexperienced contractor, (5) Works in conflict with existing utilities, (6) Poor site management & supervision by consultant, (7) Unrealistic contract duration imposed by client, (8) Environment restrictions, (9) Slow coordination and seeking of approval from concerned authorities, (10) Client variation/changes of scope
Assaf and Al-Hejji (2006)	Saudi Arabia	(1) Shortage of labors, (2) Unqualified work force, (3) Ineffective planning and scheduling of project by contractor, (4) Low productivity level of labors, (5) Hot weather effect on construction activities, (6) Conflicts encountered with sub-contractors'schedule in project execution, (7) Poor site management and supervision by contractor, (8) Inadequate contractors experience, (9) Effects of subsurface conditions (soil, existing of utilities, high water table, etc), (10) Change orders by owner during construction
Koushki et al. (2005)	Kuwait	(1) Change orders, (2) Owners' financial constraints, (3) Owners' lack of experience in the construction business

When the table examined, it is seen that the researchers focused on a number of different delay factors in construction projects from different countries. Although there exists a divergence of factors according to country specific conditions, there is a certain level of commonality in the identified delay factors. In this context, it is helpful to classify and categorize similar factors causing delays in construction projects to prevent delays and take necessary measures to minimize the negative effects of them. Likewise, previous researches classified and categorized well-recognized construction delay factors (Assaf & Al-Hejji, 2006; Odeh & Battaineh, 2002) and researchers utilized these categories in their studies as well (Sambasivan & Soon, 2007; Gunduz et al., 2013; Wang et al., 2018). This study adopted a methodology that is in line with the previous studies which have used similar categorizations. Accordingly, 70 prevalent delay factors were identified and classified into nine major categories associated with their nature and frequency of occurrence. Thus, nine major categories are: (i) owner related factors, (ii) project manager related factors, (iii) design/designer related factors, (iv) contractor related factors, (v) project and contract related factors, (vi) material related factors, (vii) equipment related factors, (viii) labor related factors and (ix) external related factors. The categories and their associated delay factors are presented in Table 2.

Table 2. Delay factors with categories.

Factor categories	**Delay Factors**
Owner related factors	• Financial and cash flow problems

	• Unrealistic owner requirements • Improper project feasibility study • Change orders • Conflicts between joint owners • Delay in approving design documents • Delay in site delivery • Slow decision making • Exceptionally low bids • Lack of experience of owner in construction projects • Poor communication and coordination with other parties
Project manager related factors	• Delay in performing inspection, testing and poor site management • Conflicts between project manager and design engineer • Late in reviewing and approving design documents • Inadequate contract management and project management assistance • Delay in approving major changes in scope of work by project manager • Accepting inadequate design drawings • Lack of experience of project manager • Poor communication and coordination with other parties
Design/designer related factors	• Mistakes and delays in producing design documents • Design errors and omissions made by designers • Unclear and inadequate details in drawings • Complexity of project design • Poor use of advanced engineering design software • Misunderstanding of owner's requirements by designer • Insufficient data collection and survey before design • Lack of experience of design team in construction, • Poor communication and coordination with other parties
Contractor related factors	• Contractor's cash flow problems • Rework due to errors • Problems with subcontractors • Contractor's poor site management and supervision • Obsolete technology • Ineffective project planning and scheduling • Incompetent technical staff assigned to the project • Lack of experience of contractor in construction projects • Poor communication and coordination with other parties
Project and contract related factors	• Shortness of original contract duration • Mistake and discrepancies in contract document • Revision in contract documents • Revision in specification • Complexity of project • Changes in the scope of the work • Misunderstanding of contract documents • Inaccurate cost estimates • Inadequate early planning of the project
Material related factors	• Material allocation problem • Changes in material & specifications during construction • Inappropriate material selection • Non-storability of materials • Unreliable suppliers
Equipment related factors	• Equipment allocation problem • Inadequate modern equipment • Low efficiency of equipment • Failure of equipment
Labor related factors	• Labor shortage • Slow mobilization of labor

	• Low worker productivity • Low worker motivation and morale • Unqualified/inexperienced workers • Personal conflicts among workers
External related factors	• Unfavorable weather conditions • Unexpected surface and subsurface conditions • Changes in government regulations and laws • Delay in obtaining permits from municipality • Price fluctuations • Delay in performing final inspection & certification • Accidents during construction • Natural disasters (flood, hurricane, earthquake) • Global financial crisis

After the analyis of the identified dispute factors, a questionnaire was developed to evaluate the perceptions of participants in Turkish construction industry on the causes of delays and importance of delay factors. The questionnaire survey was conducted among design and construction professionals working on large construction projects in Turkey. Responses of the survey participants were collected and statistically analyzed. The result of the analysis will be given and discussed in a further study.

Conclusions

Delays can be minimized or prevented providing that their causes are identified. This study aimed to identify and classify the most important delay factors in construction projects, since delays are considered to be a serious problem in the construction industry. In order to achieve this purpose, a total of 70 different delay factors were identified and categorized into nine major groups based on a detailed literature review.

Based on the literature review findings several recommendation can be made. First of all, financial issues are crucial factors in the timely completion of the project; therefore owners should ensure that adequate funds are available before the initiation of the project; and should make progress payments to the contractors on time to finance the work. Owners should receive site as soon as possible after a project is awarded and design documents should be approved immediately; otherwise, work progress could be delayed. Owners should minimize change orders during construction to avoid delays. Consultants should be experienced in construction projects and they should professionally manage the whole project process. Contractors should prepare effective planning of project execution before the construction phase starts. Poor quality and unexperienced workers have negative impacts on projects. Thus, project participants should paid attention to employee selection before construction phase and should assign enough number of labors and should motivate them to improve productivity. Project participants should double check documents and should be sure that documents are complete, clear and free of errors. Architects and engineers should set a schedule to complete design documents on time; otherwise this can be result in a delay of work completion. Communication and coordination are very important as well, as it can be seen from the findings of the literature review. Accordingly, formal relationships among project parties should be clearly identified, as well as roles and responsibilities.

Consequently, the findings of the review can be helpful for project participants in order to help them to identify and mitigate causes of delay factors in construction projects. The aforementioned recommendations can help to achieve completion within specified time with the required quality, and estimated cost; and prevent negative effects of delays such as time overruns, cost overruns, claims, disputes, and termination. Whenever a delay occurs, its implications to the future performance of the project can be immediately determined and corrective action can be taken to minimize any negative impacts on project performance.

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Utilisation of Decision Support Systems in Construction Management: A Literature Survey

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Abstract

Today, computers are widely used in all industries for data collection and analysis, interpretation of data and decision making processes. Especially Decision Support Systems, which are computer-based Information Systems providing tools for assisting managers in making semi-structured decisions, have gained stronger ground parallel to the latest developments in information technologies including artificial intelligence applications like fuzzy logic, machine learning, natural language processing, etc. There are on-going efforts to produce effective models, frameworks, and algorithms for decision making processes. However, construction industry has an intense volume of semi-structured or unstructured knowledge, and knowledge is mostly transferred as experiences from one project to another. This paper aims to find out how decisions are made in practice and how effective Decision Support Systems are in the construction industry.

Keywords: *Construction management, decision making, decision support systems.*

Introduction

Management, in any domain, is a series of decision making processes. Good decisions eliminate problems, improve quality of work, reduce waste and loss of time, and eventually increase profitability; whereas, bad decisions may lead to adverse results. Historically, good decisions have been identified with experience and wisdom. But today, mainly facts and data are relied on. Computers can process huge amounts of data, which is impossible for human brain to handle. Information Technology (IT) —which is getting closer and closer to the way human brain works—is widely used in all industries for data collection and analysis, interpretation of data and decision making processes. Especially Decision Support Systems (DSS), which are computer-based Information Systems providing tools for assisting managers in making semi-structured decisions, have gained stronger ground parallel to the latest developments in information technologies including artificial intelligence applications like fuzzy logic, machine learning, natural language processing, etc.

Information systems help managers to make better decisions, since risk is inversely proportional to knowledge. Because of this, there are on-going efforts to produce effective models, frameworks, and algorithms for decision making processes. On the other hand, construction industry has an intense volume of tacit knowledge, which is mostly transferred as personal experiences from one project to another. Thus, this paper will be based on a literature survey in the construction industry to find out the answers to the following questions:

- How are decisions made in the construction industry?
- How effective are decision support systems in the construction industry?

Decision Types

Decision making used to be the domain of managers, but today, even lower-level employees are responsible for making some decisions. There are three key decision-making groups as senior management, middle management and operational management with decisions characterised as unstructured, semi-structured and structured respectively. Structured decisions are the repetitive and routine decisions encountered daily during standard operation of works. Semi-structured decisions are those where only part of the problem has predefined answers, and unstructured decisions are novel, important and non-routine decisions in which the decision maker uses judgement, evaluation and insight (Laudon and Laudon, 2012).

Construction industry has idiosyncratic characteristics compared to manufacturing industries. Construction industry is project based where each project is unique and has its own complexities. What works in one project may not work in another. This increases the intensity of tacit knowledge in construction industry, which is characterised as highly personal, hard to formalize, hard to document, transfer, teach, and learn, and involving a lot of human interpretation (Sharda et al., 2014).

Decision Making Process

Henry Mintzberg has identified ten roles for managers, four of which were decisional roles as entrepreneur, disturbance handler, resource allocator, and negotiator (Pardeep, 2015). In fact, most important roles of a manager are the decisional roles, as justified by Nobel Prized Herbert Simon, called as “the father of the sciences of decision”, who said that a manager must primarily be viewed as a decision maker (Pomerol and Adam, 2004). According to Pomerol and Adam, decision related research was mostly dominated by the science of economy before Simon, rather than management, and mostly based on von Neumann’s game theory. In 1977, Simon proposed his famous four phases for decision making which are (i) intelligence, (ii) design, (iii) choice, and (iv) implementation. These phases are interdependent and they supply feedback to each other.

The first phase—intelligence—is about classification and decomposition of the problem. A formal problem statement is achieved at the end of this phase. Design phase is a process of finding possible solutions to the problem, or opportunity. A model is developed and the problem is conceptualised and abstracted into quantitative and/or qualitative form. The choice phase is the one in which the actual decision and the commitment to follow a certain course of action are made. Finally, in the implementation phase, the recommended solution is put into work (Sharda et al., 2014).

Utilisation of Decision Support Systems in Construction Industry

In 1971, Gorry and Scott-Morton (1971) defined "Decision Support Systems" as interactive computer-based systems, which help decision makers to solve unstructured problems by utilising data and models. Today, DSS can be summarised as interactive software-based systems to help decision makers compile useful information from raw data, documents, personal knowledge and/or business models to identify and solve problems to support business and organisational decision-making activities (Bastias, 2006). The advantage of DSS is that they can be used by non-technical users and managers for making educated decisions. Key benefits of DSS may be summarised as follows (Bastias, 2006):

- DSS extend the decision maker's information and knowledge processing ability.
- DSS extend the decision maker's ability to deal with large-scale, time-consuming, complex problems.
- DSS shorten decision making time.
- DSS improve reliability of the decision or the outcome.
- DSS reveal new approaches to a problem or decision.
- DSS generate new evidence.
- DSS create strategic or competitive advantage over competing organizations.

Although construction is one of the industries that digitalised latest, decision support tools are getting more and more widespread in the industry. DSS are especially helpful where the intuition of unaided human decision maker falls short. DSS can complement human cognitive deficiencies by integrating information sources, enabling intelligent access to relevant knowledge, and supporting the structuring of decisions. However, most DSS models are considered to be impractical because they are complicated and difficult for most people to use (Omar et al., 2016).

Dikmen and Birgönül (2004) argue that companies rely on "gut feeling" and subjective judgement in certain areas, which are hard to quantify. Similarly, Berezka (2018) argues that personal assessment of decision is still necessary for optimum decision making, as most decision support systems lack the experience and intuition used by human experts on the basis of heuristic knowledge. On the other hand, Chau et al. (2002) oppose the general understanding which considers construction works as temporary and specific activities where data of one project cannot be used for another project. The authors argue that there are similarities between construction projects, and construction processes and management skills are common in all projects.

In a paper focusing on building design, Labonnote et al. (2017) point to the need of decision support systems that integrate a selection of processes, constraints, time span and performance criteria that are relevant to all stakeholders for more sustainable and intelligent construction activities. The authors argue that although there has been a great interest in building optimisation studies for the last two decades, application of DSS for real-world design challenges are still in the early stage of development, and the use in practice has been limited. However, advances in intelligent technologies will probably enhance decision support tools for the construction industry, producing more usable data and more useful knowledge.

This section will be concluded with six examples, in which DSS models addressing different aspects of construction process are proposed. Selected aspects are risk analysis, design works, tendering, construction logistics, safety monitoring, and negotiating.

DSS for Risk Analysis

A risk assessment tool using analytical methods was developed by Taroun and Yang (2013), backed up by case studies with senior managers. Initial questionnaires and interviews showed that professionals mainly relied on their practical experience and personal judgement in risk assessment even during complicated situations, and did not necessarily use DSS for assessment of risk in complex projects. Past experience and personal judgement were relied on, even if such tools were in use, because managers did not want to lose control over the decision making process.

Taroun and Yang pointed at the failure of construction industry in successful risk assessment and argued that risk is usually either ignored or a contingency is added as a non-objective solution. In the research, an assessment methodology was proposed, in which risk is modelled as the product of likelihood of occurrence and the impact of the event on project success. During the tests, the participants found the proposed methodology especially useful for analysing complex and unique projects. Thus, it was concluded that the proposed approach was a viable alternative for assisting risk analysis and decision making in construction management.

DSS for Design Works

A BIM Interoperable Web-Based DSS for Vegetated Roofing System Selection was created by Charoenvisal (2013), arguing that general design process is derived from the creative process of research, analysis, synthesis and evaluation, which is very similar to Simon's four phases of decision making. Architectural design process is somewhat different from other disciplines because it is ill-structured, open-ended and there is no fixed starting point. Still, DSS have a great potential for enhancing design processes and increasing quality of design decisions. DSS can enrich design decisions by the powerful computer-based processes based on big data, computational models and organisational knowledge.

Charoenvisal performed a post-use interview which aimed to question the usefulness of the prototype DSS developed during the first phase of research. As a result of the interview, the prototype DSS was found to be useful because it provided a framework, or a more structured approach, which helped the interviewees to simplify the decision-making processes that were employed. Charoenvisal concluded that DSS had a potential to improve decision-making and design processes in following ways:

- DSS provide more structured and knowledge-driven methods for decision making, whereas conventional methods rely on intuitions and experiences.
- DSS enable quick and accurate decisions by means of decision support information.
- DSS can be used for documenting how decisions are made.
- DSS provide time savings and improved effectiveness of design process through knowledge distribution.
- DSS can use data contained in BIM models in support for decision making.
- DSS facilitate communications between project team members.

DSS for Tendering

A model for selection of the best contractor during tendering process was developed by Noor (2005), which consists of a web-based DSS—an electronic tendering system—as a data acquisition module to collect information about clients, contractors and project details to manage and facilitate tendering activities. It is argued that web-based DSS are easily accessible to all users with an Internet connection, providing a cost-effective and innovative public procurement system.

As stated by the author, while many countries have introduced electronic tendering systems for transparency and efficiency, tendering processes are still mainly based on paper and mail. And although many competitive tendering strategy models have been developed, only a few of them were used in practice because they didn't meet the needs of construction contractors. Awarding construction contracts requires huge paperwork, and it is time consuming and costly to handle. There are only a few tender analysis products currently available, most of which do not specifically address construction tenders.

The tool developed in this research is specific to construction contracts. It enables transmission of online documents, analysis and evaluation of tender documents, and selection of the best contractor. The system also supports real-time communication between client/owners, consultants and contractors. This tool provides open, competitive, and transparent public procurement by scaling contractors that offer the best value. It is also cost and time effective because when the tenderers input their data to the system, the result is instantly produced.

The author argues that use of web-based DSS for tendering processes is still in its infancy in the construction industry, but at the same time, the industry is beginning to recognise the potential advantages of web-based DSS. So, although there is resistance, the trend is towards the adoption of electronic tendering. At the end of the study, the tool was tested in a real world case study, and a web-based survey was conducted to collect opinions, comments and suggestions from the users to test the applicability of the web-based DSS. The participants gave high scores to the DSS in 'utility' and 'efficiency' criteria, and it was also considered as user friendly.

DSS for Construction Logistics

In this study, the authors proposed a GIS-based set of DSS for improving construction logistics and supply chain to be used by public and private decision makers (Guerlain et al., 2019). This DSS tool helps to understand, quantify and compare the impacts of policy and optimisation measures on the delivery of building materials on construction sites. Restrictions on size and emission standards of delivery vehicles are addressed as well, where the user can quantify the impact of restricting the size of vehicles.

Internet of Things (IoT) sensors on vehicles, infrastructure and goods enable capturing of real-time data including traffic data, truck movements or movement of goods at low costs. In this way, urban freight transport can be improved and effective transport strategies can be developed. The authors argue that impact of transport is generally underestimated during planning phase, and transport and logistics issues are usually addressed during the execution phase. Addressing these earlier in the planning phase would have positive impacts with regards to accidents, congestion, noise and pollution. Simulations performed by the researchers produced very good results.

DSS for Construction Workers Safety Monitoring

A fuzzy DSS focusing on construction workers' fatigue conditions was based on the concern that fatigue prediction could be vital since high fatigue level means increased risk of accidents (Winanda et al., 2019). Starting point of the study was that fatigue is a physiological process, so it should be monitored real-time. The authors used fuzzy logic to mimic human reasoning because assessment, evaluation and decision-making related to safety of construction workers are not easy to quantify and they require qualitative human expertise. Fuzzy logic minimised the disadvantages of qualitative approach when there is subjectivity, doubt and expert judgement. Thus, an objective measurement could be made which has a higher accuracy than subjective measurement.

The researchers used real-time measurable indicators such as heart rate, body temperature, muscle activity and working space temperature for fatigue prediction. Workers' characteristics such as age, height, weight, lifestyle, and workload, which are measurable indicators contributing indirectly to physical fatigue, were considered as well. When the system was tested, it was observed that performance classification through fuzzy reasoning worked well. Thus, the output was concluded to be useful in producing recommendations in decision making related to worker safety conditions before and during work. The authors stated that the system could be further improved as an early warning system by combining software and hardware to be carried on workers.

DSS for Negotiating

In construction projects, negotiation is indispensable for a harmonious relationship between the parties involved. However, it is also considered as a time and energy consuming activity. It is a decision making process, in which two or more parties seek to reach a consensus, and complex technical and human issues are addressed in negotiation (Ren et al., 2003). DSS addressing negotiation processes are mostly based on game theory applications, and the last example to be given in this paper covers methodologies for conflict resolution in construction projects using nonzero-sum games with fuzzy payoffs (Sharif and Kerachian, 2018).

Sharif and Kerachian (2018) argued that it is difficult to assess the payoff when game theory is applied to real-world problems such as decision making. However, the authors asserted that it is reasonable to model the problems as games with fuzzy payoffs, and thus proposed two fuzzy matrix games to resolve disputes in construction projects considering the fuzzy payoffs of the owner and the contractor.

Applicability and efficiency of the fuzzy games were tested on a large oil project in the Persian Gulf, and an equilibrium status was achieved for different preferences of the parties. Thus, optimal mixed strategies could be provided by the fuzzy games in the negotiations between the owner and the contractor, which showed that proposed games could be effectively utilised for incorporating the existing uncertainties in the payoff matrices, and the fuzzy games could be applied to more complicated contractual or constructional conflicts (Sharif and Kerachian, 2018).

Conclusion

Today, IT is widely used in all industries, including the construction industry, for data collection and analysis, interpretation of data, and decision making processes. However, construction industry has its unique characteristics, such as temporary and specific activities, where data of one project cannot readily be used for another project. Although decision support tools are getting more widespread in the construction industry, many authors point at the inefficiency of most decision support systems, lacking the experience and intuition used by human experts. It is argued that application of decision support systems for real-world challenges is still in the early stage of development, and the use in practice has been limited. Professionals still rely on "gut feeling" and subjective judgement in decision making, and it is needless to say that human beings do not always follow the rational path.

Reviewing the literature, six examples were selected from existing research, which offered DSS models addressing risk analysis, design, tendering, logistics, safety and negotiation processes in the construction industry. It was observed that decision support systems had greater potential in certain areas such as design and tendering, but they fell somewhat short in risk analysis and negotiation processes, where human judgement still seems more preponderant. Apparently, decision support tools within the construction industry should be dynamic models based on learning systems, which can process both objective and subjective information. On the other hand, advances in intelligent technologies are enhancing decision support systems for the construction industry as well, producing more usable data and more useful knowledge. Technologies such as sensor networks, the IoT, and artificial intelligence applications like fuzzy logic, machine learning, natural language processing are providing powerful tools. Therefore, in parallel to these developments, decision support systems may be expected to be more prevalent in the construction industry soon.

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Interoperability for The Integration of Building Information Model to Game Engine

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Abstract

The increasing use of building information modeling (BIM) in the architecture, engineering, construction, operation, and facility management (AECO/FM) industry triggers the emerging technological tools to be updated for full integration. The BIM platform needs to interact with new technologies. Interoperability researches enable the technological tools for ontology-based communication with BIM. Since game engines serve a reality-based environment, integration with BIM may obtain opportunities for the information model to coherently replicate the real-world experience. This study aims to present the developments in the BIM and game engine integration implementations and process. Data related to game engine integration in BIM was collected by examining the scientific literature and the industry implementations. The findings demonstrate the chronological developments with a comparison of the old and new integration processes of the BIM model to the game engine. As a result of the comparison, it was found that building model information and game engine-produced information can be integrated with the smoothest and lossless way with solving the interoperability problem via the new software plugin. As the results show, thanks to the study, any model created in a well-information-structured building model can be easily integrated with the game engine-model which may be available in virtual reality platforms.

Keywords: *Building Information Modeling (BIM), game engine, virtual reality technologies.*

Introduction

The complexity of construction projects and the approach to each constantly changing building project results in delays and errors (Rahimian, et al., 2020). Since 4D to 7D information is not integrated into models widely today, chaos and inefficiency are evident in the implementation phase of the project. One of the most important premises of BIM is achieving collaboration and communication among all stakeholders (Succar, 2009). User as a determinant of the construction project should be seriously taken into consideration since the user is one of the main influencers of the change during construction. The building information share with the user can be realized with augmenting the virtual reality within the digital modeling. Therefore, there is an increasing demand in augmented reality (AR), virtual reality (VR), mixed reality (MR), and extended reality (XR) integration to building information model (Wyczałek, 2018). The AECO/FM industry has adopted an object-based parametric modeling method namely Building Information Modeling (BIM) platform, transitioning from a 2D and 3D approach to an nD approach throughout the lifecycle of a building (Azhar et al., 2012). The BIM model with integrated real-world data is the only and unique platform that can import, process, analyze, and visualize (Vincke et al., 2019). Standards for data transfer from and to the BIM platform include BuildingSMART led Industry Foundation Classes (IFC). IFC connects all aspects of design, providing a global database for interoperability for construction projects (Brito et al., 2019). Many BIM software allow importing and exporting common IFC data for making possible fast and feasible visualizations. As such, software companies are in an effort to integrate the software they will release for the AECO/FM industry into the BIM model in IFC format. With the development of the game engine technology and the solution of interoperability problems for integrating into the BIM technology, the game engine industry has a strategic effort to involve itself in the AECO/FM industry. However, the integration of BIM and game technology is still an evolving field in both research and practice (Omaran et al., 2019). Game engines allow the various users to input and interact over the creation of a virtual world (Pavelka and Michalik, 2019). They allow users to interact with the data they visualize just as if they were experiencing the real-world. It also provides the necessary tools to intuitively pass the model to ensure that all stakeholders get a better observation and analysis of the construction project. Thanks to the interoperability of these techniques, it is expected to facilitate the design of the optionally created model for image processing and tracking in the virtual environment. Owing to the powerful animation capability of the game engines, it is possible to integrate the latest technological solutions by combining the optional simulation of a model with the BIM platform and virtual reality systems through image processing. This article first gives an overview of current technologies, focusing on the interoperability of BIM and game engines. Then, the techniques of a game engine and how these technologies were used in the past and today are compared to integrate data from BIM models and create virtual realities. As conclusion, the paper suggests for future research to improve the work is done so far and the developed system.

Methodology

The methodology of this study consists of integrating the building data modeled on the BIM platform in 3D with a game engine. The model visualized with the game engine is aimed to allow users to circuit easily and intervene whenever needed. The study first began by conducting literature review on current technologies on the interoperability of BIM and game engines. The literature review phases applied are as follows (Figure 1);

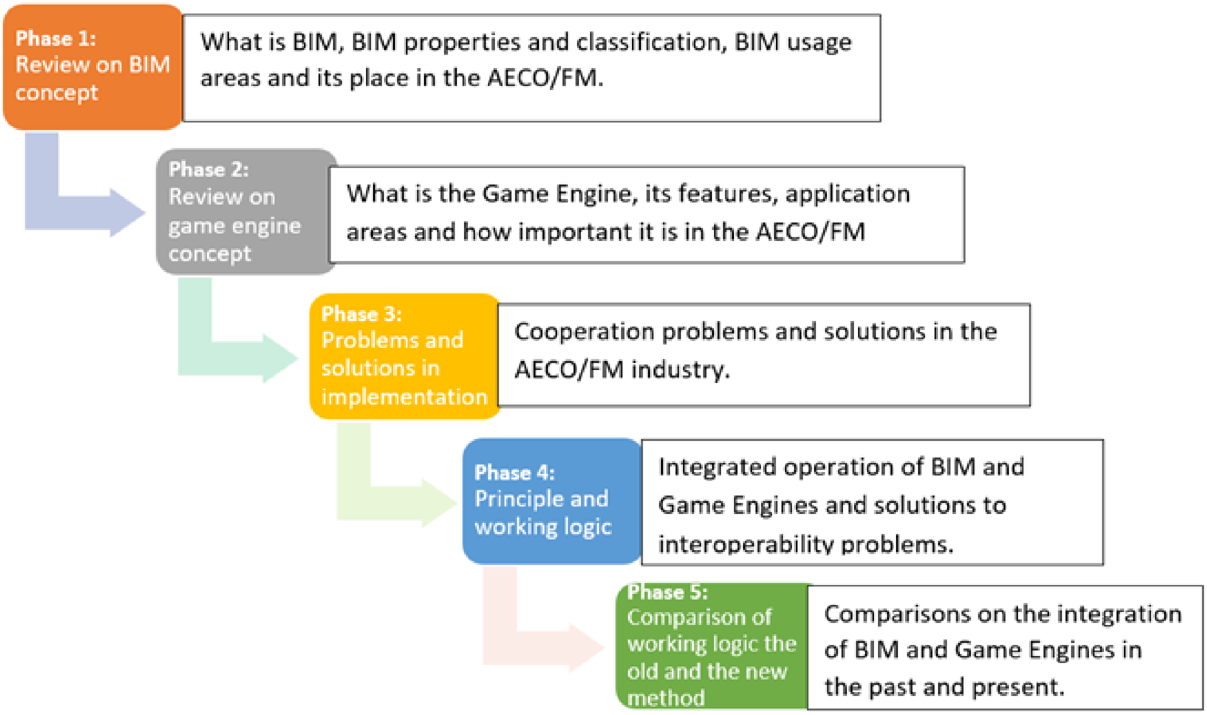

Figure 1: Research phases.

An important conclusion is reached with the literature review, as the integration of BIM model data into the game engines is still troublesome, resulting in complex applications in collaboration and efficiency (Du et al., 2017). As in the light of findings, in order to increase cooperation and efficiency, researches have been conducted on the integration studies developed by the Game Engines in line with the BIM sector for the AECO/FM industry (Agirachman and Shinozaki, 2020). Unlike previous BIM and game engines research, this study focuses on the effortless and easy integration of a game engine's model created on the BIM platform. The importance of this study is to enable users to intervene with game engines without professional knowledge about software or programming. In this research, BIM and game engines are examined in terms of interoperability during the integration process, comparisons are realized between the old and the new interoperability approaches in systems integration, and suggestions are made to examine for better management.

Findings and Discussion

With the examination of the literature review, it turns out that there are several different methods for the integration of BIM and game engines. As seen in Figure 2, the first method is to save the BIM model with * .ifc format and then import the IFC information into the Blender via an IFC OpenShell which is an open-source plugin. The transfer is then saved with * .blend file format and finally imported to Unity. However, it is not a useful method since only the geometry of the model is transferred. The second method is to transfer the BIM model to 3DS Max as * .rvt-file with Autodesk Revit, then transfer it from 3DS Max to * .max-file to Unity. The third method is the Lumion LiveSync plugin for Autodesk Revit, thanks to the Lumion program, and it exports the mesh surfaces with Collada (* .dae) file format. Collada files are then imported into Unity (Vincke et al., 2019).

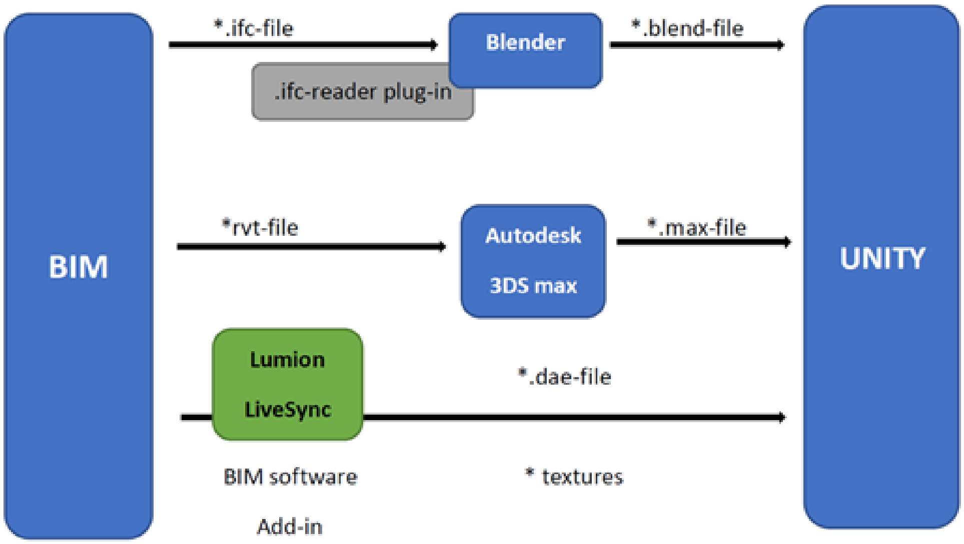

Figure 2: File transfer methods from BIM platform to Unity. (Vincke et al., 2019).

It is the second method that gives the best visual result among these methods. That's why the most common and preferred method is the process of creating the design with Autodesk Revit in the BIM platform and then transferring it to the Unity game engine with the help of the Autodesk 3DS max program (Chou et al., 2017). Unity User Interface (UI) cannot detect some data unless the designed model is converted to standard objects. For this reason, a few transformations are required to convert the model. As a result, the direct transfer of the model from Revit to the Unity game engine causes the loss of data (Chiang et al., 2015). (Figure 3).

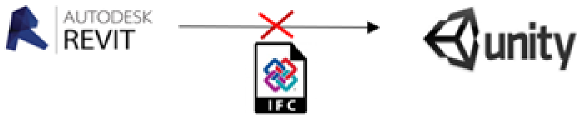

Figure 3: The * .ifc file format system modeled with Autodesk Revit in the BIM platform cannot be detected by the Unity UI because of interoperability problem.

Therefore, the model created in Revit is converted to 3DS Max by first converting the file format to FilmBoX (FBX) to visualize the model in the Unity game engine. Standard objects are then converted with the 3DS Max software. The file is then exported to an FBX file format. Finally, model transfer from 3DS Max to Unity game engine is done in FBX file format (Wong et al., 2019) (Figure 4).

Figure 4: File transfer method from BIM platform to Unity game engine.

Maintaining robust information transfer during the transition of the model to the virtual reality simulation platform is crucial for standardization. Model information is converted to standard dictionary objects thanks to 3Ds Max software. Then, at the game engine stage, the transfer is achieved on the Unity game engine platform with less data loss to conclude by importing the FBX file (Boga et al., 2018). As can be seen in the findings, integration of BIM and game engine platforms is possible, but it is still troublesome and time-consuming. That's why game engine developers are trying to get themselves into the AECO/FM industry quickly and easily. Unity Reflect, a new solution for AECO/FM industry activities developed by the Unity game engine technology, is included as an add-on within the BIM platform, and it takes a single click to bring a Revit model to the virtual game environment in real-time and provide a simultaneous connection between them. Under normal conditions, users utilize multiple tools to prepare BIM data, integrate, and optimize it with the game engine, this creates requiring dozens of transactions that take days or even weeks. Now, Unity Reflect makes converting Revit models to the virtual game environment in real-time very easy. After integrating the Unity Reflect plugin into the software, users simply click on the Unity icon in the Revit toolbar to start syncing the models. The designer, without any coding knowledge and skill, can use Unity Reflect to transfer BIM data to real-time environments such as AR, VR, MR, and XR (Figure 5).

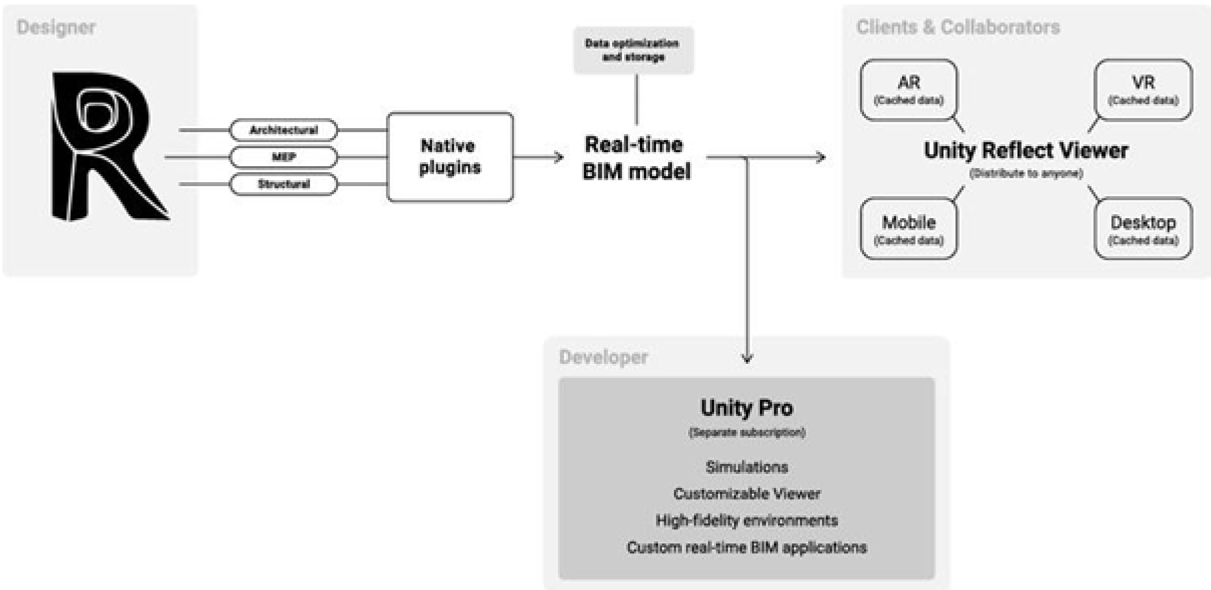

Figure 5: The process of importing Autodesk Revit model into Unity Reflect (adopted from https://unity.com/products/reflect).

All stakeholders, from project managers to clients, increase their interoperability thanks to the simultaneous access to any device. In addition, Unity Reflect brings real-time BIM applications to Unity Editor, allowing one to build on Unity Reflect. Although the Unity Reflect plugin starts with Revit interoperability, Rhino and Sketchup software are also integrated. In the years to come, Unity Reflect will support integration with many more software within the BIM platform and will be indispensable for the AECO/FM industry. As a result of the review, although BIM and game engines integration were applied in the past, it required more effort, but now, thanks to the developing technologies, BIM technology, which is growing day by day, has become easier to be included in the game engines and it is thought to increase its interoperability for more accurate construction management within the AECO/FM industry.

Conclusion

This research article explains how a BIM-based 3D model is integrated into a game engine, is managed, what benefits are included in virtual reality systems, and compared to current methods with integrated methods implemented in the past. In the reviewed literature, it is seen that although 3D designs are adopted modern technologies, 3D designs are not used well due to interoperability problems between these technologies. The transfer of the BIM model at the design stage to a game engine context and the work done on the application process is within a very limited framework. This study highlights the necessity of a platform that enables design managers and clients to access effectively with the designed BIM model by enabling instant software updates. Thanks to the virtual reality technologies, using the latest game engine software of the data transferred directly from the BIM platform. The data visualization capabilities of the users are significantly improved and it provides convenience in making instant interventions. This virtual environment offers a realistic and more interactive context. It can replace the components in the model through the game engine software and have the atmosphere just like playing a game. Clients are able to add or remove products according to their requirements and change them according to environmental factors. Other stakeholders, such as the client also can better analyze and understand the problems of the project through this process. It also turns it into a more useful tool for tracking progress in the site, making decisions and controlling them. Using the platform at the same time leads to better-integrated decision making. In this way, it provides efficiency in interoperability with all these factors. The potential of this technology in the AECO/FM industry is huge and valuable. This potential can achieve more coordination, compatibility, and most importantly, time-saving criteria in the industry. With the inclusion of constantly developing technologies in the BIM platform, it is expanding the scope of the AECO/FM industry by increasing its features and capabilities day by day. The AECO/FM industry should continue to grow by adopting many new technologies such as the internet of things (IoT), machine learning (ML), artificial intelligence (AI), deep learning (DL), big data, virtual technologies, and game engines in the near future.

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Conceptualization and Visual Representation of Uncertainty and Complexity Factors in Public-Private Partnership Projects

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Abstract

Public-private partnership contracts have acquired a substantial interest in the construction industry of many different countries, and therefore, the importance of the PPP project's success has surged forward. Uncertainty and complexity are two inseparable features of PPP contracts, which can cause failure in the project and decrease the success rate. Information visualization techniques provide decision-makers with a superior perception of these two features and consequently assist them in making a better decision. For this reason, there is a demand to develop a visual representation to understand the impact of complexity, uncertainty, and their interactions upon PPP project performance. This research study aims to develop a conceptual model to explore and visually represent uncertainty and complexity in public-private partnership projects and their impacts on project performance by considering vulnerability and resilience concepts. The findings of this study may provide decision-makers with a conceptual framework to better understand the interaction of uncertainty and complexity in a project as well as their influences on project behavior and subsequently make a better decision.

Keywords: *complexity, uncertainty, public-private partnership, visualization, resilience*

Introduction

The construction industry is bedeviled by many problems, including scarcity of cooperation, diminish trust, and inadequate communications (Chan et al., 2004). These problems are reflected on projects as cost and time overrun, litigation, vague scope, and even adversarial relationship among project stakeholders. Public-Private Partnership (PPP) projects similar to other projects in the construction industry suffer from these highly problematic issues. These issues significantly affect the success of the project and put obstacles in the way of the project managing team. Visualization techniques can be adopted to overcome these issues. The term visualization is delineated as "the use of computer-supported, interactive, visual representations of data to amplify cognition" (Card et al., 1999) and as "the act or process of interpreting in visual terms or of putting into visible form" (Nielsen & Erdogan, 2007). This study aims to develop a visual representation of uncertainty and complexity factors in PPP projects so that necessary strategies can be developed to manage them.

Visualization is generally adopted in the construction industry for knowledge sharing and reporting purposes. It also provides this industry with a variety of benefits, including (Chiu & Russell, 2011): (a) identifying interdependent relationships across several different data items to improve data interpretation and decision making potency of a project team (Liston et al., 2000); (b) controlling the quality of a construction schedule (Russell & Udaipurwala, 2000); (c) preventing misconceptions by cause of a paucity of data; (d) simplifying cognition of quantitative data; and (e) verifying and enhancing data accuracy.

Visual metaphors and/or representations are necessary to explore the interaction of complexity, uncertainty, vulnerability, and resilience concepts, as well as their consequences on the project performance. This paper is the first part of a more extensive research study that seeks to develop a computer tool to visualize factors of uncertainty, complexity, and their interactions by considering vulnerability and resilience concepts in PPP projects. This paper reports the initial findings of this study, which is the conceptual model that can be used to explore the concepts of uncertainty and complexity, as well as interrelated factors in PPP projects. Based on this conceptual model, visual representations can further be developed to manage complexity, uncertainty, vulnerability, and resilience in a PPP project.

Public-Private Partnership Projects

Conventionally, national and local governments have been responsible for developing public facilities such as hospitals, roads, sports facilities, prisons, and other infrastructures by using public money. Considering the growing urbanization rate and, therefore a massive increase in the demand for infrastructure as well as government budget constraint and limited public funds, the world has turned to an alternative mechanism of funding public facilities, named public-private partnership (Emek, 2015; Li et al., 2001). The level of public debt, which snowballed during the macroeconomic dislocation of the 1970s and 1980s, played a pivotal role in changing the conventional model of public procurement. Nowadays, PPPs are extensively used to deliver a series of public facilities and services in more than 85 countries in the world (Cheung & Chan, 2011; Cui et al., 2018).

Akintoye (2006) presents a broad definition for PPP as "a contractual agreement of shared ownership between a public agency and a private company, whereby they pool resources together and share risks and rewards, to create efficiency in the production and provision of public or private goods." According to the Hong Kong Efficiency Unit (2008), PPP is a long-term collaboration approach in which both the public authority and private sector have a different level of responsibility in order to deliver more efficient public services. Generally, PPP refers to a contractual partnership between the private and public sectors "which aims to ensure the funding, construction, renovation, management or maintenance" (European Commission, 2004) and to deliver an asset or provide a service (Birgonul et al., 2016; Chan et al., 2011). Basically, in contrast to the conventional procurement systems, a private company is contracted to operate the asset after construction in behalf of the public authorities for an agreed duration (Li et al., 2002); therefore, the government can transfer plenty of risks to the private sectors (Cheung & Chan, 2011).

Complexity

The complexity theory was applied to project management in the 1990s. The significance of complexity to the project management process is extensively acknowledged afterward (Baccarini, 1996; Bennett & Cropper, 1990; Bubshait & Selen, 1992; Morris, 1997, 2002) for several reasons such as its impacts upon project planning, project objectives identification, and project organization form selection. Moreover, it can influence project management arrangement selection and different outcomes of the project.

Complexity can be challenging to define as it has several different connotations. The Oxford Dictionary defines complexity as "the state of having many different parts connected or related to each other in a complicated way that makes it hard to understand or deal with." Complexity is a crucial characteristic of construction projects (Brockmann & Kähkönen, 2012); nevertheless, there is not any widely accepted definition of the term project complexity in this industry (Wood & Gidado, 2008). There is also a lack of consensus on what complexity is in project management contexts (Bakhshi et al., 2016; Bosch-Rekveldt et al., 2011; Brady & Davies, 2014; Geraldi et al., 2011; Padalkar & Gopinath, 2016; San Cristóbal et al., 2018; Vidal et al., 2011). Sometimes, the world complex is used where complicated is meant (Wood & Gidado, 2008).

To better understand the project complexity, projects can be seen as a hierarchy of simple, complicated, complex, and chaotic. A simple system can be defined by a low degree of interaction and dependable predictability; in other words, the same action produces the same results every time (Sargut & McGrath, 2011). Bakhshi et al. (2016) defined simple projects as "limited activities undertaken to create products or services with clear cause-and-effect relationships." All operations in a simple project are self-evident, predictable, and repeatable.

Complicated systems comprise many elements, and many interactions function according to precise patterns, which are also predictable. Tasks and elements in complicated projects have cause-effect relationships. Nason (2017) stated that "the components can be separated and dealt with systematically and logically that relies on a set of static rules or algorithms." In other terms, complicated projects consist of a group of simple projects but are not merely reducible to them (Bakhshi et al., 2016).

On the other hand, complex systems are identified by the terms of multiplicity, interdependence, and diversity. The greater the multiplicity, interdependence, and diversity, the higher the complexity. Complex projects consist of ambiguity and uncertainty, interdependency, non-linearity, unique local conditions, autonomy, emergent behaviors, and unfixed boundaries (Bakhshi et al., 2015). Their outcomes are challenging to foresee. The same system configuration at the start allows for different results (Sargut & McGrath, 2011). Nevertheless, chaotic projects (crises and disasters) cannot be instantly addressed (Snowden & Boone, 2007).

Bakhshi et al. (2016) have culled 14 different definitions for the term of complexity among 450 published articles between 1990 and 2015 where a definition presented by Hatch and Cunliffe (2012) has been identified as the most circulated one which depicts complexity as the presence of "many different elements with multiple interactions and feedback loops between elements." Complexity is an attribute that makes understanding, predicting, and controlling the project challenging for project teams even if they are well-informed about the project (Vidal & Marle, 2008). There is no doubt that complexity contributes to failure in a project; what is not clear is to what extent this statement holds (Parsons-Hann & Liu, 2005). Recognizing and portraying various aspects of project complexity has been a thrilling topic in the area of construction project management.

Vidal and Marle (2008) identified four factors as essential but insufficient for project complexity viz. project size, project variety, project context, and interdependencies within the project. Geraldi et al. (2011) analyzed the trend of complexity frameworks development and categorized complexity into five different types, namely uncertainty, dynamic, pace, socio-political, and structural complexity. Bosch-Rekveldt et al. (2011) developed the TOE framework considering 15 Technical, 21 Organizational, and 14 Environmental complexity components from literature and their new empirical research. A metric method has been created to assess the complexity of project activities (Sinha et al., 2011) while Vidal et al. (2011) quantified relative complexity score among various projects employing the analytic hierarchy process. San Cristóbal et al. (2018) identified 12 significant factors that influence project complexity viz. size, interdependence & interrelations, goals & objectives, stakeholders, management practices, division of labor, technology, concurrent engineering, globalization & context-dependence, diversity, ambiguity, and flux. He et al. (2015) identified 28 complexity measurements from the literature and categorized them into six factors, namely, Technological, Organizational, Goal, Environmental, Cultural, and Information complexities. Then they developed a complexity measurement model in order to determine the level of complexity in Chinese projects. Dao et al. (2017) identified 22 complexity factors and 34 associated indicators that measure those factors. Zhu and Mostafavi (2017) presented the Complexity and Emergent Property Congruence (CEPC) framework that evaluates the complexity degree of a project with the resilience degree of the system to deal with complexity. Nguyen et al. (2015) utilized the Fuzzy Analytic Hierarchy Process (Fuzzy AHP) to measure the overall project complexity. They classified 36 complexity factors under six different categories viz. sociopolitical, environmental, organizational, infrastructural, technological, and scope complexities.

Uncertainty and Complexity

A review of project management literature discloses that there are numerous different points of view on how uncertainty and complexity exert an influence over each other. Atkinson et al. (2006) and Qazi et al. (2016) considered complexity as an element of uncertainty that is at odds with opponents who defined uncertainty as a part of complexity (Geraldi et al., 2011; Geraldi &Adlbrecht, 2007). Perminova et al. (2008) considered complexity as systematic uncertainty, but Pich et al. (2002) equate complexity with deficient information when several variables interact. Brady et al. (2012) quarrel with both points of view and perceive complexity and uncertainty as two entirely distinct concepts. A taxonomic research study reveals three broad strands of contention in project management literature: (a) complexity as a source of uncertainty, (b) uncertainty as a source of complexity, and (c) two entirely independent concepts (Padalkar & Gopinath, 2016). Despite the lack of consensus on how uncertainty and complexity influence each other, there is a broad and clear consensus that both have severe repercussions on project performance.

Data Visualization

Data visualization is a process to represent information in a visual and meaningful way. It transforms raw information into digestible data and actionable insights. It is a combination of various fields such as Human-Computer Interaction (HCI), visual design, cognitive and computer sciences (Healy, 2018; IDF, 2019; Myatt & Johnson, 2009). Any visualization technique should at least satisfy the following three minimal criteria: (a) it should be based on non-visual, abstract or at least not immediately visible data; (b) it should produce an image which is the primary means of communication; (c) it should produce precise, recognizable and understandable results.

Nowadays, in the construction industry, researchers and practitioners have greatly benefited from several visualization techniques including but not limited to fault tree analysis, analytic hierarchy process (Hyun et al., 2015), social network analysis (Akgul et al., 2017; Chinowsky et al., 2008), event tree analysis (Phan & Noguchi, 2010) and building information modeling (Brad & McCool, 2015; Sacks et al., 2018). Moreover, Songer et al. (2004) advanced four visualization tools, including scatterplot, linked histogram, hierarchal tree, and treemap, to present cost control data. Zhang et al. (2009) employed digital images captured on-site and an integrated building information system to semi-automate the progress measurements calculation.

In PPP projects, similar to other construction projects, decision-makers need to access both project information and a tool to visualize that information in order to understand the project situation better and consequently make a better decision. Nonetheless, not all visualizations are really helpful. Inappropriate visualization can be at best confusing, and at worst misleading (Steele, 2012). Accordingly, it is imperative to develop a method that effectively exposes something new about the underlying patterns and relationship contained within uncertainty, complexity, and their impacts on project performance for the decision-makers.

Conceptual Model

The research plan of the in-progress parent study is set up on capturing the insight gained in past PPP projects, and it consists of four consecutive steps. First, semi-structured interviews will be arranged with experts from public, private and financial organizations who are involved in a PPP project. In contrast to structured interviews, semi-structured interviews allow interviewees the freedom to express their thoughts in their own terms, which is more beneficial for the lesson learned studies. Then, considering the collected information during the semi-structured interviews, a conceptual framework that depicts the interaction of complexity and uncertainty related concepts will be developed. Next, distinctive alternatives will be discussed and evaluated with a focus group study in order to fulfill PPP projects stakeholders' visualization requirements. Finally, a computer tool will be programmed to visualize the conceptual framework.

In order to lay the foundations for the semi-structured interviews in the first part of the parent study and to conceptualize and organize information obtained from experts appropriately, a model that displays the relationship between uncertainty, complexity and project performance factors is needed. After a comprehensive literature review, within the scope of this study, a delineation of the initial model has been prepared (Figure 1). In this representation, complexity and uncertainty have been considered as two independent concepts, which is the broadest and one of the widely accepted theories on how these concepts affect each other in the literature. The validity of the proposed delineation and model will be further tested out during the interviews, and it will be updated in accordance. In the proposed model, complexity factors ($CF_1 \ldots CF_n$) can directly or indirectly influence one or more uncertainty factors ($UF_1 \ldots UF_m$). However, an uncertainty factor does not have to be a consequence of a complexity factor. Although complexity has been generally identified as one of the drivers of uncertainty, intending to decrease the uncertainty degree of a project may increase the complexity level of the project; therefore, a bidirectional relationship exists between complexity and uncertainty in the model.

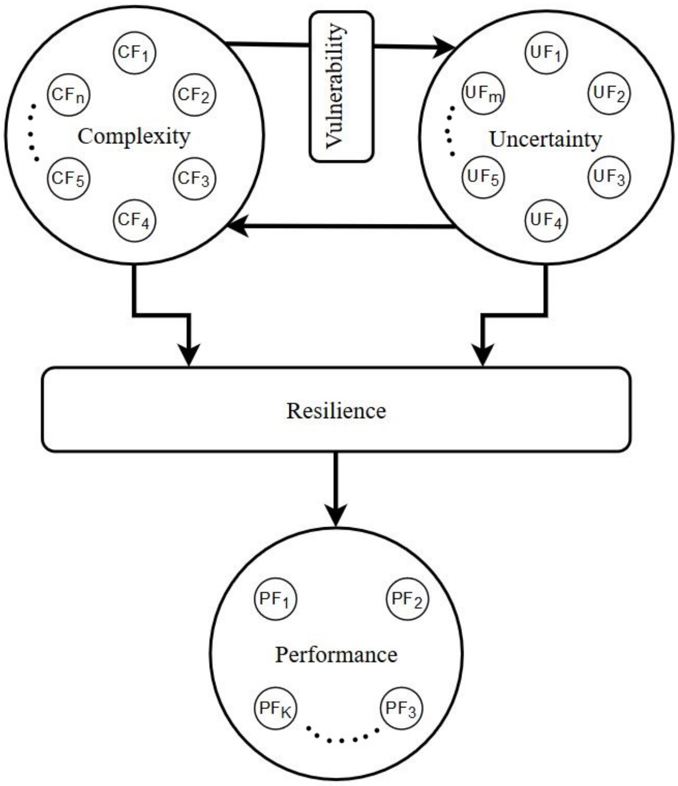

Figure 1: Delineation of complexity, uncertainty and performance factors.

The thickness of the symbol for complexity, uncertainty, and performance factors represents their importance, whereas the thickness of arrows represents the significance of the relationship. Vulnerability and resilience concepts are also depicted in the proposed framework. The concept of resilience is almost new in the construction sector, and not yet prevalent among researchers. Resilience is a set of strategies to cope with any disturbances, and it indicates how fast a project can recover from the undesirable consequences of a specific complexity or uncertainty factor, while vulnerability means how sensitive the project is to a complexity factor. In addition to clarifying the relationship between uncertainty and complexity factors in the project, this representation brings both uncertainty and complexity factors influences on the performance factors (PF_1 … PF_k) to decision-makers' attention.

Some examples may shed more light on the model. For instance, a construction site was set out to have two separate accesses from a highway. However, after completing almost half of the project, the primary access was still vague by the client due to the complexity of the access road design, and it leads to uncertainty in the main project scope. This situation could negatively affect the schedule of the project. However, the secondary road, which was narrower and had interference with traffic, provided access to the site. Although using only the secondary road influences the safety performance of the project, it helps the contractor to soften the undesirable consequences of the unwanted delays in the project. As another example, the uncertain condition of the political and economic situation of a country as a source of environmental complexity can contribute to rising prices and consequently influence the project budget negatively. As a resilience strategy, a contingency budget is required and should be considered to cope with this disturbance.

Concluding Remarks

This paper is the first step of a more extensive and in-progress study, which is expected to facilitate the decision-making process by providing dynamic visual information about project behavior under real conditions of uncertainty and complexity. First, within the scope of this paper, an initial model that displays the relationship between uncertainty, complexity and project performance factors is proposed. This model helps to conceptualize and organize information that will be collected later during semi-structured interviews with a group of experts involved in PPP projects. The validity of the proposed model will be further verified during the interviews. Next, a conceptual framework will be developed by clustering the findings of the interviews on the proposed model. Qualitative data analysis methods will be applied for coding and organizing the transcripts of the interviews. Then available visualization alternatives in the literature that can satisfy the decision-makers' demands in PPP projects will be explored. After that, those alternatives will be discussed with participants of a focus group study in order to find an option that adequately and appropriately satisfies their visualization requirements. At the same time, the validity of the conceptual framework will be tested out during the focus group study. Finally, a computer program will be created to visualize the relationship between complexity and uncertainty factors and their impacts on project performance indicators as well as their ultimate impacts upon the success of PPP projects by considering resilience and vulnerability concepts. This visualization program is expected to provide decision-makers' in PPP projects a better understanding of the dynamic behavior of the project under uncertain and complex conditions.

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Managing the Connection between Project and Organization Levels: A Case Example of Lessons Learned Practices in Building Projects

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Abstract

Conversion of knowledge and experience gained in projects into organizational assets is amongst the typical challenges of job production. Lessons Learned (LL) is a management tool which managers can effectively use to distill experiences from past projects and turn each into a valuable learning experience to achieve higher performance in future projects. Unlike the common practice in the construction industry, where managers often tend to use LL in the closure phase of projects, the real potential of LL practices lies in their systematic implementation over the project life cycle. Paper reports the outputs of a case study from an ongoing PhD thesis which aims to develop a model to identify the most efficient configuration of LL practices in building projects in relation to project management knowledge areas. Authors conducted a retrospective analysis of a completed school project of about 20.000m2 over its entire life cycle by triangulating data from meeting minutes, project diaries, site reports and audio-visual materials that encapsulate the production process. Systematic analysis and visualization of data from the case example support the scholarly perspective that LL should be a standard practice in construction project management from the beginning of any project to derive lessons from past experiences to enhance organizational learning.

Keywords: *building projects, construction project management, lessons learned, organization memory, project life cycle.*

Introduction

Transferring project-based knowledge and experience to organization level is amongst the major challenges in project-based, service-enhanced businesses. Internalization and routinization of project-level knowledge and experience at the corporate level require systematic approaches to provide information flow between these two levels and ensure the sustainability of organizational learning to achieve corporate goals and objectives. Competitive pressure within a knowledge economy is amongst the challenges that enforce construction firms to adopt proactive approaches to create favorable organizational environments, promote a learning culture and cultivate a sustainable learning agenda (Ternant & Fernie, 2013).

One of the systematic approaches that facilitate organizational learning (OL) at operational level is the *Lessons Learned* (LL) practice. While LLs in the form of post-project evaluations are commonly used by many firms, LLs can be especially conducive to enhancing corporate performance, if firms periodically benefit from LL methodologies over the project life cycle, before the temporary coalitions of different firms, people and resources dissolve. Retrospective evaluations in the project closure phase alone are likely to be inefficient in many cases, not only because the dissolution of project teams start long before the closure phase, but also because the team members may miss some critical information simply due to individual memory problems.

Carrillo (2005) argues that available evidence on LL practices which generally focuses on the context of routine-based organizations is overwhelmingly based on theoretical analyses and conceptual analogues, requiring practical verification and empirical support. Various scholars in the AEC field have pinpointed the potential problems arising from copy-and-paste approaches which ignore the peculiarities of the AEC industry (e.g., discontinuities and difficulties in flows of human resources, materials and information) when transferring or developing LL methodologies from other industries (Bresnen & Marshall, 2001; McIntyre, 2015; Mahdiputra et al., 2005; Almaian & Qammaz, 2019).

Although there are several initiatives regarding LL in the AEC literature (Barlow & Jashapara, 1998; Kululanga et al., 2001, 2002; Bresnen et al, 2004; Mahdiputra et al., 2005; Carrilo et al, 2013; McIntyre, 2015, Eken et al, 2020), and promising developments (e.g., BIM) that may facilitate co-learning in construction networks (Tennant & Fernie, 2013), there are yet several challenges to address in the field, considering that construction firms are rarely successful in integrating OL principles into their business processes and value chains (Eken et al, 2020). Apart from the apparent need for developing holistic models and systematic approaches that connect project-level practices to corporate strategy making, scholars such as Almaian and Qammaz (2019) pinpoint also several practical problems such as the lack of knowledge sharing mechanisms in many organizations, or simply not knowing how to share knowledge.

Paper presents the methodological approach of an ongoing PhD research study which aims to develop a LL model that captures LLs over the life cycles of projects according to project management methodology and transfer learning to organizational level in relation to corporate strategies. Data from a completed school building were analyzed systematically as a case example and various LLs were identified to exemplify why capturing LLs while projects are ongoing can be critical to benefit efficiently from LL practices from a corporate lens. Efficient use of LL practices can be conducive to developing competitive advantages in the market (Carrillo et al, 2013), enhancing intellectual capacity of firms (Webb, 1998), managing change and providing inputs for efficient risk management.

Literature Review

Organizational Learning in Project-Based Organizations

On a broader level, organizational learning (OL) is “*encoding inferences from history into routines that guide behavior*" (Levitt & March, 1988). Systematic problem solving; rapid and efficient knowledge transfer amongst various corporate functions; creating opportunities for continuous learning and professional development; creating appropriate internal environment and systems that encourage cooperation, teamwork and innovation; the empowerment of employees with a shared culture and intensive dialogue with the external environment are amongst the commonly cited characteristics of learning organizations (Ayden & Düşükcan, 2002; Watkins & Marsick, 1993; Marsick & Watkins, 1999, 2003; Mahdiputra et al., 2005).

Following a review of the OL literature, Sense (2011) accentuates three distinctive perspectives that emerge from academic research studies: i) *cognitive*, ii) *behavioral*; and iii) *sociological*. *Cognitive* perspective is the "*information processing view of OL*" which is generally concerned with knowledge, understanding and insights, which may not necessarily be converted to actions. *Behavioral* perspective focuses on actual or potential (future) behavioral change in organizations as an outcome of learning. Finally, *sociological* (or, *social-constructivist*) perspective focuses on the conversations and interactions of individuals in their workplaces and social environments which result in various meanings and actions as the outcomes of learning. Various theoretical lenses have also been used in the project-based construction industry to approach OL. While the earlier approaches tended to look at projects as mechanistic processes, contemporary approaches think of projects from the perspective of different actors, who continuously reconstruct projects and their contexts as social phenomena (Sense, 2011). Situated Learning Theory, for example, postulates that knowledge and learning are the direct results of project practices and the surrounding socio-cultural conditions of the project environment, where people interact to develop technical and social competencies, and develop a team practice via collective sense making. Discontinuous nature of projects, however, may easily result in the failure of social networks that support knowledge sharing and learning (Almaian & Qammaz, 2019).

Scholars from the OL field distinguish between *single-* and *double-loop learning*. While the former is the outcome of handling emerging and practical problems as part of daily routines, the latter derives from comprehensive, self-reflective and abstract thinking on the daily work routines (Argyris & Schön, 1996). Researchers argued that single-loop learning in the form of practical problem solving is the predominant form of learning on construction sites (Argyris & Schön, 1996).

Table 1 shows various learning mechanisms which function as a bridge between project and organization levels, thereby connecting learning experience of individuals to OL (Mahdiputra et al., 2005). One of the critical points to highlight in Table 1 is that the existence of pre-learning systems, which might be partly or fully available in many organizations as part of their quality management system, facilitate the codification, storage and communication of learning from a portfolio of projects.

Table 1. Organization learning mechanisms at organization and project levels (Mahriputra et al., 2005).

Locus of learning	Learning processes				
	Pre-learning systems	Experience accumulation	Knowledge Articulation	Codification/ Storage	Dissemination/ Distribution
Project Learning	• Project operating procedures • Strictly observed overlap for departing/arriving members • Project information system	• Pre-project meeting • Developed groupthink • Project team communication • Informal encounters • Inter-project visits • Onsite information exchange • Project team exposure	• Project planning meetings • On-site project meetings • Post-project review • Project evaluation • Project progress meetings • Inter-project-meetings • On-site problem solving	• Project plan/audit • Milestones/ deadlines • Meeting minutes • Case writing • Project history files • Intra-project lessons learned' database • Learning histories • As-built drawings • Project progress reports • Project final reports	• Inter-project correspondence • Inter-project personal exchange • Project quality cycles • Staffing shift from project to home organisation
Organisation Learning	• Allocated resources available for learning • Flexible organisation to allow mobility of employees • Reward system • Established informing system • System for control mechanism • Reporting system • Evaluation system • Formalized relationship with boundary system • Reward system • Employee feedback system	• Informal organisational routines, rules and selection processes • Departmentalisation and specialisation • Benchmarking (internal & external) • Imitation • Induction programs for new members • Staff development /on-the-job training • Re-use of experts • Professional-based networks • Inter-company based networks • External & internal seminars • Initiative of individual learning • Partnering • Corporate mentoring • Environmental scanning	• Project manager camps • Knowledge retreats • Professional networks • Knowledge facilitators and managers • Personal reflection • Error corrections • Joint project research • After-action reflection • Review from success & failure • In-house research Improvement programs	• Drawings • Process maps • Project management process • Lessons learned database • Job descriptions • Routines • Standard operational procedures • Rules & regulations • Artefacts • Diary • Reporting system • Individual systems design • Individual memory • Embedded experience • Formal learning procedure • Sub-contracting agreements • Engineering contract	• Communities of practice • Information technology • Regular formal & informal meetings • Story telling • Informal communication • Updating & coordinating meetings among various teams • Job/role rotations • Trade shows and exhibitions

Lessons Learned Practices in Project Environments

As a practice at the intersection of organizational and knowledge management fields, Lessons Learned (LL) can be defined as "kn*owledge or understanding gained by experience*" (Secchi et al., 1999), either they are positive (success stories) or negative (failure stories). LL has different names in different industries or organizations, including but are not limited to post-project reviews, post-project appraisals, project post-mortem, debriefing, reuse planning, reflection, corporate feedback cycle, experience factory (Carrillo, 2005). By definition, any LL should have impact on operations, be factually and technically correct and applicable in the sense that it should reduce or eliminate potential problems (Rowe & Sikes, 2006). LLs can be *internal* practices (by the participation of firm employees) or *external* practices (by the participation of clients or other stakeholders (Carrillo, 2005). Fig. 1 shows a typical LL process.

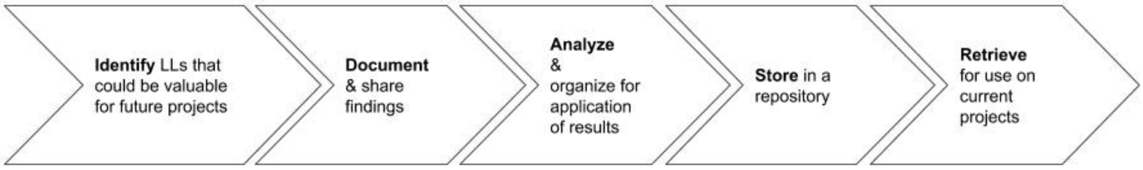

Figure 1: Typical phases of a LL process (Rowe & Sikes, 2006).

While LLs can be valuable to blend various experiences to draw coherent conclusions from project processes and outcomes for OL, they may also have several drawbacks such as being costly, creating embarrassing situations for participants, the reluctance of people to involve in a practice beneficiaries of which are the participants of future projects (Carrillo, 2005), the lack of appropriate formats/systems to classify LLs, and the overemphasis on failures or incidents rather than on synthesis of positive or negative experiences (Kartam & March, 1996).

A review of the LLs in the project management (PM) literature shows that there is a lack of consensus on the methodology of LL practices in the researcher and practitioner communities. As the systematic analysis of the Project Management Institute's (PMI) PMBOK versions by Duffield (2017) shows, LL practices have been associated with various PM knowledge areas in the past including integration-, communication-, scope-, schedule-, cost-, and stakeholder management. It was the 3rd edition of the PMBOK in 2004 that PMI placed a special emphasis on the collection and use of LL through the project life cycle. The 4th edition of PMBOK in 2008 placed specific emphasis on the use of LLs to improve project processes. The 5th edition in 2013 focused on the LL practices mostly as part of the project closure phase. It was the PMBOK's 6th edition in 2017 that LL was more explicitly seen as a critical element of project knowledge management by the introduction of a new process - 'Manage Project Knowledge'- as part of 'executing process group.' PMI defined this new process as "*the process of using existing knowledge and creating new knowledge to achieve the project's objectives and contribute to organizational learning*." Thus, the critical connection between project- and organization-level learning was acknowledged by PMI with a knowledge management lens.

Research Design

As part of an ongoing PhD research study, which aims to develop a LL model that captures LLs over the life cycle of projects and transfer learning to organizational level in relation to corporate strategy making, a 2-step empirical research was designed. In the first step, data from a completed school building project were retrospectively analyzed to identify how different types of LLs scattered over the project life cycle. Table 2 shows the attributes of the case project, delivery model of which was Construction Manager as Agent (CM/A). Meeting minutes, email traffic between CM/A and the contractor regarding project-related problems, project issue logs, and audio-visual materials provided by the CM/A were the inputs for the analysis. Output of the content analysis of empirical data was a diagram which showed the distribution of potential LLs over the project life cycle (see Fig. 1).

Table 2. Project characteristics.

Characteristics	
Project delivery system	Construction Manager as Agent
Plot area	: 18,733 m^2
Total construction area	: 17,835 m^2
Planned duration	: 9 months
Actual duration	: 16 months
Contract type	: Unit price
Architectural program	
Primary school	: 11,645 m^2
Kindergarten	: 3,900 m^2
Multi-purpose hall	: 2,190 m^2
Dining halls	: 820 m^2
Gymnasium	: 606 m^2
Classrooms	: 2,400 m^2

The second step of the research study aimed to develop a preliminary research model to investigate the relationships between project-level LLs, organizational learning, and corporate strategy making. Fig. 2 shows the proposed model, where knowledge and experience from different projects are articulated, codified and stored in a mod*ular learning space* at organization level. An innovative example of a modular learning space is the 'Learning Station' concept, which was developed by Istanbul Technical University Center for Excellence in Education (ITU CEE - http://mukemmeliyet.itu.edu.tr) (see Fig. 2). A modular learning space allows any contributor to organize and share knowledge and experience in relation to various learning outcomes, which can be defined according to Bloom taxonomy. Contributors are free to add any alternative delivery modes (e.g., add columns) to their modular design, which can be physical (e.g., on-the-job-training), digital (e.g., a webinar or an online course module), or both (e.g., a physical learning environment supported by digital elements). According to model, modular organization of learning materials from different projects at the organizational level allows corporate managers to articulate, codify and store LLs according to various audiences (e.g, white-collar / blue-collar workers), content (e.g., PM knowledge areas and processes), delivery modes (e.g., online, face-to-face, and others), and over appropriate platforms (e.g., Intranet, mobile phones, and others). LLs are then processed within the quality management system of the organization (e.g., by the use of pre-learning system, see Table 1) to establish the relationship between individual LLs and higher-level priorities/systems such as corporate functions, corporate strategies; programs/activities/projects; performance tracking and reporting systems, before they are stored in the corporate LL database (CLLD), and disseminated to ongoing or future projects. LLs are continuously monitored, reviewed and processed to update CLLD.

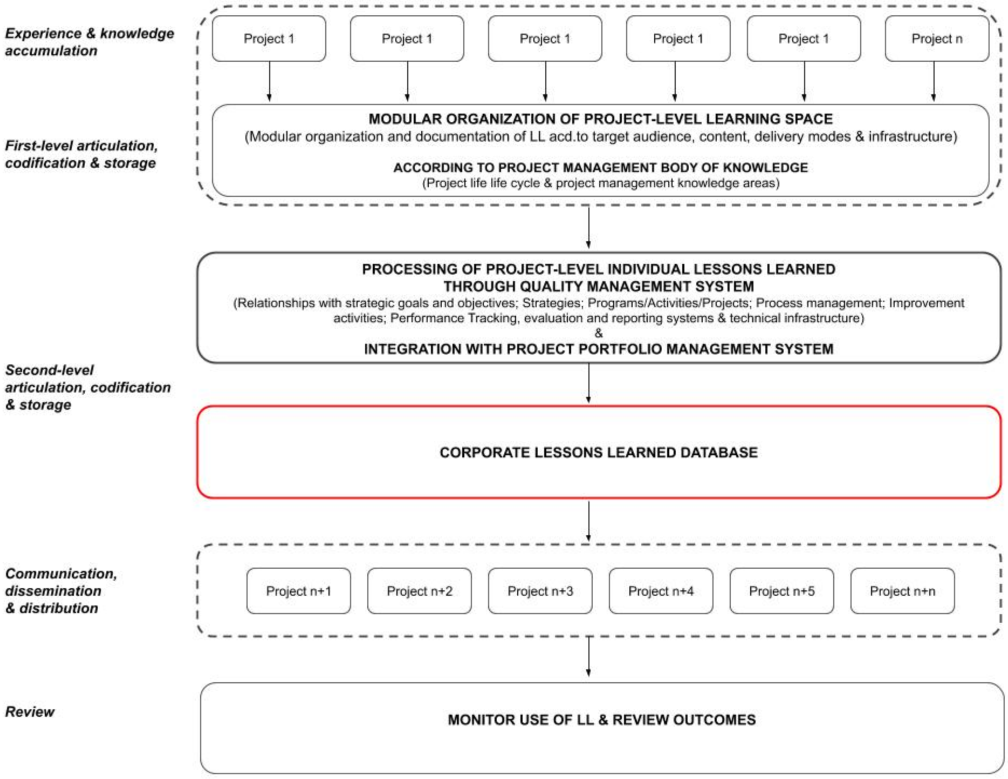

Figure 2: Proposed model.

LEARNING OUTCOMES	READING	VIDEO	CASE EXAMPLE	GUEST SPEAKER	SITE VISIT	SOFTW.	PRACTICAL EXERCISE	ASSESS.
Learning outcome 1								
Content 1	✓	✓		✓		✓	✓	
Content n	✓					✓		
Learning outcome 2								
Content 1	✓	✓						
Content n							✓	
Learning outcome 3								
Content 1			✓	✓				✓
Content n			✓		✓			✓

Figure 3: Example of a modular learning space (http://mukemmeliyet.itu.edu.tr).

Findings

Following the retrospective analysis of the case project and classification of problematic areas, 17 potential LLs were identified over the life cycle of the case project. Fig. 4 displays the communication traffic between CM/A and the contractor firm regarding problematic issues. According to analysis, while the major concerns of CM/A (over the x-axis) were related to project revisions, production quality, and production methods; contractor's concerns (below the x-axis) focused more on changes in unit prices, project revisions, payments and the approvals for building materials. Figure 4 shows that one-off or recurring LLs to be captured, codified and stored scatter over the project life cycle, when different specialized teams (e.g., sub-contractors) and individuals are yet on the construction site.

	CONTENT OF CORRESPONDENCE	Correspondence Count	
		CM/A	CONTRACTOR
1	General information	13	3
2	Material approval	18	10
3	Work progress	11	5
4	Delay	14	0
5	Health and safety	13	2
6	Rework	27	1
7	New unit price	5	27
8	Production quality	31	8
9	Design revision	41	17
10	Material change	3	0
11	Payment	3	14
12	Staff approval	7	6
13	Subcontractor approval	2	1
14	Site arrangement	10	0
15	Production method	29	1
16	Staff/Equipment/Materials demand	3	0
17	Site question	21	64
	Total number of story	251	159

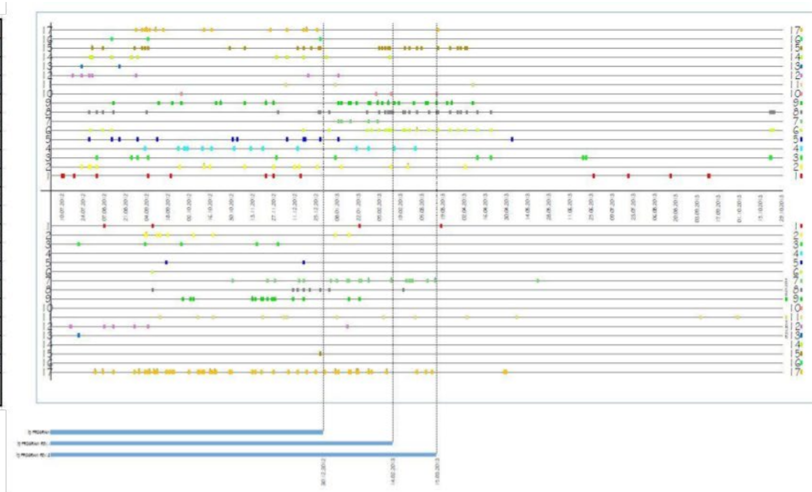

Figure 4: Distribution of LLs over the project life cycle in the case project.

For the purpose of illustration, Table 2 extracts a set of LLs from Fig. 4. For thematic integrity, selected sample LLs were all related to procurement and resource management. Table 3 shows also that decisions made in the early phases influence successive phases of the project life cycle.

Fig. 5 exemplifies the organization of LLs in the form of a modular learning space according to the proposed research model (see Fig. 2). Bottom left part of Figure 5 comprises various LLs materials from different projects, selected according to the learning outcome of the LL module, as defined according to Bloom taxonomy. Each learning material has codes which identifies the source project, life cycle phase, associated PM processes and knowledge areas. Bottom right part of Fig. 5 various content delivery options. Individual contributors or groups have the flexibility to add or subtract columns (delivery alternatives) according to their needs (see Table 1 for the alternatives, or learning mechanisms, to articulate, codify, store and disseminate knowledge). Red-dashed part in Fig. 5 establishes the relationship of the LL module with the organization-, inter-project- and project-level knowledge assets via a coding system, which identifies the target audiences for learning; corporate strategies and functions; processes/programs/activities; key performance indicators (KPIs), and other projects.

Table 3. Sample LLs from the case project.

LL Code	LL Category	Issue Name	Project Code	Phase	Stakeholders	Description	Impact	Recommendation
001	Procurement / Fast-track construction	Excavation	P1-001-2012	▪ Planning ▪ Executing	▪ Client ▪ CM/A ▪ Excavation contractor	After the conceptual design of the building was completed and approved by the municipality, excavation works were separately put out to tender to allow fast-track construction.	▪ Separation of excavation works from other works, while tender documents were being prepared for the building construction, shortened the construction process by about 45 days. ▪ Observation of excavation works allowed potential tenderers to understand the construction site and estimate cost more accurately	▪ Analyze project scope to identify and use the potentialities for fast-track operations and develop alternative procurement strategies (e.g., multi-party contracting).
002	Procurement / Fast-track construction	Rainwater pipeline	P1-002-2012	▪ Executing	▪ Client ▪ CM/A ▪ Pipework contractor	Rainwater pipeline works were separated from the contractual agreement with main contractor and a new agreement was signed with another contactor to complete piping before the end of construction season.	▪ Completion of drainage before the end of construction season eliminated the risk of flood during the rainy days and potential delays.	▪ Analyze project scope to identify and use the potentialities for fast-track operations and develop alternative procurement strategies.
003	Procurement / Fast-track construction	Electrical works / Transformer	P1-007-2012	▪ Planning	▪ Client ▪ CM/A ▪ Electrical works contractor	Transformer installation was completed by a separate contractor before the tendering stage. Transformer was used by both the main contractor in the construction phase and by the client when the construction was completed.	▪ Completion of transformer installation before the construction phase eliminated potential delays.	▪ Analyze project scope to identify and use the potentialities for fast-track operations and develop alternative procurement strategies.
004	Resource mgmt./ Fast-track construction	Water / Artesian well	P1-008-2012	▪ Planning	▪ Client ▪ CM/A ▪ Artesian well contractor	An artesian well was constructed before the construction stage to supply water for construction phase and be used for garden irrigation in the post-construction phase	▪ Construction of a multi-purpose artesian well before the construction stage reduced irrigation costs in the post-construction phase.	▪ Analyze project scope to identify/understand potentialities for reducing operational costs in the building life cycle.

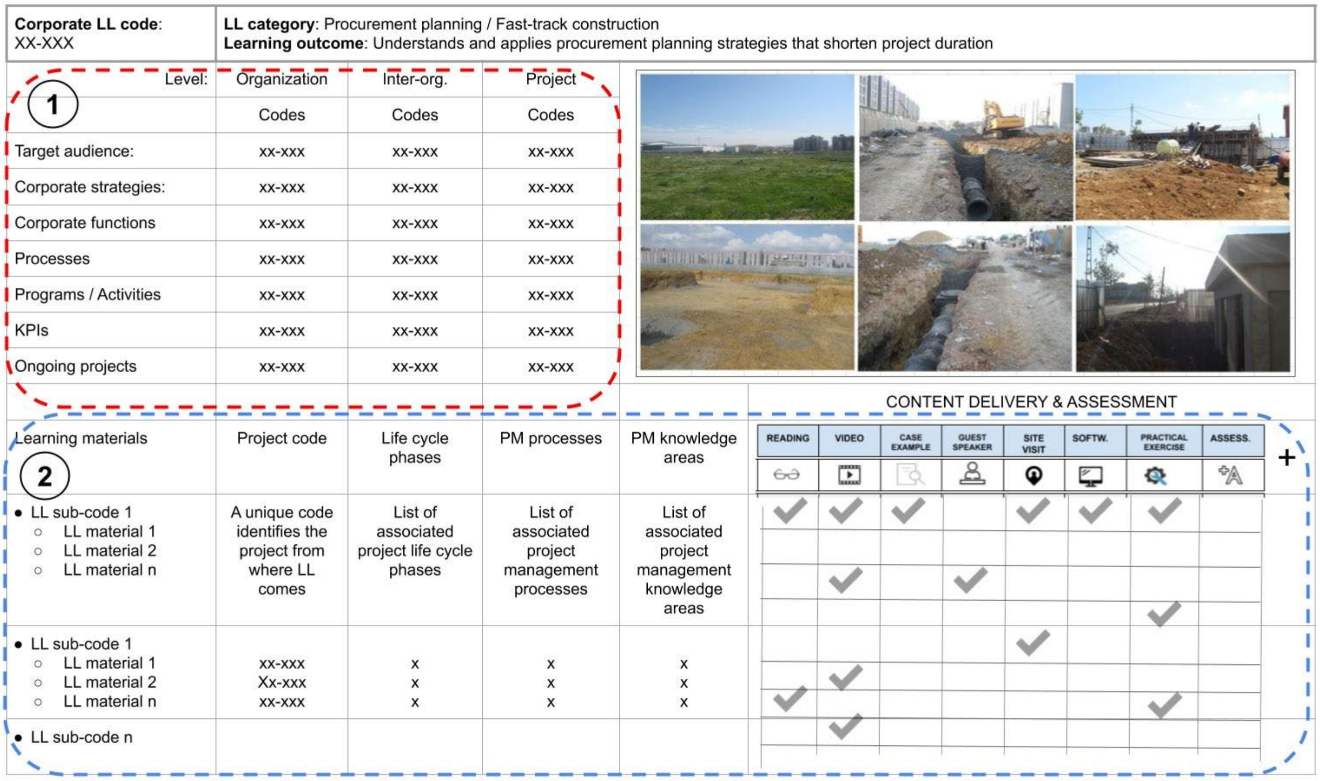

Figure 5: Modular organization of corporate LL learning space.

Conclusions

Authors have reported the methodological approach of an ongoing PhD thesis, which aims to develop a model that captures LLs over the life cycle of projects and transfer project-level learning to organization level in relation to corporate strategy making. LL practices can be more efficient, when construction firms develop systems that facilitate the accumulation, articulation, codification, storage, and distribution of project knowledge and experience. Connection between project- and organization-level learning is especially critical in the construction industry construction, where single loop learning in the form of everyday problem solving is prevalent. Since LLs and their sources/actors scatter over the life cycle of projects, LL should be a continuous practice to capture the valuable experiences of human resources, from the beginning of any project. More importantly, LLs can be converted to valuable knowledge assets of a construction company and support value creation through the development of competitive advantages, as part of a sustainable learning agenda which supports corporate strategy making. In this regard, projects can function as the learning laboratories of project-based, service enhanced firms, when appropriate corporate mechanisms are designed.

Authors argue that modular organization of LLs -a modular learning space- can be a more appropriate way to cope with the discontinuities resulting from the characteristics of job production. A modular learning space may be also more appropriate for the adoption of alternative theoretical perspectives, depending on whether *cognitive* (information processing) view, *behavioral* (behavioral change) view or *sociological* (conversational and interactional) view of learning become prominent in a particular learning environment or for a particular type of learning experience. Considering that many scholars criticize the overemphasis on failures or incidents in the LL literature, a modular approach may facilitate the synthesis of positive and negative experiences from past projects and achieve higher-order learning outcomes that lead to value creation at corporate level.

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Assessing Existing Buildings for LEED Retrofit: Case Study of a University Building

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Abstract

The sustainable built environment concept gained significant attention from the scientific community due to the tremendous increase in the emission of greenhouse gases triggered by the exploitation of natural resources. Changing the conventional way of building construction and retrofit into a greener one is an indispensable step to ensure a sustainable built environment as the buildings cover most of the surrounding. Accordingly, Architecture Engineering and Construction (AEC) industry has started to incorporate green building rating systems like LEED and BREAM in past decades. In this context, accreditation systems have been used in many countries, for both new and existing buildings. The purpose of this study is to assess an existing university building's sustainability potential. First, the current condition of the building is examined using a LEED checklist. Then alternative retrofit strategies, considering potential improvements, are identified from the Life Cycle Cost (LCC) and cost efficiency perspectives. Based on the findings, investing in buildings' sustainability can easily be compensated, as it leads to a remarkable reduction in resource allocation in the long run. Especially, from the cost-efficiency perspective, location and transportation, and indoor environmental quality-related improvements are leading solutions while water and energy efficiency-related improvements are prominent when LCC is considered.

Keywords: *campus building renovation, green building certification, LEED, life cycle cost, retrofit.*

Introduction

In recent years, the soaring emissions of greenhouse gases (GHG) due to the exploitation of natural resources raised a great concern in society. Especially, the use of natural resources in the Architecture Engineering and Construction (AEC) industry is quite extensive. The amount of energy used in the AEC industry accounts for over 35% of global use, and about 40% of the global GHG emissions associated with it (Global Status Report, 2017). The highest portion of this usage arises in the construction, maintenance, and rehabilitation of the structures. This issue reveals the need for radical changes in the built environment. Accordingly, the sustainable built environment concept has garnered significant attention from the scientific community. One of the most important steps to ensure sustainability in the built environment is to transform the traditional building construction and retrofit methods to greener ones. Therefore, green building rating systems like LEED and BREEAM are established in the early

1990s by the United States Green Building Council (USGBC) and the Building Research Establishment (BRE), respectively.

The USGBC defines a 'green' building as a building that uses energy, water, and other natural resources efficiently during its design, construction, and operation. Green buildings do not only save natural resources but also contribute to the occupants' health and comfort through measures taken in terms of temperature and humidity control, indoor air quality, natural lighting, and waste management (USGBC, 2020). To ensure greater transparency on the sustainability of the buildings, green building certification has become more crucial than ever. Therefore, the exploration of the building rating systems and the green building concept has gained momentum in recent years by both practitioners and researchers. Various studies have been conducted over the world with different concentrations. For instance, some focused on the financial benefits of green construction (e.g., Kats, 2003, 2006; Liu et al., 2018; Winkler et al., 2002). Others studied the building energy performance assessment and energy reduction in green buildings (e.g., Feng & Hewage, 2014; Wang et al.,2012; Zou & Zhao, 2014; Diamond et al., 2006; Sinou & Kyvelou, 2006; Fowler et al., 2010). Fuerst (2009) evaluated the investment trends in green-certified buildings in the USA. Da Silva and Ruwanpura (2009) discussed the bottlenecks of the green building certification system's utilization by examining the cases from Canada. As opposed to studies investigating new construction projects, there is limited work on energy efficiency in existing building stock (California Energy Commission, 2005; Waide, 2007; Holness, 2008; Jones et al., 2013).

The green building applications in both new and renovation projects are already consolidated in developed countries, but in developing countries, the importance of these concepts has been recently understood. The percentage of retrofits of existing buildings in developed countries such as the USA, Canada, and Ireland can reach up to 50% of the building stock. Whereas in emerging markets, such as Brazil and India, this value is around 20%, since their focus is on new buildings (Jones & Laquidara-Carr, 2018). Furthermore, in their review of the cases from Turkey, Aktas and Ozorhon (2015) pointed out that the regulation of energy performance in buildings, which became mandatory in 2011, has been used effectively in new constructions while there is still a lack of regulations for existing buildings. This problem is the biggest obstacle for developing countries to achieve sustainability in the built environment since most of the energy is consumed by existing buildings rather than the newly constructed green ones (Energy R., 2010). In this sense, the most appropriate way to reduce these consumptions lies in the renovation of the existing buildings (Construction M. H., 2009).

Nevertheless, sustainable building renovations are one of the most challenging types of construction projects due to several uncertainties. According to Mitropoulos and Howell (2002), these are physical constraints, lack of knowledge, and limited documentation of existing conditions. Thus, the renovation projects are tough to be implemented on the site efficiently. Moreover, there is a perception that sustainable strategies are not as cost-effective as new construction. McKim et al. (2000) stated that renovation projects have worse performance than new construction projects regarding the overall cost, schedule, and quality. Hence, the green building certification programs like BREEAM and LEED are the most pervasive methods of assessing, rating and certifying the sustainability of the buildings. Unfortunately, although the renovation studies are ubiquitous in commercial sectors, there are limited studies concerning the educational buildings in Turkey (Korkmaz et al., 2009). Furthermore, the report of USGBC regarding the country market brief for Turkey confirms this trend. This report reveals that there exist 897 projects with sustainability potential in

Turkey as of March 3, 2020. The report indicates that 380 of these projects are currently certified, while 517 are registered for certification. Moreover, the distribution of these projects according to space type and LEED rating system shows that only 2.56% and 4.46% of the projects are related to the higher education and retrofitting (e.g., O+M). The highest portion is composed of commercial and residential buildings and new constructions (e.g., BD+C). Therefore, considering the potential, the concentration should be diverted to retrofitting existing educational buildings. USGBC has created a LEED project checklist for school retrofit to increase awareness, namely “LEED v4 for Operations & Maintenance: Schools Project Checklist”, which is referred to as LEED Checklist from now on.

This study aims to assess the sustainability potential of an existing university building. In this sense, the main building of the Middle East Technical University (METU) – Civil Engineering Department is evaluated for retrofit. First, its current condition is monitored using the LEED Checklist. Alternative retrofit strategies, considering potential improvements, are identified from the Life Cycle Cost (LCC) and cost-efficiency perspectives.

Methodology

The characteristics of the case study building are identified, categorized, and discussed. Then, data is collected for the corresponding categories by a combination of on-site walkthrough observation, document analysis, and administrative staff consultancy. Afterward, the existing condition of the building is assessed based on the LEED Checklist. Finally, the potential improvements for retrofit are examined based on benefit-cost and cost-efficiency analyses.

Analysis of Existing Condition

The characteristics of the K-1 building are presented in this section.

Site and Landscaping: The building, which is positioned to receive daylight from four fronts, is located at the center of the METU Campus. The bus stop right in front of it makes the building easily accessible. It has a 4742 m^2 of the settlement area, 2771 m^2 of parking space, and 2553 m^2 of the green area, mostly covered with more than 30-year-old trees. The nearest building is located at least 100 m away from the building.

The Building Type: K-1 building, a reinforced concrete structure, consists of three stories, basement, entrance, and the first floor. The building’s actual views obtained in Google Earth Pro 3D are shown in Fig. 1, where the details of landscaping, site layout, and exterior body can easily be perceived trough. The building is referred to as the main classroom building of the civil engineering department. 29% of the building façade is covered with glass as it mainly consists of classrooms and offices. The number (shown in parenthesis) and classification of the rooms in the K-1 building according to their intended use are as follows: study room (3), storage room (2), laboratory (3), classroom (17), conference room (3), office (79), boiler room (1), staff-archive-server (8), and meeting room (4).

Mechanical and Electrical Systems: The mechanical systems of a building can be evaluated considering heating, ventilation, and air-conditioning (HVAC). The building has a central heating system with radiators. There is no mechanical ventilation system in the building, except for the transportation engineering laboratory, so air circulation is typically provided by natural ventilation. Although the building has sensor lights, it is mostly illuminated with manually controlled fluorescent bulbs. The building provides its energy from the distant power plant through the main distribution line. Energy is transferred to corresponding building systems via the internal electricity distribution network.

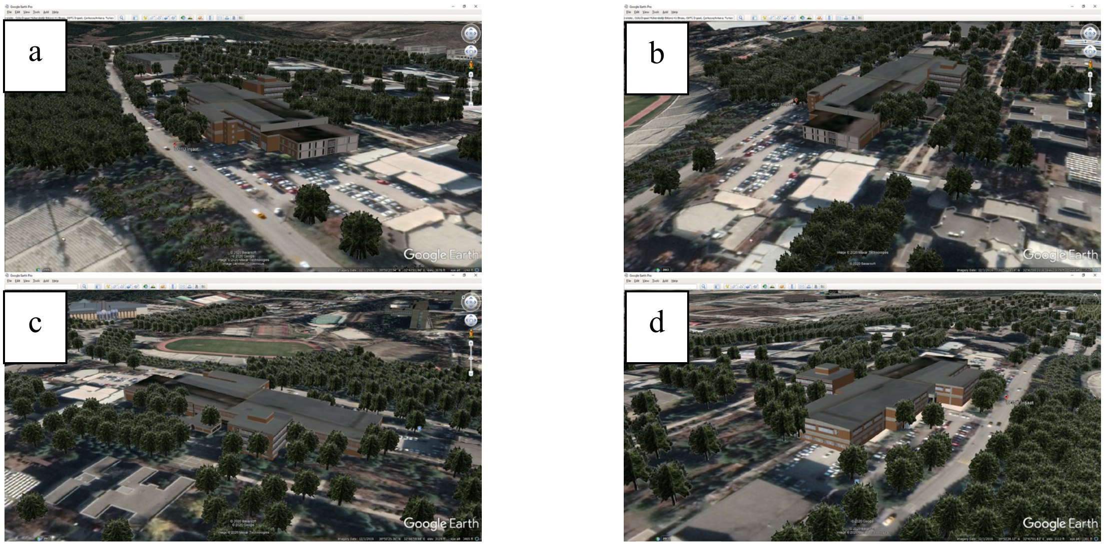

Figure 1: Real images of the building captured counterclockwise from a (south) to d (north).

Data Collection Methods and Objective Identification

The objectives of the study are to assess how sustainable the existing building is and the sustainability potential of the building besides to understand whether retrofitting of the buildings is cost-efficient. Thus, the LEED checklist is reviewed, and possible improvements are identified considering the existing condition of the building. In data acquisition for the analysis of the current condition and the identification of improvements, several data collection methods such as on-site observations and walkthroughs, interviews with the administrative staff, document analysis, and market price analysis supported by retailor consultancy are used. During this process, assumptions are made and categorized into five sections: general, location and transportation, water efficiency, energy and atmosphere, and indoor environmental quality.

General Assumptions: Documentation procedures for green building certification, such as document preparation and policymaking, will be assigned to the department staff. Therefore, no additional costs will be incurred in executing these types of works, such as ongoing purchasing and waste, facility maintenance and renovations policies, and initiating an indoor air quality management program. The expected lifetimes for the possible improvements are detected based on the manufacturer's catalogs. If the information is missing or there is more than one value, the expected service life is acknowledged as ten years.

Assumptions related to Location & Transportation: All members having vehicle stamp travel with their vehicles, and in total, 30 people use motorcycles as a means of transportation.

Assumptions related to Water Efficiency: Since the water supply throughout the campus is done by pumping water from the surrounding water wells, the annual water consumption value of the building can be estimated based on the daily individual water usage values announced by Turk Stat in 2018. It is assumed that (1) out of all building participants, 122 people, including 108 academicians and 14 administrative employees, use the building eight full hours a day, while it is on average two hours a day for students, (2) the total of 900 students visit the building daily, and (3) the building will not be used on weekends.

Assumptions related to Energy & Atmosphere: The share of the building's energy use within the campus total energy consumption is considered the same as the building's natural gas use percent in gas consumption calculations.

Assumptions related to Indoor Environmental Quality: The building's natural ventilation system provides the minimum required indoor air quality condition.

Out of 1500 people using the building, 550 have vehicle stamps, allowing them to access the campus and park their cars to designated parking areas. Also, weekly observations revealed that 30 people use a motorcycle, which does not need a vehicle stamp. It is assumed that all these people provide their transportation by themselves, while the rest use alternative transportation modes. Some were assumed to use the parking spaces of near-by buildings. Furthermore, interviews revealed that the water and energy consumption was measured with a single meter for the entire campus. However, the energy consumption values have been obtained from the relevant transformer of a set of building blocks. Then, the individual consumption values of the K-1 building have been estimated based on the use purposes of these buildings. Similarly, the total water consumption values were also estimated for up to one year. It is assumed that the catalog performance values of the replacement materials such as meters, bulbs, and water-saving faucet aerators can be acquired without any deviations.

Assessment of LEED Criteria

In this study, the LEED Checklist is used to evaluate the existing condition and identify improvements for retrofitting. This checklist consists of several subjects (Fig. 2), and it is used as a guide for assessing the potential of the building to receive LEED certification. To be able to assess through based on the scoring system, some prerequisites specified in the list must first be met. The assessment of the current condition for the K-1 building is performed based on the assumptions given in the preceding part. The acquired score and related explanations are structured according to the categories presented in Fig. 2.

Location and Transportation (13 points): Alternative transportation usage percentage is calculated as 63% based on the information obtained from the building administration on the numbers of vehicle stamps and building participants. Alternative means of transportation such as buses, minibuses, and metro are available from the campus. Moreover, bicycles and rings are provided inside the campus.

Water Efficiency (2 points): The water supply of the campus originates from Elmadağ groundwater basin. The water seeps through the lake Eymir and collected in three deep-water wells which are operated by METU. The water level in these wells is monitored daily and conveyed to the central station on campus via three pumps. Since water is free of charge (groundwater), neither campus-wide nor building-based water consumption values are measured. Building-level water consumption value is estimated as 6,048 m^3 per year in line with the assumptions. Presently, the prerequisites for water efficiency could not be provided for the K-1 building. Also, no water reduction system is deployed outside or inside. Since there is only one water meter station for the entire campus, the building is also insufficient in water metering.

LEED v4 for Operations & Maintenance: Schools
Project Checklist

Project Name:
Date:

Y	?	N			
0	0	0	**Location and Transportation**		**15**
			Credit	Alternative Transportation	15
0	0	0	**Sustainable Sites**		**10**
Y			Prereq 1	Site Management Policy	Required
			Credit	Site Development-Protect or Restore Habitat	2
			Credit	Rainwater Management	2
			Credit	Heat Island Reduction	2
			Credit	Light Pollution Reduction	1
			Credit	Site Management	1
			Credit	Site Improvement Plan	1
			Credit	Joint Use of Facilities	1
0	0	0	**Water Efficiency**		**12**
Y			Prereq 1	Indoor Water Use Reduction	Required
Y			Prereq 2	Building-Level Water Metering	Required
			Credit	Outdoor Water Use Reduction	2
			Credit	Indoor Water Use Reduction	5
			Credit	Cooling Tower Water Use	3
			Credit	Water Metering	2
0	0	0	**Energy and Atmosphere**		**38**
Y			Prereq 1	Energy Efficiency Best Management Practices	Required
Y			Prereq 2	Minimum Energy Performance	Required
Y			Prereq 3	Building-Level Energy Metering	Required
Y			Prereq 4	Fundamental Refrigerant Management	Required
			Credit	Existing Building Commissioning– Analysis	2
			Credit	Existing Building Commissioning–Implementation	2
			Credit	Ongoing Commissioning	3
			Credit	Optimize Energy Performance	20
			Credit	Advanced Energy Metering	2
			Credit	Demand Response	3
			Credit	Renewable Energy and Carbon Offsets	5
			Credit	Enhanced Refrigerant Management	1

Y	?	N			
0	0	0	**Materials and Resources**		**8**
Y			Prereq 1	Ongoing Purchasing and Waste Policy	Required
Y			Prereq 2	Facility Maintenance and Renovations Policy	Required
			Credit	Purchasing- Ongoing	1
			Credit	Purchasing- Lamps	1
			Credit	Purchasing- Facility Management and Renovation	2
			Credit	Solid Waste Management- Ongoing	2
			Credit	Solid Waste Management- Facility Management and Renovation	2
0	0	0	**Indoor Environmental Quality**		**17**
Y			Prereq 1	Minimum Indoor Air Quality Performance	Required
Y			Prereq 2	Environmental Tobacco Smoke Control	Required
Y			Prereq 3	Green Cleaning Policy	Required
			Credit	Indoor Air Quality Management Program	2
			Credit	Enhanced Indoor Air Quality Strategies	2
			Credit	Thermal Comfort	1
			Credit	Interior Lighting	2
			Credit	Daylight and Quality Views	4
			Credit	Green Cleaning- Custodial Effectiveness Assessment	1
			Credit	Green Cleaning- Products and Materials	1
			Credit	Green Cleaning- Equipment	1
			Credit	Integrated Pest Management	2
			Credit	Occupant Comfort Survey	1
0	0	0	**Innovation**		**6**
			Credit	Innovation	5
			Credit	LEED Accredited Professional	1
0	0	0	**Regional Priority**		**4**
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
0	0	0	**TOTALS**	Possible Points:	**110**

Certified: 40-49 points, **Silver:** 50-59 points, **Gold:** 60-79 points, **Platinum:** 80+ points

Figure 2: LEED checklist for operations & maintenance: schools.

Energy and Atmosphere (7 points): The annual energy consumption value for the entire campus is around 35,300,000 kWh per year consumed from the grid, and around 54,000 kWh per year generated on-site. Building specific annual energy consumption value is estimated as 975,500 kWh per year. Moreover, the buildings on the campus are heated based on the provided steam from the central plant. The thermal capacity of this plant is known to be 40 MW, with annual fuel consumption of 11 million m^3 of natural gas. At the building level, a heat exchanger converts the steam energy to heat water. Similarly, building level fuel consumption is estimated as 295,400 m^3 per year. The prerequisites for energy and atmosphere could not be met. There has been no systematic study on energy metering, optimization, demand response, renewable energy systems, and refrigerant management. The building met only the requirements of the existing building commission - analysis, implementation, and ongoing commissioning items from those given in the checklist.

Indoor Environmental Quality (1 point): Pre-assessment requirements for indoor air quality as (1) minimum Indoor Air Quality (IAQ), (2) control of environmental tobacco use, and (3) green cleaning policy items are already satisfied. The entryway systems (e.g., steel grating doormats) exist at each of the entrances of the building

Sustainable Sites (3 points): Documents related to site improvement and management plans and future goals have been established, and action plans have been prepared on how to evaluate and monitor these processes by the administrative staff. In terms of the shared use of facilities, the building has several alternatives, such as a photocopy room, sports equipment, faculty members' lounge, meeting rooms, and public parking areas.

Materials and Resources (2 points): Only ongoing solid waste management requirements are met within the LEED Checklist evaluation criteria for the building. Finally, no **Innovation** was observed in the assessments, and **Regional Priority** does not apply to the building. The overall score of the current condition is calculated as 28 out of the possible 110 points.

Potential Improvements

Potential improvements were studied after the identification of insufficiencies in the current state of the building. The primary purpose of improvements is to enable the building to obtain a LEED certificate in the most efficient way. At least 40 points from the checklist should be collected to get a LEED certificate. Therefore, potential improvements have been identified, and the most cost-efficient ones were selected for retrofitting. The details for the improvements and the related score potentials are as follows:

Location and Transportation: To reduce the conventional travel rates of building occupants, it is planned to (1) design a carpool matching website, (2) promote ridesharing by labeling preferential parking spaces for rideshare participants, and (3) launch a carpool program in which the information technology assistants of the department and the university staff will play an active role. Based on these three improvements, it is expected to gain two points.

Water Efficiency: There are two prerequisites to be completed: (1) indoor water use reduction and (2) building-level energy metering. To this end, it is planned (1) to modify the faucets, siphons, and urinals in the building with water-saving systems (e.g., water saver faucet caps, water-free urinals, and dual flushes); and (2) to install a water meter to the main water line of the building. The modification of plumbing items, water-free urinals, water saver faucet aerators, and water-saving dual flush systems will reduce annual water consumption by 750, 592, and 637 m^3, respectively. It will lead to getting five more points.

Energy and Atmosphere: Four possible improvements were designated for this item. The first and second one is on energy performance optimization. In the first one, it is planned to replace the traditional bulbs with the led ones and installing solar panels on the roof. These measures are expected to provide 2.6% energy savings. Besides, installing the solar panels will also satisfy the conditions considered under renewable energy and carbon offset. Therefore, this will lead to getting points from two different items with one improvement. The third one is to insulate the building façade, which will provide an additional 30% energy saving. For the last item, advanced energy metering, individual energy meters are planned to be installed in each laboratory in the building. With the improvements mentioned above, the building can be rewarded ten more points.

Indoor Environmental Quality: There are several prerequisites: minimum indoor air quality performance, environmental tobacco smoke control, and green cleaning policy. Mandatory warning signs and directions are available in and out of the building for environmental tobacco and smoke control. For the green cleaning policy, a comprehensive market price study was conducted, and it was concluded that there was no significant price difference between green and traditional cleaning materials. Hence, it is discerned that updating the cleaning policy towards a greener one will not cause any additional costs. Apart from the prerequisites, several improvements are considered: (1) initiating an IAQ management program covering the issuing documents for standardization of the related processes, (2) installation of air quality alarms to the openings, cafeteria space, management building, and the main entrance for enhanced indoor air quality strategies, (3) improving the interior lightning by replacing room's on-off electric switches with the adjustable ones, (4) measuring indoor daylight intensity, (5) assessing green cleaning custodial effectiveness and purchasing green cleaning products, materials, and equipment, and (6) conducting an occupant comfort survey. Based on the improvements, a total of four additional points can be earned.

Cost-Benefit and Cost-Efficiency Analysis

In this study, Cost-Benefit Analysis (CBA) is used to perform a comparative analysis of potential improvements according to their annual equivalent benefit to cost ratio (BCR) calculated considering different expected service lives. The aim is to identify among the alternative improvements that provide the lowest cost with the highest benefit (e.g., maximum sustainability potential based on LCC) in LEED assessment. Throughout the calculations, the monetary values and the expected service lives related to the improvements are determined based on comprehensive market research. Nevertheless, these values are subject to change.

In conducting CBA, the Annual Equivalent (AE) method is preferred since the improvements have unequal service lives. The analysis is performed by following the steps: (1) the Equivalent Annual Cost (EAC) for the initial investment and the expected incomes are calculated using the finance investment analysis equations 1, 2, 3, 4, and 5, based on the estimated prices, individual expected service lives, and 10% constant interest rate, (2) the LEED score contributions and service lives of the improvements are identified, (3) following the LCC perspective, the EAC value of the expected incomes are divided by the EACs of the initial investments and maintenance costs, to find the BCR for each improvement as in equation 6, (4) the obtained BCRs are compared, and (5) all relevant improvements are identified until reaching the required amount of points (40 points) to get certified by giving priority to the prerequisite improvements and starting from the possible improvement having the highest BCR. The used equations are as follows,

$$NPV = \Sigma(Cash\ Flow_t / (1+r)^t) - Initial\ Investment \quad (1)$$
$$EAC = (NPV \times r) / (1-(1+r)^{-n}) \quad (2)$$
$$P = F \times (1 / (1+r)^n) \quad (3)$$
$$A = P \times ((r \times (1+r)^n) / ((1+r^n)-1)) \quad (4)$$
$$A = F \times (r / ((1+r)^n-1)) \quad (5)$$
$$BCR_s = EAC(Expected\ Incomes / (Initial\ Investment + Maintenance\ Costs))_s \quad (6)$$

where *EAC* is Equivalent Annual Cost, *r* is Discount or Interest Rate, *n* is Number of Years, *NPV* is Net Present Value, *t* is Cash Flow Period, *P* is Present value, *A* is Annual Equivalent, *F* is Future Value, *BCR* is Benefit-Cost Ratio, and *s* is Improvement Alternative Number.

Although this analysis offers the most profitable solutions in the long term, it may not be the cheapest in terms of the initial cost. The reason for this is that some improvements have an initial cost and a point gathering potential in the LEED assessment, but their BCRs are 0 since they do not provide any income in time. Therefore, as an alternative, to identify the cheapest solution set to get certified based on the initial investment cost (i.e., obtain LEED certification with the minimum investment), the total initial cost (TIC) / Point Potential (PP) ratio of each improvement is calculated. Then, starting from the lowest value, all relevant improvements are identified until reaching the total targeted score of 40 points to get certified. The identified improvements for each of the analyses are highlighted in the appendix.

Based on the CBA analysis, the potential improvements are determined to be eligible in the following order; building-level water meter installation, building-level energy meter installation, water-saving faucet aerators installation, water-saving dual-flush system replacement, lighting bulb replacement, building façade insulation, water-free urinal replacement, and solar panel installation. Accordingly, with a 270466.5 TRY initial investment cost, 13 points are gathered, and the building collected a total of 41 points.

Based on the cost-efficiency analysis, the potential improvements are determined to be eligible in the following order; building-level water meter installation, building-level energy meter installation, daylight measurement device installation, advanced energy meters installation, preferential parking delineators installation, air quality alarms installation, replacement of 50% of electrical switches, water-saving dual flush system replacement, solar panel installation, and water-free urinal replacement. Accordingly, with a 48799 TRY initial investment cost, 13 points are gathered, and the building collected 41 points.

The comparison of two analyses reveals that the potential improvements that are profitable in the long run and the ones that provide the cheapest solutions differ. For example, the preferential parking delineators installation costs 600 TRY while it has a potential of two points. However, it does not provide incomes in the long run. On the other hand, the water-free urinal replacement having ten years of expected service life, costs 15000 TRY while it has a potential of one point and 3557.50 TRY of annual income. Thus, ultimately it is determined that investing in sustainable retrofitting items related to water and energy efficiency is the most profitable solution in the long run as they lead to a remarkable reduction in resource allocation.

Conclusions

In this study, the sustainability potential of the civil engineering department's main building in the METU campus, namely the K-1 building, is assessed to develop a better understanding of the LEED certification process of existing campus buildings for green retrofitting. Undoubtedly, the only aim in this process should not be score hunting by omitting the sustainability, but in this study it is aimed to collect the minimum required score to get LEED-certified to raise awareness and form a motivation in educational facilities with limited budgets. Moreover, it is intended to demonstrate that it is possible to perform monetary analysis and attain profitable outcomes for the construction industry, which is predominantly driven by economic decisions. Accordingly, the existing situation of the building is assessed, and the potential improvements are identified. The individual and joint point contributions for the potential improvements are determined. Then, the benefit/cost ratio (BCR) and Total

Initial Cost (TIC)/Point Potential (PP) ratio for each of the potential improvements are calculated. These values are observed to vary from one improvement alternative to another, but to the extent allowed by the budget, it is thought that sustainable options should be implemented with a holistic approach. Nevertheless, the most profitable solution sets based on both LCC and cost-efficiency (cheapest solution set based on initial investments) are presented. The findings show that when the building's sustainability potential is assessed from the LCC perspective, improvements regarding water and energy have the priority. On the contrary, when assessed from the cost-efficiency perspective, the location and transportation, and indoor environmental quality related ones come to the fore. Furthermore, it is comprehended that the initial cost of sustainable improvements could be compensated quickly, and these improvements will subsequently make a profit as they reduce resource usage in the building. Accordingly, this study is quite useful for benchmarking in LEED campus building renovation research. As a future study, the environmental impacts of improvement sets will also be evaluated by conducting a Life-Cycle Assessment (LCA).

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Appendix: Details of benefit-cost and cost-efficiency analysis.

Checklist Item	Potential Improvements	Needed Units	Unit Price (TRY)	Total Initial Cost (TIC) (TRY)	Point Potential (PP)	Joint Potential Point	Expected Service Life (yr.)	B / C (Ratio)	TIC / PP (Ratio)
Location and Transportation	Preferential Parking Delineators Installation	5	120	600	2	2	10	0	300
Water Efficiency	Water-saving Faucet Aerators Installation	15	7.9	118.5	0	5	1	44.01	-
	Water Free Urinal Replacement	15	1000	15000	1		10	2.37	15000
	Water-saving Dual Flush System Replacement	15	173	2595	1		10	21.63	2595
	Building Level - Water Meter Installation	1	550	550	0		10	0	-
Energy and Atmosphere	Lighting Bulb Replacement	630	50	31500	0	10	10	17.31	-
	Solar Panel Installation	28	945	26460	2		10	1.01	13230
	Building Façade Insulation	2218	87.5	194075	4		50	15.22	48519
	Building Level Energy Meter Installation	1	168	168	0		10	0	-
	Advanced Energy Meters Installation	3	168	504	2		10	0	252
Indoor Environmental Quality	Air Quality Alarms Installation	3	336	1008	1	4	10	0	1008
	Replacement of 50% of Electrical Switches	60	30	1800	1		10	0	1800
	Daylight Measurement Device Installation	114	1	114	2		10	0	57

Blue	Prerequisite improvements
Red	Identified improvements based on LCC analysis
Yellow	Identified improvements based on cost-efficiency analysis

Life Cycle Analysis of a Single-family House in Mediterranean

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Abstract

In this study, life cycle assessment of a single family house in Bodrum, Turkey was carried out. Three scenarios that mainly focus on structural systems were assessed. Scenario 1 is a reinforced concrete frame structure, scenario 2 is a straw bale structure, and scenario 3 is a stonemasonry structure. The results show that both scenario 2 and 3 has a smaller global warming potential. The comparison between scenarios 2 and 3 varies depending on the method. The results are discussed based on the effects of the materials and building techniques differed among the scenarios. One of the objectives of this study is to compare the results from two different tools. Therefore, the same building was assessed with One Click LCA and Athena Impact Estimator tools. The results obtained via different tools are close to each other. The potential reasons for the differences of the results from different tools are also discussed.

Keywords: *life cycle assessment, material efficiency, single-family house.*

Introduction

The negative impacts of the climate change on nature, environment and people can no longer be ignored (Parry *et al.*, 2007). While, an important factor causing climate change is the increasing amount of energy consumption and the associated greenhouse gas (GHG) emissions, these emissions also yield unprecedented environmental, social, and financial impacts. One major source for the increase in energy consumption in the world is the building sector, where construction, operation, and maintenance activities account for approximately 40% of the energy demand, and 45% of the global carbon emission (Calautit *et al.*, 2016). As a response to these problems, research efforts for reducing carbon emissions have accelerated in recent years. It is emphasized that the emissions in the building sector are derived not only from carbon emissions during operation of a building, but also from embodied carbon of material production, transportation, and installation (RICS, 2017).

In this respect, it is important to consider both embodied carbon and operational carbon as a whole. For this purpose, the life cycle assessment (LCA) methodology is being adopted by construction industry since 1980s. For instance, the excessive energy spent in the production, transportation, and installation of the building material may not provide benefits in life cycle more than its operational energy. Therefore, the evaluation of these two parameters on the common ground plays a critical role in the assessment of a building throughout its lifetime.

In this study, the environmental impacts of a single-family house were assessed according to LCA methodology. It was aimed to test the effects of natural and local materials in the life cycle of a single-family house building. It was also seen that, by providing adequate environmental data to designers and architects, it is possible to disseminate the practice of sustainable works and render the principles of sustainable design more common than ever.

Literature Review

In an LCA study, all environmental factors in a material's life cycle can be examined. In other words, it is possible to obtain all the analysis from the production of the material, its transportation to the construction site, its assembly and the condition of the product after its expiration (Margni & Curran, 2012). This comprehensive approach in LCA has been considered as the greatest asset of the methodology. Moreover, as this comprehensive methodology provides environmental data for every material used in the building, it may also be critical for the decisions at the design stage. In short, LCA shows the environmental consequences of architectural decisions, investor and user requests in detail (Han & Srebric, 2011). According to Shelton (2007), choosing durable, local, and natural materials is the strategy has been determined that help architectural projects become more sustainable. In addition to that, Brophy and Lewis (2011) and Webster-Mannison et al. (2013) mentioned that selection of the appropriate and local materials regarding with the climate and environment is one of the methods which is applied in concept design stage.

The LCA study on a four-story residential building in Vaxyo, Sweden can be given as an example in this regard. The aim of this study is to examine the effect of wood used in the building on the carbon footprint of the building with eight different design alternatives. At the same time, these design alternatives are intended to be used by non-experts (Peñaloza et al., 2013). Another example investigated for LCA studies is the intervention scenarios of a 40-year-old building in Portugal. Two different scenarios are tested in this study. The first of these is to demolish the existing building and construct a completely new building in its place. The second is that the existing building is renovated according to new architectural decisions. Since the costs of these two scenarios are close, the environmental impacts of these scenarios are determined as decision makers. Analyzes of this environmental impact have also been calculated by conducting an LCA study (Gaspar & Santos, 2015).

Method & Material

The methodology for this study is based on the EN 15978 standard of "Sustainability of construction works: Assessment of environmental performance of buildings - Calculation method" and "Whole Building Carbon Assessment for the Built Environment" (RICS, 2017) guidebook.

The first LCA tool used in the study is Athena Impact Estimator. It is an LCA software that is specifically designed for life cycle assessment of buildings. The second LCA tool used in the study is One Click LCA. It is an online software that is designed for the architecture, engineering, construction industry, that is capable of calculating the environmental impact of buildings and generating EPDs for construction materials. Other than the LCA tools, there are several other tools used in order to have more accurate calculation of the operational carbon emission, such as Climate Consultant, DesignBuilder and EnergyPlus. For the modelling and calculation of the quantities of the house, SketchUp was preferred.

Procedure

The following sections of this study have been structured according to LCA standards. First, goal and scope of the study assessment was determined. Second, inventory analysis was carried out. Then, environmental impact assessment was conducted depending on the prepared inventory. Finally, interpretation of the results is discussed in relation with the other stages.

Goal and Scope

For the comparison of the environmental impacts of building materials used in residential projects via LCA tools, it was decided to investigate a single-family house project in Bodrum, Turkey (Fig. 1). This newly built house has two stories without a basement, has a flat roof and gypsum board interior walls. Double glazing with aluminum frames is used in the windows. The interior doors are hollow core wooden doors and the exterior door is a steel door. The building is settled in a 6m x 15m rectangle area. The gross internal area (GIA) of the building is 180 m² and the net internal area (NIA) of the building is 141 m². Three design scenarios that focus on changes in structural system and exterior walls were tested in this study, which can be seen in Table 1.

Figure 1: The single-family house as a case study.

- Scenario 1 has a reinforced concrete frame structure. Its exterior walls are made of AAC coated with plaster and paint. It has rock wool insulation on exterior walls. The columns are placed inside the exterior walls on two longitudinal sides.
- Scenario 2 has straw bale units as structural system and exterior walls. These units are coated with clay-straw plaster.
- Scenario 3 has stonemasonry load-bearing walls as structural system and exterior walls. The stones used in these walls are assumed to be gathered on-site after an excavation work related to another construction project. These walls are left uncoated.

Table 1. Scenario characteristics for the LCA study.

	Scenario 1	**Scenario 2**	**Scenario 3**
Structural System	Reinforced Concrete Frame	Straw Bale Units	Stonemasonry Loadbearing Walls
Exterior Walls	Autoclaved Aerated Concrete Walls	Straw Bale Units	Stonemasonry Loadbearing Walls
Wall Finishes	Rockwool Insulation + Plaster + Water Based Paint	Clay and Straw Plaster + Water Based Paint	None

The study includes LCA analysis of a single-family house. Components included are: Substructure, frame, upper floors including balconies, roof, external walls, windows and external doors, internal walls and partitions, internal doors, wall finishes, floor finishes, ceiling finishes Components to be excluded are: stairs, facilitating works, fittings, furnishings and equipment (FF&E), building services/MEP, external works, and demolition.

These components are analyzed in terms of outputs of the following stages as highlighted in Fig. 2: Raw Materials [A1], Transport [A2], Manufacturing [A3], Transport [A4], Replacement [B4], and Operational energy use [B6].

Product Stage			**Cons. Process Stage**		**Use Stage**							**End of Life Stage**		
Raw Materials	Transport	Manufacturing	Transport	Construction	Use	Maintenance	Repair	Replacement	Refurbishment	Operational Energy	Operational Water	Demolition	Waste Processing	Disposal
A1	A2	A3	A4	~~A5~~	~~B1~~	~~B2~~	~~B3~~	B4	~~B5~~	B6	~~B7~~	~~C1~~	~~C2~~	~~C3~~

Figure 2: LCA stages that are included in the study.

The selected impact category to be assessed is the global warming potential (GWP) that represents the amount of carbon dioxide equivalent emissions. GWP is one of the most commonly used impact category in LCA studies and it renders this study to be comparable by other studies in the literature. The functional unit is $kgCO_2$-eq/m^2 per year for a single-family house (GIA: 180m^2, NIA: 141 m^2). The reference study period (RSP) is 50 years which is representative duration in a Turkish case and is also suggested by standards and guidelines.

Data Sources for the Study

For the Athena Impact Estimator part of the study, the main data source is the database of Athena Institute which is natively integrated into Athena Impact Estimator. For the One Click LCA part of the study, One Click generic construction materials database is the main data source. However, where this database fell short, other applicable databases that are integrated into One Click LCA, such as BAU-ELD or BRE, were benefited from in the One Click LCA part of the study.

Unlike One Click LCA, Impact Estimator does not have alternative databases other than the database of Athena Institute. Therefore, when suitable data were not available in the Athena Impact Estimator, existing local environmental product declarations (EPD) in Turkey were integrated into the study (EPD Turkey, 2020). It must also be noted, because that Athena Institute does not cover straw bale units and there is no local EPDs for straw bale units, these units are assumed to be imported from Lithuania in the Athena Impact Estimator part of the study. Hence, EPD from a Lithuanian straw bale unit manufacturer were used in the study. Transportation of these units are calculated accordingly. For the Athena Impact Estimator part of the study, transportation data is either data from Athena Impact Estimator or data from the study of Chester and Horvath (2009). For the One Click LCA part, transportation data of One Click LCA were used.

Lastly, Climate Consultant software which converts EPW format raw climate data into different types of information was used for illustration of some weather data of Bodrum. For the simulation, the weather data of Muğla were used because Muğla has the closest weather data to Bodrum. Information from Climate Consultant was fed into EnergyPlus engine which is plugged into the DesignBuilder software. Therefore, an accurate estimation of operational energy use of the house was generated. The values of temperature range and comfort zone were used according to ASHRAE 55-2004 standards.

Results and Discussion

Impact Assessment

The results of the analyses from both of the LCA tools can be seen in the figures below. Carbon emissions are considered in two categories: embodied carbon and operational carbon. Fig. 2 shows the total GWP of the building throughout its lifetime. GWP caused by the embodied carbon can be seen in Figure 3. GWP caused by the operational carbon emissions of the building is shown in Fig. 4.

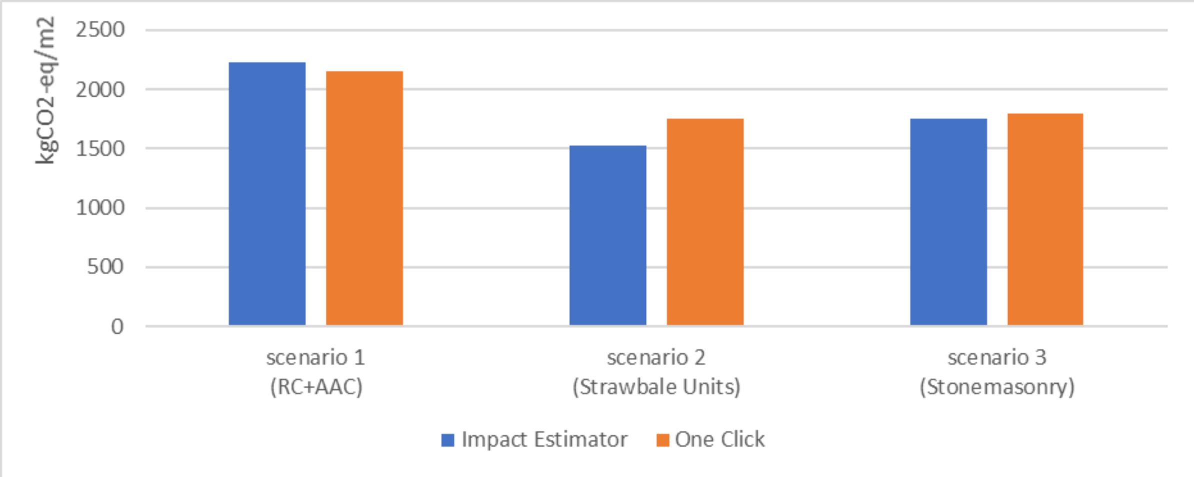

Figure 3: Comparison of total GWP per m^2 for scenarios from both LCA tools.

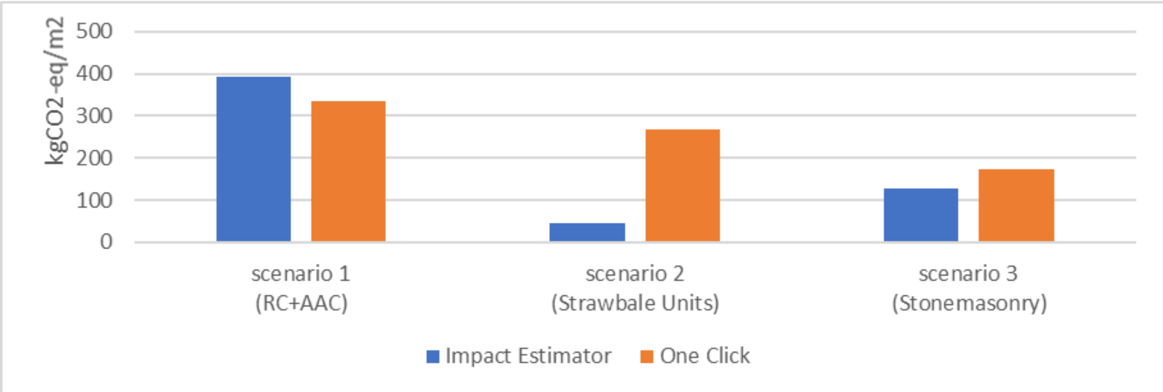

Figure 4: Comparison of total embodied carbon per m^2 for scenarios from both LCA tools.

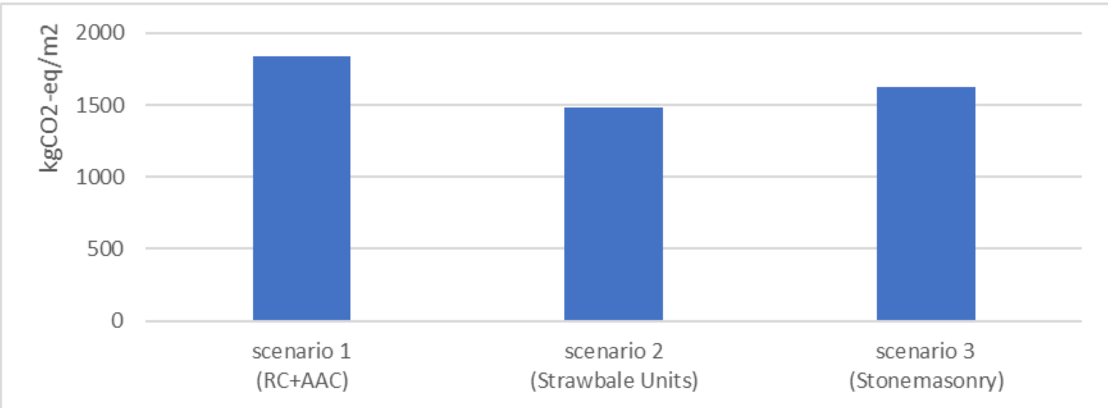

Figure 5: Comparison of annual operational carbon per m^2 for scenarios.

Analysis of the Scenarios

There are several points that can be discussed on the outputs. First of all, operational carbon emissions (B6) clearly account for a vast majority of the total emissions. Even though the amount varies between the scenarios, operational carbon emissions are responsible for more

GWP than any other lifecycle stage. As an example, GWPs of different lifecycle stages of the scenario 1 can be seen in Fig. 5.

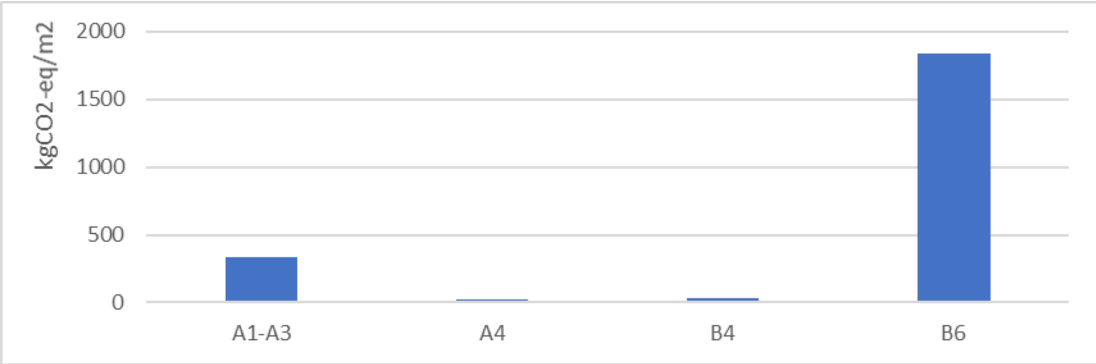

Figure 6: GWPs of different lifecycle stages for Scenario 1.

When the operational carbon emissions are analyzed on a component basis, the most demanding component is the cooling system. This is because of the fact that Bodrum has a hot and humid climate. The distribution of energy demand of different building systems can be seen in Fig. 6.

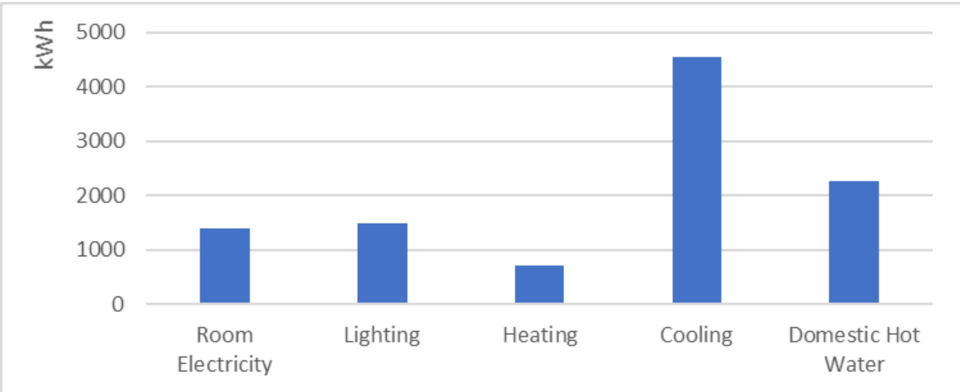

Figure 7: Breakdown of energy consumption of Scenario 1.

It was seen that Scenario 1 has significantly higher embodied carbon than the other scenarios. This situation has two main reasons. The first reason is the material preference for exterior walls. In Scenario 1, the exterior walls are made of AAC blocks. The production and transportation of these blocks account for significant amount of emissions. On the other hand, Scenario 2 has straw bale wall units. These units have net negative carbon emissions due to the carbon absorbed by the plant-based raw material. Even though they are imported from Lithuania, the overall production and transportation (A1-A4) emissions is still net negative. As a result, the lowest embodied carbon is observed in Scenario 2. Finally, Scenario 3 has stonemasonry walls that are obtained from a nearby excavation; therefore, they are assumed to have zero production and transportation emissions (A1-A4). Thus, the effect of the exterior walls in Scenario 3 is much lower than Scenario 1, but higher than Scenario 2. Comparison of the effect of the exterior walls can be seen in Fig. 7.

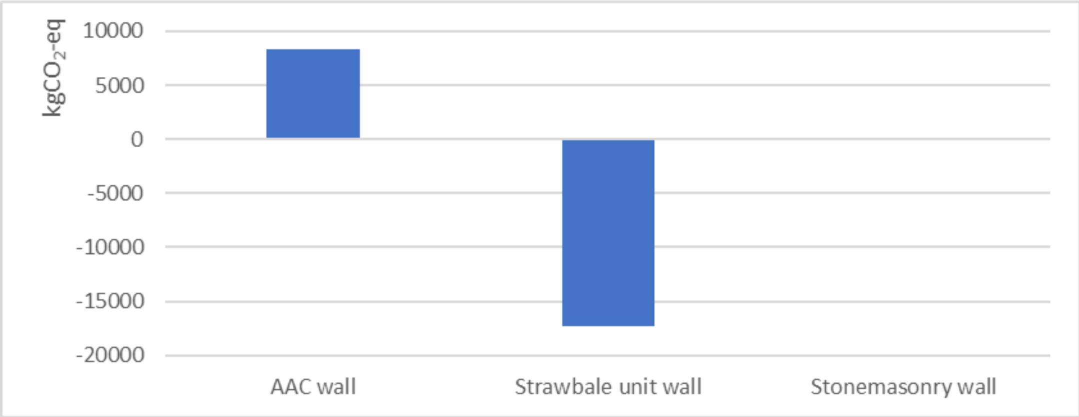

Figure 8: Comparison of GWP of the exterior walls.

The second reason is the structural system. Scenario 1 has a reinforced concrete (RC) frame structure. Even though the concrete material has low carbon emissions per unit, the amount of concrete used in the structural system is significantly larger than other materials. As a result, RC frame system causes a very high amount of carbon emission. It was seen that the embodied carbon of the scenario 3 is the highest. As vertical load bearing elements, Scenario 2 and Scenario 3 has the exterior walls. In the case of flooring and horizontal elements, both Scenario 2 and Scenario 3 has glulam beams and timber joist slabs. Due to their relatively low amounts, they have a smaller effect on the total embodied carbon and they perform better than RC floors in terms of carbon emission. Thus, embodied carbon is lower for Scenario 2 and Scenario 3, as can be seen in Fig. 8.

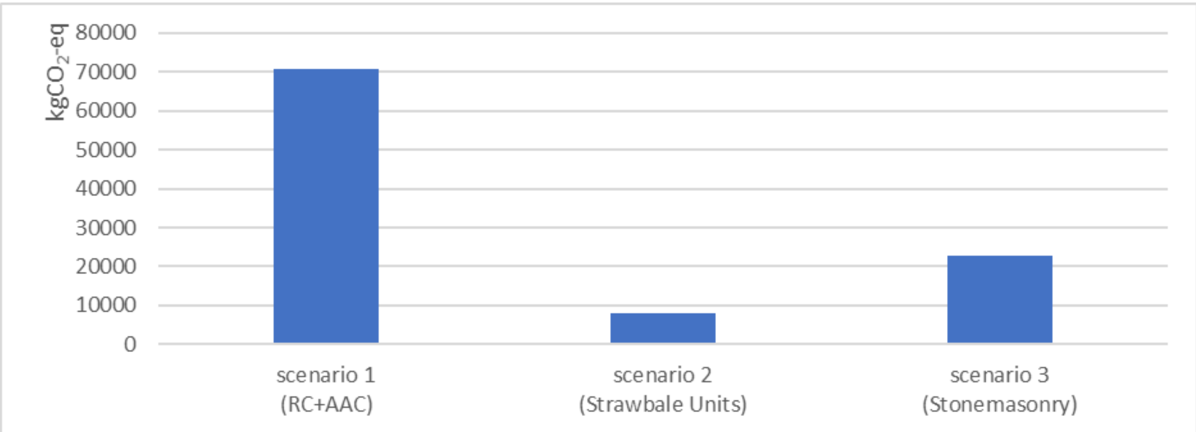

Figure 9: Embodied carbon of different scenarios.

One of the most important issues to consider about the straw bale wall units and timber floors is the afterlife scenario of these materials. If they are burned after the demolition of the building, almost all the environmental benefits of these materials are lost. Therefore, it is absolutely essential that these plant-based materials would be recycled/down cycled or left in the nature to be properly decomposed after they complete their lifecycle. Figure 9 shows the comparison of sums of GWPs of embodied carbon and end of life phases (A1-A3 + C2-C3) of two different cases for afterlife scenarios of straw bale units. In the first case, straw bale units are properly recycled or decomposed into nature; however, in the second case they are incinerated. The drastic difference clearly indicates the importance of afterlife treatment for Scenario 2.

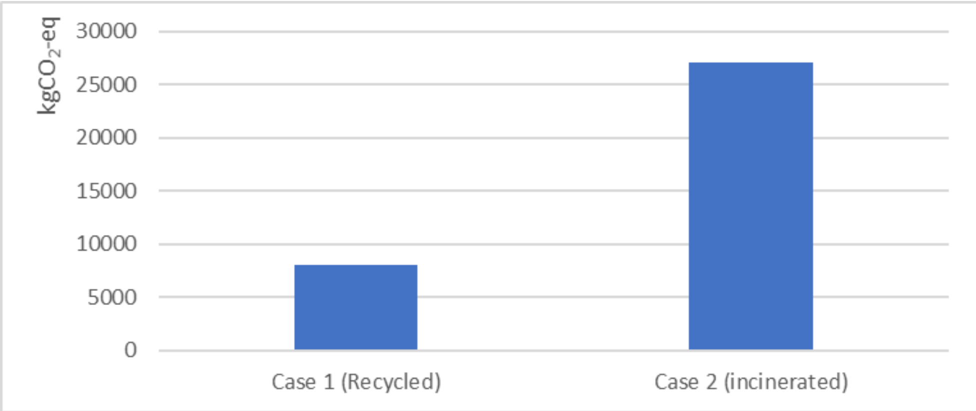

Figure 10: Cases for afterlife of straw bale units (including phases A1-A3 + C2-C3).

The transportation emissions (A4) are the highest for Scenario 1 and the lowest for the Scenario 3. It is the highest for Scenario 1 because of the high amount of the concrete and AAC blocks used. Transportation emissions are higher in Scenario 2 than Scenario 3 because the straw bale units are assumed to be produced in Lithuania and transported to the site by trains, freighters, and trucks. On the other hand, the stones used in Scenario 3 are produced directly in the site as a result of an excavation nearby so they do not cause any transportation emissions. The comparison of the effect of transportation can be seen in Fig. 10.

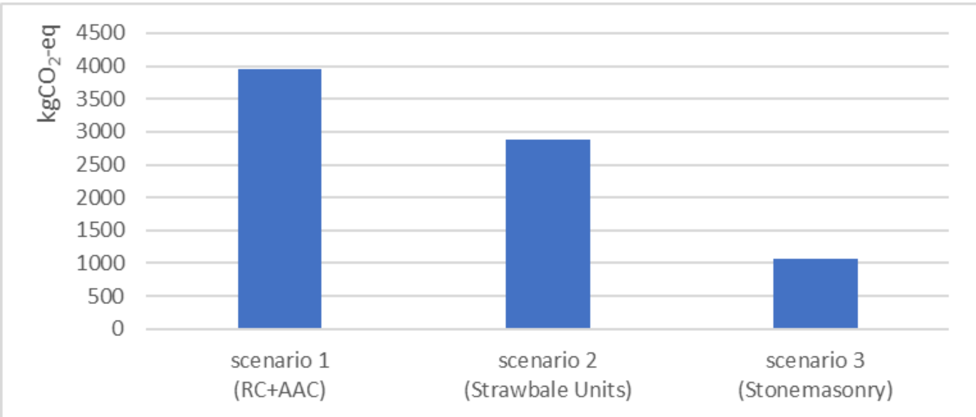

Figure 11: Comparison of the effect of transportation.

Discussion of LCA Tools

One of the goals of this study was to investigate how different the results would be when two different LCA tools are used to analyze the same building. As it can be seen in the impact assessment section, the results are significantly close to each other. This situation confirms both the reliability of the analyses carried out on the building, and also the validity of the Athena Impact Estimator and One Click LCA as life cycle assessments tools.

However, it also must be noted that the operational carbon emissions of the building were not calculated via the LCA tools, but rather with energy simulation software packages. Same operational carbon emission outputs were used in LCA calculations with both Athena Impact Estimator and One Click LCA. Considering how substantial operational carbon emissions are for the overall GWP of the buildings, this decision is critical for comparativeness of the study. If the operational carbon emissions were calculated directly on the LCA tools, the calculations and results might differentiate for two LCA tools. That could cause a larger gap between the results derived from the LCA tools.

When the embodied carbon results are compared, above mentioned effect of the operational carbon emissions can be seen. The results are not as similar as the total GWP. The largest difference is between the embodied carbon emissions of Scenario 2. This is because of the fact that, the carbon absorbed by the plants in the straw bale units, was included in the calculations on the Athena Impact Estimator. As a result, the net GWP of the straw bale walls are negative. However, in One Click LCA, carbon absorptions of the plant-based materials were technically not possible to include in the calculations. Therefore, GWP of Scenario 2 is higher in the results from the One Click LCA.

Even though it is less contrasting then Scenario 2, Scenario 1 also has a difference between results of two LCA software. This difference is caused by the differences in GWP of the reinforced concrete. Depending on the methods used in the production plants that the concrete procured from, the GWP values may vary. The fact that the two LCA tools use different data for reinforced concrete might cause this kind of a difference.

Results for Scenario 3 are also similar to each other. The relatively small difference is due to the use of plant-based materials (wooden beams and floors) as it is explained in Scenario 2. However, since the amount of plant-based materials is much less in Scenario 3 compared to Scenario 2, the difference between the results from the LCA tools is also less.

Conclusions

For all scenarios, while the material of interior applications, window types, window frames, interior and exterior walls do not change, the structural type and material of the slab varied. While reinforced concrete flooring is used in RC structure, in other two scenarios, wooden structure is used. It was seen that the change of the wall material, the differences in the use of different building materials, production methods, the distance from the production location to the construction site, and the life span also have a significant impact on the LCA result.

For instance, AAC blocks for Scenario 1, straw bale blocks for Scenario 2 and stone for Scenario 3 are used as wall material. When listing these materials by distance from the production location to the construction furthest to nearest, the sorting of AAC block (300 km), straw bale (3300 km) and stone (0 km) is occurred. The stone material is excavated from the construction site because of the topographic feature of the site. Therefore, there is no environmental impact for the transportation of this material. Moreover, straw bale and stone are natural building materials so their embodied carbons are lower according to AAC blocks.

The other factor affecting the results is the accompanying façade system for different wall material. For instance, there is no need for insulation material for straw bale wall and stone wall. For the straw bale wall and AAC walls, the finishing layer is paint. However, for stone walls there is no need for plaster and paint layers. For this reason, besides the carbon emission in A1-A3, and A4 stage, there is also a decrease in the value in B4 stage since paint is not used.

In this study, the comparison of the LCA of three different structures is executed. One of these structures is reinforced concrete which is the traditional building method; the others are the structure made with natural and local materials which are straw-bale and natural stone. These analyzes also include embodied carbon and operational carbon separately. In addition, these life cycle analyzes were performed in two different software and their results were compared.

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Occupational Health and Safety Legislation: A Comparative Analysis between Australia and Turkey

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Abstract

Turkey's Occupational Health and Safety Code, issued in 2012, has triggered a wide range of practical changes in the Turkish construction industry. Similarly, Australia's Work Health and Safety Act, issued in 2011, has created a significant impact on the Australian construction industry for safety management. However, the numbers of accidents at work in these two industries are still high. Therefore, comparing these two legislations may bring different insights to improve safety performance of both countries. In this study, current occupational health and safety legislation frameworks of Turkey and Australia were compared to each other in particular topics. Consequently, it is stated that an inclusive definition of aim for Occupational Health and Safety Code may be more useful for Occupational Health and Safety management for Turkish construction firms. Until radical changes were seen in working life, employees may be represented using current descriptions. Definition of workplace should always be made considering the recent developments. Occupational Health and Safety Code has emphasized the significance of use of machinery and personal protective equipment, while Work Health and Safety Act has not. It can be beneficial to update Occupational Health and Safety Code and shorten the limit of time to make the notification.

Keywords: *Australia, legislation, occupational health and safety, Turkey.*

Introduction

The construction industry has been one of the most problematic industries considering the occupational health and safety (OHS) risks (Carter & Smith, 2001). This industry in developed and developing countries is usually ranked among industries with poor safety records in terms of occupational fatalities and injuries (Ulubeyli et al., 2014). Therefore, OHS management becomes a significant concept in order to reduce the number of accidents and deaths in the construction industry. In this regard, a solid OHS legislation may have a great impact on the performance of construction safety management. Moreover, these legislations may be updated in accordance with the changing needs of industries.

Turkey's OHS Code, issued in 2012, has triggered a wide range of practical changes in the Turkish construction industry. The aim of this code is to regulate duties, responsibilities, rights, and obligations of employers and employees in order to ensure OHS at workplaces and to improve current OHS conditions (OHS Code, 2012). Turkish OHS legislation was updated in order to meet the needs of working life and to be compatible with European Agency for Safety and Health at Work. However, several changes were made on this law by the governments up to date. Similarly, Australia's Work Health and Safety (WHS) Act, issued in 2011, has created a significant impact on the Australian construction industry for safety management (Furci & Sunindijo, 2020). The first significant effort to regulate OHS policy in Australia was the establishment of National Occupational Health and Safety Commission in 1985 (Johnstone, 2008). After that, there were many other attempts to improve OHS system in the county in the following years. Finally, WHS Act 2011 was issued to protect the health and safety of workers, improve safety outcomes in workplaces, reduce compliance costs for business, and improve efficiency for regulatory agencies (WHS Act, 2011). Therefore, it can be claimed that these legislations are open to be improved. From this perspective, comparing different OHS legislations may be advantageous for authorities during the process of improvement of these legislations.

The construction industry has gained a reputation with its unsuccessful safety management performance. Occupational incidents and OHS-related problems of the construction industry show similarities in different countries around the world (Ulubeyli et al., 2015). According to the given statistics of fatality in 2018, construction sector is ranked first in Turkey (SGK, 2019), while it is in the third place in Australia (SWA, 2019). These statistics indicate that the numbers of accidents in construction industry in these two countries are still high. In this study, current OHS legislation frameworks of Turkey and Australia were compared to each other in particular topics and analysed in a detailed manner. The results of the study may have a potential for both countries to improve their OHS legislation and decrease the number of occupational incidents.

OHS incidents are one of the most significant problems in the construction industry. Therefore, there are numerous studies about OHS in the literature. However, to the best of our knowledge, only Bilir et. al (2014) conducted a study to compare OHS legislations of Turkey, Russia and Australia from the perspective of inspection activities. They presented differences of these legislations in terms of inspection fundamentals and practical applications. In this study, basic concepts of OHS legislations of Turkey and Australia were compared.

Research Method

Turkish OHS legislation consist of the OHS Code and relevant regulations. Similarly, Australian WHS legislation contains WHS Act, WHS regulation and Codes of Practices. In this study, OHS Code no. 6331 and WHS Act 2011 were examined to reveal a general perspective of two countries on OHS concept. In this regard, these two law texts were compared in several topics, such as aim, terminologies, duties, responsibilities, and incident notification. These topics and discussion headings were summarized in Table 1.

There are a plenty of topics to compare in these legislations. However, five basic concepts were analyzed in this study. This is because, this study is a part of larger study exploring differences of OHS legislations of several countries. Therefore, listed five topics were considered adequate to have an opinion about advantages or disadvantages of these OHS legislation.

Table 1. Discussed topics.

	OHS Code no. 6331	WHS Acts 2011
Aim	To regulate duties, responsibilities, rights, and obligations of employers and employees.	To improve safety outcomes in workplaces, reduce compliance costs for business, and improve efficiency for regulatory agencies.
Employee	The person employed in public or private workplaces, regardless of their status in their private law.	The person carries out work in any capacity for a person conducting a business or undertaking.
Workplace	The places where the employer produces goods or services and connected workplace, which are committed in terms of quality and organized under the same management.	The place where work is carried out for a business or undertaking and includes any place where an employee goes, or is likely to be, while at work.
Duty of employees	● Not to endanger the health and safety of themselves and other employees affected by their actions or work. ● To use machinery, devices, tools, equipment, dangerous goods, transportation equipment and other production vehicles in the workplace in accordance with the rules; ● Correct use and protection of personal protective equipment provided to them. ● To cooperate with the employer and employee representative in order to eliminate any deficiencies and non-compliance with the legislation determined by the inspection authority. ● To cooperate with the employer and employee representative in order to ensure occupational health and safety in his / her field of duty.	● To take reasonable care for his or her own health and safety. ● To take reasonable care that his or her acts or omissions do not adversely affect the health and safety of other persons. ● To comply, so far as the employee is reasonably able, with any reasonable instruction that is given by the person conducting the business or undertaking to allow the person to comply with this Act. ● To cooperate with any reasonable policy or procedure of the person conducting the business or undertaking relating to health or safety at the workplace that has been notified to workers.
Incident notificatio n	The notice must be given within three working days after the accident.	The notice must be given in accordance with this section and by the fastest possible means.

Findings and Discussion

According to the Table 1, OHS Code was aimed to regulate duties, responsibilities, and rights of employers and employees, while perception of WHS Act has a wider content as it considers to improve safety outcomes and cost for businesses. From this perspective, the aim of OHS Code can be regarded as more specific than WHS Act since it has more clear definition.

However, a wider description may be more useful for a legal regulation and can comprise detailed solutions for incidents.

Another important issue is to identify the concepts adequately. One of the main characters of OHS is the employee. In this regard, identifying employee in legal regulations becomes a significant issue. Table 1 shows that definition of employee in both legislations is generic and quite similar. Therefore, it can be claimed that the concept of employee was well defined in OHS legislations in Turkey and Australia.

An occupational accident is an unexpected and unplanned occurrence, including acts of violence, arising out of or in connection with work which results in one or more workers incurring a personal injury, disease, or death (Alli, 2008). In this context, an accident related to the work is considered as occupational accident. For this reason, definition of workplace is a notable question to identify if an accident is occupational or not. OHS Code and WHS Act agree that workplace is not only the location where the actual work is done but also the other places that employees go. Instead of identifying a location, an extensive definition of workplace may have a positive impact on safety of employees. Hence, one can state that OHS Code and WHS Act have an adequate description of workplace in the law texts.

In the scope of OHS legislation, there are several duties and responsibilities of employees which they must obey for the benefit of their working life. Each of these duties and responsibilities were designed to maintain a safe working environment. Therefore, identifying and understanding these duties and responsibilities may be considered as a vital issue for OHS management. When the two legislations were compared, it is clear that taking responsibility to take reasonable care not to endanger the health and safety of themselves and other employees affected by their actions or work is the first place. Furthermore, employees must comply with any reasonable instruction that is given and cooperate with the employer and employee representative to eliminate any deficiencies. However, OHS Code has a difference in the topic of duty of employees. In addition to given instructions, employees were warned to use machinery, devices, tools, equipment, dangerous goods, transportation equipment and other production vehicles in the workplace in accordance with the rules and to utilize personal protective equipment provided to them. Consequently, an extra effort was made to indicate the importance of machinery, tools, and personal protective equipment in the scope of occupational health and safety.

Incident notification is the last topic discussed in this study. Here there is a significant difference between OHS Code and WHS Act. In the WHS Act, notice of an occupational incident must be given as fast as possible, while OHS Code leaves maximum three days for the notification of an accident. In this respect, OHS Code can be considered as inadequate. Because occupational incidents should always be evaluated as vital issues and immediate notification should be made in order to take actions for a better OHS management.

Apart from aforementioned topics, there are some other notable points that should be concerned. OHS Code and WHS Act contain offences and penalties in several situations. For example, according to WHS Act, if a person is reckless as to the risk to an individual of death or serious injury or illness, there is a penalty of $300 000- or 5-years imprisonment or both. However, there is not any specific amount of money to be charged to anyone in case of an injury or death in OHS Code. From another perspective, OHS Code specified the health and safety experts, while there is not such a profession defined in WHS Act. Finally, WHS Act does not classify workplaces, but hazard classes of workplaces were identified in OHS Code.

Consequently, an inclusive definition of aim for OHS Code may be more useful for OHS management for Turkish construction firms. Description of employee in both law texts seems to be adequate. For this reason, until radical changes were seen in working life, employees may be represented using current descriptions. In accordance with improvement and change of the technology in time, working place concept may also change. The key factor here is to identify working environment properly to maintain a suitable OHS management. Therefore, definition of workplace should always be made considering the recent developments. In order to maintain a better OHS management, everyone should take necessary actions. For employees, these actions were collected under the title of duties and responsibilities. Employees should follow the given instructions and not harm themselves or others. OHS Code has also emphasized the significance of use of machinery and personal protective equipment. Considering this difference, it may be beneficial for WHS Act to add related regulations for machinery, tools, personal protective equipment, etc. Another vital factor is the notification of occupational incidents. In this regard, it can be beneficial to update OHS Code and shorten the limit of time to make the notification.

Conclusion

This study is a part of larger study exploring differences of OHS legislations several countries. The aim of this paper is to compare current occupational health and safety legislation frameworks of Turkey and Australia in terms of terminologies, duties, responsibilities, incident notification. For this purpose, OHS Code no. 6331 and WHS Act 2011 were examined. The results obtained reveal that OHS Code and WHS Act have potential to be improved for a better OHS management system. For this reason, legal authorities, academics, and practitioners may constitute a working group and develop the most appropriate legislation for the benefit of employers and employees.

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Evaluation of Turkish Contractors' Views after Mandatory Mediation in Turkish Construction Sector

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Abstract

With the adoption of the Legal Dispute Mediation Act in Turkey in 2012, mediation have become a popular way of dispute resolution. Considering the Turkish construction literature, the studies about mediation are extremely limited and there is no data on how the construction sector was affected by these developments in the Turkish Legal system. Therefore, a survey was conducted with the members of Turkish Contractors Association. In this survey, the main aim was to measure the perspectives of the members about mediation. The survey was conducted between 2018 and 2019. However, in the beginning of 2019, mediation became mandatory in the commercial disputes including construction disputes. Therefore, to measure the dynamics changed by this new rule that came to the sector, at the beginning of 2020, a survey was conducted again with the contractors. In this study, by comparing the results of these two surveys, it is tried to measure the perspective of the sector professionals about mediation and understand their reactions for the mandatory mediation in the construction sector. As a result of the study, it has been observed that there is an orientation towards mediation in the Turkish construction sector and they are willing to use this method for dispute resolution.

Keywords: *ADR, construction mediation, dispute, mediation, Turkish construction sector.*

Introduction

In the Turkish construction sector, it has been observed that there is a lack of study to determine the views of construction professionals about mediation and its implementation to the construction sector. For this reason, a survey was conducted between the years of 2018-19 with contractors who frequently encounter disputes in the Turkish construction sector and are significantly affected by this issue. But then, in 2019, mediation in commercial disputes has been prerequisite for court proceedings. Thereupon, at the beginning of 2020, the previous survey was repeated.

In this study, the data obtained by comparing these surveys will be shared. Thus, the effects of the concept of mandatory mediation, which is an important development for the Turkish construction sector will be explained and the changes will be revealed with that prerequisite.

Construction Mediation

In recent years, awareness of the cost and burden of courts has begun to develop in the construction sector. Cost and duration are the apparent burdens of courts. In addition to these burdens, the invisible burdens of the courts such as damaging the relations and prestige of the dispute parties, the time allocated by senior employees to disputes have directed the construction sector to new alternative dispute solutions (Agapiou & Clark, 2012). For this reason, ADR methods have become increasingly important in the sector and mediation is one of the important ADR methods.

ADR (Alternative Dispute Resolution) includes the dispute parties to resolve the dispute in "friendly" ways without resorting to judicial remedies. In ADR methods, the dispute parties are encouraged to solve their disputes by a neutral third party (Özbek, 2002). In the construction sector, the usage of ADR methods is highly advantageous. ADR methods provide dispute parties flexible and creative solutions. Also, in these methods, the dispute processes are managed by experts who are experienced in the dispute issues. These experts can lead the processes with the flexible rules other than strict rules of the judicial remedies. (Rubin & Quintas, 2003).

Mediation is one of the most widely used ADR methods in the construction sector (Brooker & Wilkinson, 2010; İlter et al., 2016). The construction sector shows different features from other sectors. Therefore, the use of mediation in terms of the construction sector is different from other sectors. For example, human behavior is always an important factor in decision making, but in the construction sector, "human" is involved in the process differently. Unlike the sectors where emotions such as music, advertising and even health are reflected in the business, construction sector is carried out with business performance indicators and measurements. Therefore, disputes in the construction industry rely more on data, measurements, and more clearly measurable interests. Moreover, after the disputes in the construction sector, when judicial remedies are applied, it is uncertain how the project will continue (Saleh, 2019).

In addition, in a dispute that arises during the projects, the process enters a deadlock with the claim and the construction comes to a halt. This paves the way for bigger disputes. Because the construction halt may cause loss of time and money to the parties, and the materials and equipment at the construction site start to be damaged. In this case, those who suffer from disputes increase and the project process is dragged into a deadlock. For such reasons, it will be much more accurate to use the mediation method in construction disputes than a slow solution such as court proceeding (Saleh, 2019). In addition, disputes in the construction sector usually take place between more than two parties. In judicial remedies such as the court proceeding, a third party, other than two separate parties, the defendant, and the plaintiff, cannot take part. However, there can be more than one dispute side in mediation. This feature of mediation makes this method a convenient and feasible way for the construction sector.

Construction Mediation in Turkey

Referring to Turkey, the courts burden is heavy, and the duration of the courts is very long like the other countries in the world. To bring a solution to this important problem, in June 2012 Legal Dispute Mediation Act was adopted and entered into force in 2013. Meanwhile, the Ministry of Justice established Department of Mediation and Turkey are met through mediation method. In 2015, ISTAC (Istanbul Arbitration Center) was established. ISTAC is an institution that provides services on mediation, although it provides services mostly on arbitration. In 2018, in employee-employer disputes and in 2019, in commercial disputes including construction disputes, the mediation has become prerequisite for court proceedings in Turkey. Thus, mediation has become obligatory in the disputes in the Turkish construction sector, which are intended to be brought to court. Thus, the concept of mandatory mediation for the construction industry has been implemented.

Results

When the studies on mediation in the Turkish construction sector are examined, it is observed that the studies on this issue in our country are very limited and there are deficiencies in these studies to reveal the views and ideas of the sector professionals. For this reason, a survey was conducted between the years of 2018-19 with contractors who frequently encounter disputes in the Turkish construction sector and are significantly affected by this issue. However, in 2019 in Turkey, mediation in commercial disputes has become prerequisite for court proceeding and thus, to determine view changes for mediation and to understand the sector's reaction to it, in the beginning of 2020, survey has been repeated. In this study, surveys will be named as Survey 1 (survey conducted between 2018 2019) and Survey 2 (survey conducted at the beginning of 2020).

The Research Methodology

In the Survey 1 and Survey 2, the targets have been identified as the members of Turkish Contractors Association (TMB). After that, the contact information of the companies has been reached through the TMB members list. In every company, a person is selected according to the possibility about facing disputes during the construction projects and the survey was sent digitally to the selected people. While preparing the questions of the surveys, the literature researches about construction mediation were used. In addition, questions were added to the forms to understand the thoughts and opinions about the existence, structure and functioning of the mediation institution.

The Results of the Surveys

121 survey was sent, and 40 people responded to the survey. However, the responses of 27 people who filled the survey were evaluated due to deficiencies of the remaining surveys. In the Survey 2, the target has been identified as people who has responded the Survey 1. Survey 2 was sent to 40 people and 28 people filled the survey completely. Thus, the number of valid responses was determined to be 28. Table 1 shows the profile information of the respondents.

Table 1. The profile of the respondents.

Survey 1			
	experience	**profession**	**education level**
The profile of the respondents	x>15= %51,6 11-15= %14,8 6-10= %11,2 0-5= %22,4	%66,6 civil engineer %11,2 lawyer %7,4 architect %14,8 other	%48,1 BSc %48,1 MSc %3,8 PhD
Survey 2			
	experience	**profession**	**education level**
The profile of the respondents	x>15= %60,7 11-15= %17,9 6-10= %10,7 0-5= %10,7	%67,8 civil engineer %8 lawyer %8 architect %16,2 other	%50 BSc %46,4 MSc %3,6 PhD

As can be seen in the Table 1, more than half of the respondents to Survey 1 and Survey 2 have more than 15 years of experience in the sector. Most of the respondents of both surveys are civil engineers. The level of education of the respondents appears to be mostly graduate and master’s degree.

Respondents were asked whether they used the mediation method in the disputes they have experienced. In Fig. 1, the answers given by the respondents to this question are compared for Survey 1 and Survey 2. According to the Survey 2, %47 of the respondents used the mediation method. In the Survey 1, it is seen that %26 of the respondents experienced the mediation method. With this data, it is observed that the use of mediation in the Turkish construction sector has increased even in the past year. This may be the result of increased awareness in the sector, as mediation is a prerequisite for the court proceeding. Another reason could be that, with the thought of the mandatory mediation, the sector professionals could choose to go directly to this method when they have a dispute. As a result, the mandatory mediation for commercial disputes has enabled the construction sector to become more active in mediation.

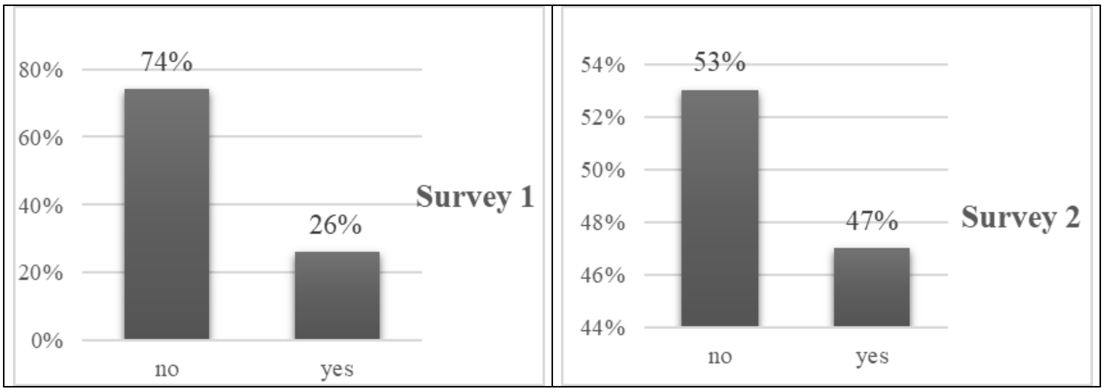

Figure 1: The mediation experiences of the respondents.

The respondents of the survey were asked if they used the mediation whether they applied this method at their own will or as a court prerequisite. Fig. 2 shows the answers of the respondents. In Survey 1, those who responded to the survey did not make such an assessment, as there is no court prerequisite in the time that survey was conducted. However, in Survey 2, this condition has been taken into consideration. Accordingly, %69 of the respondents used mediation as their own will and %31 of them as a prerequisite for the court.

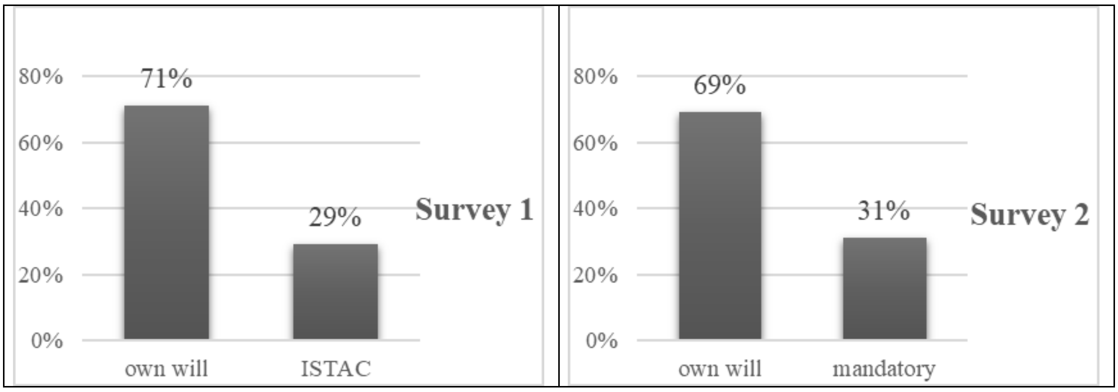

Fig. 2: The type of mediation usage of the respondents.

In Fig. 3, it is seen that the opinions of the respondents towards an institution that will serve on mediation in the Turkish construction sector are compared for the Surveys 1 and 2. As can be seen from the Figure, in the Survey 1, %85 of the respondents think that such an institution is necessary. In Survey 2, this ratio increased to %93. Although there is a very short time between the survey dates, it can be said that the need for such an institution in the sector has increased for the respondents.

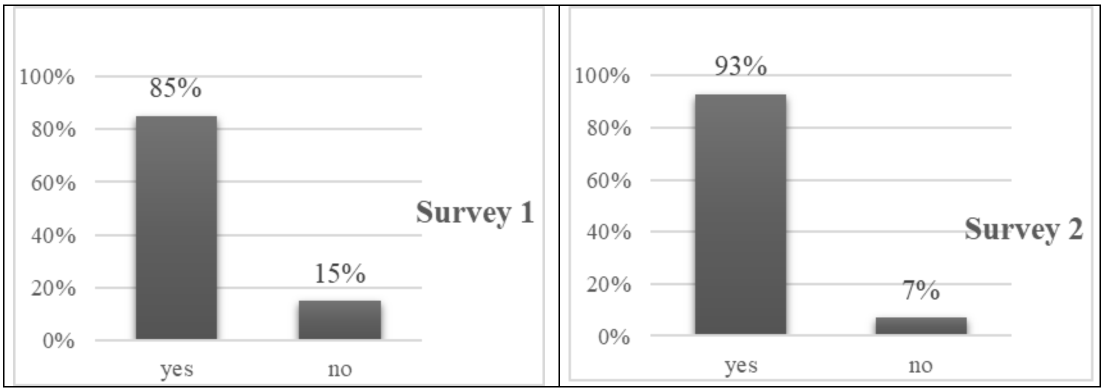

Figure 3: The opinions of the respondents towards a mediation institution.

In Fig. 4, it is seen that in Survey 1, the ratio of respondents who want to use mediation in the future is %89. In Survey 2, however, all people responded positively to this question. This is an important change. Previously, while the rate of those who want to use mediation in the future is high, now all respondents have declared that they can apply for mediation in case of dispute. The reason for this change may be the fact that the people who want to apply to the court, together with the pre-requisite, are obliged to practice mediation so the court is no longer an option alone. The fact that the persons applying to the court must follow this method irrespective of their will and request may lead people to try mediation from the very beginning. Another reason for this change may be that with the widespread use of mediation in the construction sector, the advantages of this method become known.

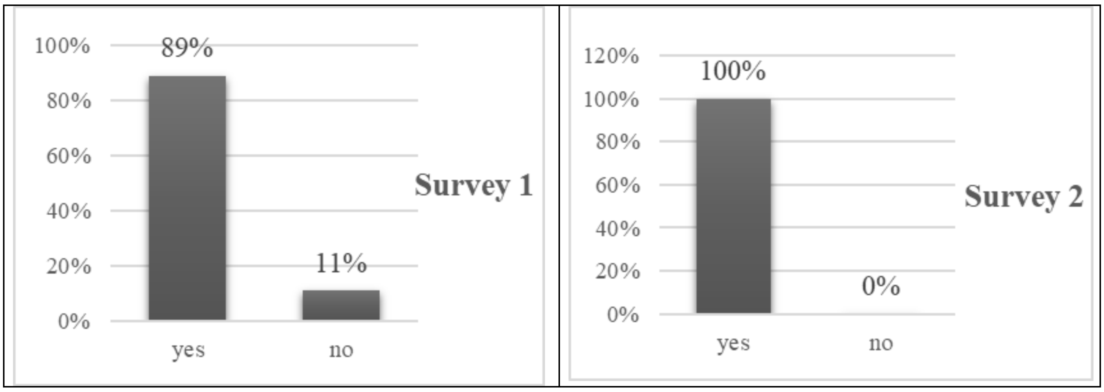

Figure 4: The mediation usage in the future disputes.

In Fig. 5, the services that the respondents expect from a mediation institution are compared in terms of Surveys 1 and 2. Looking at Survey 1, the respondents explained that they expect experienced professionals from the sector to be appointed as experts from the mediation institution, other than lawyer mediators. Accordingly, in Survey 2, as in Survey 1, the respondents' opinions have not changed and they said that they expect the institution to be appointed as experienced professionals from the sector as experts, other than lawyer mediator.

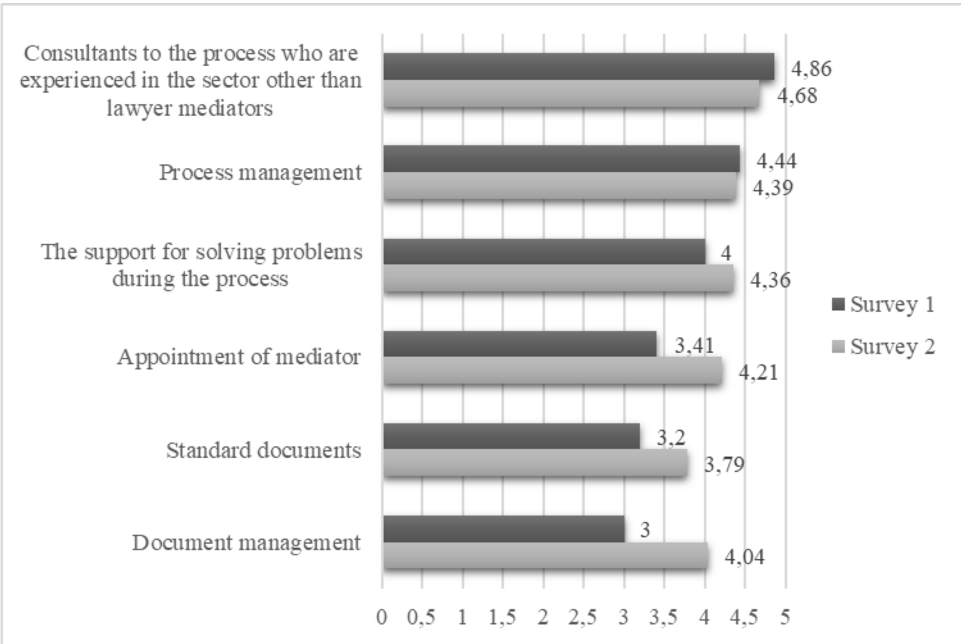

Figure 5: Construction mediation institution services.

Respondents were asked primarily about their opinions about mandatory mediation in commercial disputes. Respondents answered this open-ended question based on their experience using mediation or their level of knowledge on the subject. Table 2 shows the grouped answers from respondents.

Table 2. The opinions of the respondents about mandatory mediation in commercial disputes.

The positive and negative features of the mandatory mediation in commercial disputes	
Positive	***Negative***
*Fast process	*The technical people cannot be the mediators and the mediators cannot belong to the sectors where the dispute is experienced.
*Low cost process	*The obligation about mediators being lawyer.
*The protection of relationships	*The loss of time for unsolved disputes by mediation.
*Reduce of the burden of the courts	*The possibility of experiencing post-intent and malicious behavior.
*Free from long court proceeding processes	*The condition that the process is depend on the mediator.
*An independent dispute solution method	
* Prevention of the loss of rights in the court proceedings	

Accordingly, the most important feature that the respondents find positive for mandatory mediation in commercial disputes is that the practice of mediation is a fast process. Many of the respondents stated that mediation is a quick method and said that this feature will provide significant gains to the dispute parties in terms of cost. In addition, the respondents think that this solution is less costly than the court proceedings. The respondents stated that mediation will reduce the burden of the courts and free the dispute parties from long court proceedings. Respondents stated that the loss of rights in the courts with the win-lose manner will be prevented through mediation which is an independent solution. For these reasons, the respondents find the mandatory mediation in commercial dispute necessary and important.

Although most of the respondents found the prerequisite positive, they also said that this condition has some negative aspects. The most important factor that the respondents find negative is that the sectoral and technical persons cannot be mediators. In addition, the respondents stated that it is difficult to reach mediators who are experts in dispute issues and this situation affects the process negatively. While the respondents stated that misconduct can be experienced in the mediation process, they emphasized that in the malicious approaches, the weak can be crushed and this situation may cause negativity. According to the respondents, unsolved mediation processes can cause loss of time, and the process can be affected negatively when the situation that the mediator organizes the process unsuccessfully.

The surveys described above and conducted with Turkish construction sector contractors are important in terms of understanding their perspectives on mediation and an institution that will provide service in this regard. To summarize the data from these surveys;

- It is seen that some of the respondents in Survey 1 and Survey 2 have experienced mediation.
- %89 of the Survey 1 respondents and all the Survey 2 respondents stated that they can use mediation in a future when they face with a dispute. Considering that there is a short period of one year among the surveys conducted, it is seen that with the mandatory mediation in commercial disputes, the tendency towards this method in the sector has increased.

- %85 of the Survey 1 respondents and %93 of the Survey 2 respondents thinks that an institution that will serve on mediation in the construction sector is beneficial for the sector. With the increasing number of people using mediation, the number of people experiencing mediation in the sector has increased. In parallel to this situation, it has been observed that the need for an institution that will provide services on this issue has increased.
- In both surveys, the most important service that the respondents expect from this institution is to include professionals who are experts in the field of dispute, apart from lawyer mediators, in the process. According to Survey 2 respondents, the most negative aspect of mediation is that sectoral people cannot be mediators. For this reason, the respondents care about the involvement of professionals who are experts in the field of dispute, apart from the lawyer mediators, in the construction sector.
- According to the Survey 2 respondents, the most important features of mediation are fast and low cost etc. and the worst feature is that sectoral people cannot be mediators and the difficulty to reach mediators specialized in conflict.

Conclusions

Since 2013, mediation is a popular dispute resolution in Turkey. Mediation has become a prerequisite for employee-employer in 2018 and in 2019 for commercial disputes for court proceedings. Thus, it is aimed to use mediation more frequently in our country and to alleviate the burden of courts.

Regarding the Turkish construction sector, the studies on how such rules and practices regarding mediation are met in the sector have been very limited. Together with mediation is a prerequisite for commercial disputes, including construction disputes in 2019, this method has become even more important for the construction sector. As it is understood from this study, it is seen that the interest in mediation and the need for an institution to serve on mediation in the construction sector has increased. It is thought that the use of mediation in the construction sector will increase in the future with the contribution of mandatory mediation. Thus, the disputes in the sector can be resolved in a short time and the damages to the parties can be reduced to a minimum, which is an important problem for the construction sector.

With this study, it has been tried to obtain a missing data in the Turkish construction literature and it is aimed to guide researchers who will work on this subject in the future. However, as in every research, some limitations were encountered in this study. Especially Turkish contractors are reluctant to share information on issues such as disputes. For this reason, the number of data obtained is limited and more comprehensive results cannot be reached. However, together with the data obtained, it is thought that this study will raise awareness about mediation in the Turkish construction sector.

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A View of Smart City Strategies: Success Factors from the Perspective of Building Technology Solutions

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Abstract

The smart city concept has been emerged to solve urban problems such as overpopulation, climate change, and economic issues through Information and Communication Technology (ICT) supported systems. Although it does not have global definitions and planning regulations, most governments make considerable efforts on developing their own strategic smart city plans. One of the most important problems in smart city initiatives is to find the best solutions compatible with the smart systems for building technologies. In that context, the main focus of this study is to explore the success factors of smart city strategies from the perspective of building technology solutions. To that end, firstly, the definitions and characteristics of the smart city concept are identified for a better understanding of smart city strategies. Then, a detailed examination of smart city strategies is carried out for two reports named NSCSAP and MSCEU. NSCSAP (2020-2023 National Smart Cities Strategies and Action Plan) was reported in 2019 by the Republic of Turkey Ministry of Environment and Urbanization, and MSCEU (Mapping Smart Cities in the EU) was released in 2014 by the European Parliament. The findings obtained from the examination of the mentioned reports indicate that smart building is considered as a promising building technology solution for achieving the desired success in smart city initiatives.

Keywords: *building technology, smart buildings, smart city, strategies, success factors.*

Introduction

One of the most promising solutions to achieve the objectives of the Kyoto Protocol is based on the smart city concept (Caragliu et al., 2011; Hill, 2013; BSI, 2014; Cocchia, 2014; Bibri and Krogstie, 2017). Since urban development are directly affected not only by the economic, social, and environmental principles of sustainability but also by innovative technologies boosting hard and soft infrastructure systems, countries have faced developing their urban planning strategies that required smart solutions. (Gabrys, 2014; Vanolo, 2014; Kitchin, 2014; Angelidou, 2015; Bibri and Krogstie, 2017). Furthermore, governments advocate that smart cities are an efficient way to tackle the challenges in sustainable development (Kitchin, 2014; Caragliu and Del Bo, 2018). The concept of the smart city encapsulates two main paradigms of new smart urban development (Smart Growth) and sustainable socio-economic development (Vanolo, 2014; Neirotti et al., 2014; Maltese et al., 2016). In that context, the smart city has the main objectives such as making the citizens' needs the driving force behind all urban systems; integrating physical and digital planning; identifying and being a solution for emerging challenges in a systematic, agile and sustainable way, and creating a step-change in the joined-up delivery and innovation capacity within the city (BSI PAS 181:2014; Neirotti et al., 2014; Cocchia, 2014; MSCEU, 2014). The smart city concept is a business and governance idea and every stakeholder involved in a smart city initiative has a different kind of contribution. The success of smart city initiative is mainly based on vision, people, product, and ICT-driven solutions (Kitchin, 2014; Caragliu and Del Bo, 2018). For this reason, in the related literature scholars mostly focus on long-term smart city technologies and policies that will create economic growth or improve governance while businesses seek ways to expand citizen orientated visions and become more commonsensical and inclusive by producing ICT-supported systems (Kitchin, 2014; Caragliu and Del Bo, 2018). There is a need to uncover success factors of smart city strategies. One of the most important issues in smart city initiatives is to find the best solutions for building technology. Hence, the aim of this study is to find out the success factors identified in smart city strategies from the perspective of building technology solutions.

The rest of the study is organized as follows: Due to the complex nature of smart cities, it is crucial to define the smart city concept and its characteristics to gain a better understanding of smart city strategies. For this reason, the definitions and characteristics of the smart city concept are firstly given. In addition, based on the review of the related literature, smart city strategies are specified. Following that, two smart city strategy reports are examined in terms of their approaches to building technologies. Then, the results and discussion are presented. Finally, conclusions, limitations of the study, and some recommendations for future research are provided.

Definitions and characteristics of the smart city

The smart city concept emerged in the 1960s with the integration of cybernetics into urban planning and starting from the 1980s it has been transformed into a major criterion of sustainable development with its networked urbanism and characteristics in sustainable urban development planning (Gabrys, 2014; Anthopoulos and Vakali, 2012). In the related literature, there are various definitions of the smart city concept. Some definitions of the smart city concept are presented in Table 1. On the basis of these definitions, a smart city can be described as a multidimensional urban structure. The main targets of this kind of urban structure are:

- to make the city smarter by providing linkage among IT infrastructure, social infrastructure, physical infrastructure, and business infrastructure,
- to encourage the citizens to participate in governance,
- to facilitate capacity-building for lifelong learning and innovation with its ability to provide a higher quality of life,
- to use renewable resources more efficiently,
- to contribute to the objectives of sustainable development and manages to stand out in the global urban competitiveness.

Table 1. Smart city definitions reported in the related literature.

Source	Definition
Giffinger et al. (2007, p. 11)	“A Smart City is a city well performing in a forward-looking way in these six characteristics, built on the ‘smart’ combination of endowments and activities of self-decisive, independent and aware citizens.”
Caragliu et al. (2011, p. 70)	"A city to be smart when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance."
IBM (2011, pp. 3-4)	“A Smarter City knows how to collect information from a wide variety of sources, integrate information across departments and agencies, and then use that information to anticipate problems, coordinate services and drive sustainable economic growth.”
Nam and Pardo (2011, p. 185)	“A smart city as one with a comprehensive commitment to innovation in technology, management and policy. Innovation for a smart city entails opportunities and risks at the same time."
Dameri (2013; p. 2549)	“A smart city is a well-defined geographical area, in which high technologies such as ICT, logistic, energy production, and so on, cooperate to create benefits for citizens in terms of well-being, inclusion and participation, environmental quality, intelligent development; it is governed by a well-defined pool of subjects, able to state the rules and policy for the city government and development”
MSCEU (2014, p. 17) European Parliament	“A Smart City is a city seeking to address public issues via ICT-based solutions on the basis of a multi-stakeholder, municipally based partnership. These solutions are developed and refined through Smart City initiatives.”
BSI (2014, p. 4) The British Standards Institution	“A smart city is an effective integration of physical, digital and human systems in the built environment to deliver a sustainable, prosperous and inclusive future for its citizens.”
European Commission, Set Plan Secretariat (2015, p. 2)	“Quality of life and the attractiveness of cities as environments for learning, innovation, doing business and job creation are now key parameters for success in the global competition for talent, growth and investments.”
Moreno et al. (2016, p.45)	“A smart city can guide better decision-making with respect to prosperity, sustainability, resilience, emergency management, or effective and equitable service delivery”.
The International Telecommunications Union (2016, p. 52)	“A smart sustainable city is an innovative city that uses information and communication technologies (ICTs) and other means to improve quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social, environmental as well as cultural aspects”.
NSCSAP (2019, p. 18) The Republic of Turkey Ministry of Environment and Urbanization	“Smart cities are the ones more livable and sustainable cities that are implemented through cooperation between stakeholders, use new technologies and innovative approaches, are justified based on data and expertise, and create solutions that add value to life by predicting future problems and needs”.
European Commission (2020)	“A smart city is a place where traditional networks and services are made more efficient with the use of digital and telecommunication technologies for the benefit of its inhabitants and business. A smart city goes beyond the use of information and communication technologies (ICT) for better resource use and less emissions. It means smarter urban transport networks, upgraded water supply and waste disposal facilities and more efficient ways to light and heat buildings. It also means a more interactive and responsive city administration, safer public spaces and meeting the needs of an ageing population.”

A smart city can be evaluated with its main characteristics that are identified as Smart Economy, Smart People, Smart Governance, Smart Mobility, Smart Environment, and Smart Living (Giffinger et al., 2007; Cohen, 2014). As seen in Table 2, the mentioned main characteristics are inclusive of the tangible components (buildings, networks, devices, grids, resources, etc.) and the intangible components (organizations, knowledge, innovation, education, etc.) (Giffinger et al., 2007; Nam and Pardo, 2011; Cohen, 2014; Mancebo, 2019).

Table 2. The characteristics of a smart city (adapted from Giffinger et al., 2007 and Cohen, 2014)

THE CHARACTERISTICS OF A SMART CITY					
SMART ECONOMY (Competitiveness)	SMART PEOPLE (Social and Human Capital)	SMART GOVERNANCE (Participation)	SMART MOBILITY (Transport and ICT)	SMART ENVIRONMENT (Natural resources)	SMART LIVING (Quality of life)
. Innovative spirit . Entrepreneurship . Economic image & trademarks . Productivity . Flexibility of labor market . International embeddedness . Ability to transform . Local & global interconnectedness	. Education . Affinity to lifelong learning . Social and ethnic plurality . Flexibility . Creativity . Level of qualification . Open mindedness . Participation in public life	. Online services . Open government . ICT-supported infrastructure . Participation in decision-making . Public and social services . Transparent governance . Political strategies	. Local accessibility . (Inter-) national accessibility . ICT-supported infrastructure . Sustainable, innovative and safe transport systems	. Smart building systems . Urban planning . Compatibility with smart infrastructures . Energy saving . Pollution . Environmental protection . Sustainable resource . management	. Health & wellbeing conditions . Safety . Building quality . Cultural and education facilities . Social cohesion

Overview of smart city strategies

Smart city policies (urban) and smart specialization strategies (regional) can be identified as strategic planning approaches to smart urban development (Angelidou, 2014; Caragliu and Del Bo, 2018). The key components of the strategic planning process specified according to defining strategic vision, preparing action plan, and creating management strategy for smart cities are shown in Figure 1 (Korachi and Bounabat, 2019).

In the smart city strategic planning process, as a first step the smart city vision must be identified with clear purposes. Action plans provide different perspectives and implementation areas for making the actions gain power and adjustment. However, visions and strategies are used as the recommendation and commitment for a network of the actors to focus on the middle term or long term action roadmaps (Bach et al., 2010). Smart city policies take firstly into consideration of citizens' and governments' needs and requirements. On the other hand, smart specialization strategies have a big effect on changing economic and social structures by focusing on general-purpose technologies. As for smart specialization strategies, they consist of the identification process of competitive advantage and strategical priorities (Vanolo, 2014; Yanrong et al., 2016; Caragliu and Del Bo, 2018).

Smart urban development can be for new or existing cities (Washburn et al., 2009; Batty et al., 2012; Angelidou, 2014):

- *Smart development stage for a city to be built from scratch:* New cities are developed by using the state of the art "smart" technology and certifications of green physical planning. This strategy's top-down approach helps to identify the smart city vision from inception, and clear purposes as being in Masdar city, Abu Dhabi (by GE);

Hwaseong Dongtan, China (by ARUP); PlanIT Valley, Portugal (by Microsoft); Skolkovo Innovation Center, Russia (by IBM); Songdo International Business District, South Korea (by CISCO); Cyberport Hong Kong, China; SmartCity Malta, Malta; and Cyberjaya, Malaysia.

– *Smart development stage for existing city:* To design socially sustainable and livable smart cities, the development of older cities regenerating themselves as smart. Strategies for existing cities require that more collaboration between public and private actors, and also with citizen participation. To accelerate the innovation process, it is possible to employ open innovation techniques and a bottom-up approach as being in Silicon Alley, New York City; Silicon Roundabout, London; and Akihabara, Tokyo.

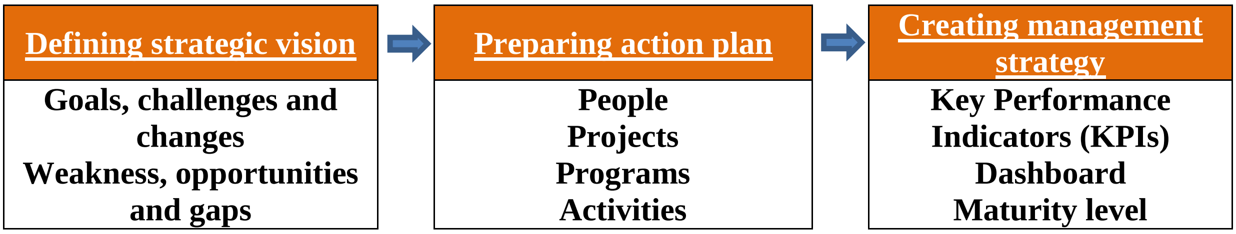

Figure 1. The key components of the strategic planning process for smart cities (adapted from Korachi and Bounabat, 2019).

There are also two different investment approaches for smart cities policies (Angelidou, 2014; Neirotti et al., 2014; Mancebo, 2019): (1) Investments on hard infrastructures (energy grids, natural resources, and water management, waste management, environment, transport, mobility, and logistics, office and residential buildings, healthcare and public security). It has the objective of providing advanced urban services; (2) Investments on soft infrastructures (education and culture, social inclusion and welfare, public administration and e-government and economy). It has a bottom-top approach. It requires the strengthening of a supportive ecosystem that enables the development of smart infrastructure, including human capabilities, legal frameworks, advanced technology policies, institutional mechanisms, and data use.

In the meantime, smart city strategies can demonstrate some differences according to their tendencies (Angelidou, 2014): For instance: (1) Economic sector-based strategies aim at the transformation of specific economic sectors of the city; (2) Geographically based strategies are the spatially determined perspective that develops applications to organize and support the prevailing character and main functions of the urban settlements (business districts, research and education areas, clusters of logistics, tourism and leisure or neighborhoods).

The main types of smart city strategies are summarized in Table 3.

Table 3. The main types of smart city strategies.

Type of smart city strategy	Core points	Example
Local	Strategies focus on a neighborhood, municipality, city, metropolitan area, or even a region and aims to foster citizen-centric governance.	New York City (USA) London (UK) Amsterdam (The Netherlands) Helsinki (Finland) Barcelona (Spain) Vienna (Austria)
	Local authorities can provide that urban problems are more effectually managed.	
	Cities can learn how to become smarter from each other.	
National	Action plans has a crucial role for smart city strategies since they have been a broader view of related policies and coordinated resources.	Turkey UK USA Italy Malta Singapore The Netherlands
	Coordination and resource allocation enhance the effectiveness of the strategy and encourage the assignment of roles and responsibilities of stakeholders in the governance level.	
	The operational continuity of decisions on the smart solutions at all levels can be provided and thereby a common platform can be formed.	
	It has some crucial risks. For example, there may be the risk of the possibility of ignoring local needs and priorities.	
Smart development stage for a city to be built from scratch	Designed and built from scratch, these cities use intensively smart systems based on advanced technology.	Masdar city (Abu Dhabi) PlanIT Valley (Portugal) Skolkovo Innovation Center (Russia) Cyberport Hong Kong (China) Songdo International Business District (South Korea) Cyberjaya (Malaysia)
	By innovative solutions to use all opportunities of technology, it can be possible to achieve best practices of smart city approaches integrating smart infrastructure and smart building systems. Yet, there is a risk of slow progression.	
	It has the potential to explore innovative business models.	
Smart development stage for existing cities	To transform existing cities into sustainable and livable smart cities, it requires a strong collaboration between public and private actors, and also citizen participation to the smart city development process.	Silicon Alley (New York City) Silicon Roundabout (London) Akihabara (Tokyo)
	To accelerate the innovation process, it is possible to employ open innovation techniques and a bottom-up approach.	
Hard infrastructure oriented strategy	Investments on hard infrastructures have the objective of providing smart urban services.	Rio de Janeiro (Brazil)
	Issues related to privacy and collection of personal data, technocratic, corporate forms of governance, and even frequently technological lock-ins can occur.	
	Some difficulties in integration all systems with different ICT-supported smart systems can arise.	
Soft infrastructure oriented strategy	It has a bottom-top approach.	Barcelona (Spain)
	It requires smart soft infrastructure systems, including human capabilities, legal frameworks, advanced technology policies, institutional mechanisms, and data use policies.	
Economic sector-based strategy	The transformation of specific economic sectors of the city is based on the smart city characteristics.	Singapore
Geographical based strategy	A spatially determined perspective has the development of some smart city characteristics applications to organize and support the main functions of the urban settlements (business districts, education areas, logistics, tourism, and leisure or neighborhoods).	Barcelona (Spain) Thessaloniki (Greece)

Research Methodology

As a research approach, a comparison of smart city strategies in terms of building technologies is made in this study. A detailed examination of smart city strategies is carried out for two reports named NSCSAP and MSCEU. NSCSAP (2020-2023 National Smart Cities Strategies and Action Plan) was reported in 2019 by the Republic of Turkey Ministry of Environment and Urbanization, and MSCEU (Mapping Smart Cities in the EU) was released in 2014 by the European Parliament. Both the abovementioned reports are focused on the development of smart city strategies.

Results and Discussion

NSCSAP has been prepared to bring a holistic perspective to the smart city policies at the national level and to ensure prioritizing investments in line with the determined policies for smart city development. It aims to create a common vision and a road map in order to monitor and evaluate smart city performances with a systematic and open governance approach, and to adapt to changing conditions, and to develop smart city maturity with a common understanding. The scope of NSCSAP is based on two main issues: (1) smart city management (governance, strategy management, policy management, integrated service management, and business management) and (2) smart city applications (smart environment, smart security, smart people, smart buildings, smart economy, smart space management, smart health, smart governance, information technologies, smart transportation, smart energy, communication technologies, information security, smart infrastructure, disaster, and emergency management and geographic information systems). It has a top-down approach with the smart city policies on a national scale.

MSCEU presents the results obtained from the assessment of existing EU-28 smart cities and provides some recommendations for the smart city development. In detail, it focuses on mapping existing EU smart cities and specifying some innovative suggestions to identify successful smart city solutions. It provides a bottom-up approach with an analysis of EU-28 smart cities according to their characteristics and maturity levels.

NSCSAP with its top-down approach focuses on hard infrastructure (technology, smart transportation, smart buildings, smart energy, ICT, geographic information systems, data sharing platform, etc.) while MSCEU recommends local governments invest in soft infrastructure (education and culture, social inclusion and welfare, public administration, and e-government and economy) through a bottom-top approach. Also, these reports have also strategic approaches in common with an emphasis on the governance and investment issues. Moreover, both reports assert that existing cities can have smart characteristics to achieve socially sustainable and livable cities through effectual collaboration among public and private actors, and citizen participation. In the reports of NSCSAP and MSCEU, smart buildings are pointed out as a promising building technology solution for achieving smart city goals. In NSCSAP The Edge in Amsterdam, Smart Buildings in Copenhagen and low energy smart building technologies in Australia are the given examples while in MSCEU ITO Tower Project in Amsterdam and Media-tic Building in Barcelona are considered to be successful smart building projects. A smart building has the features of energy efficiency, comfort, interoperability, self-generation, consumer-friendliness, reliability, health, automation, grid-awareness, demand flexibility, renewable energy, cost-effectiveness, productivity, analysis, integration, self-awareness (De Groote et al., 2017). In this kind of buildings, it is intensively used smart systems required ICT-supported systems and advanced technologies. A smart building can be designed based on the four main functions: climate response, grid response, user response, and monitoring and supervision (Al Dakheel et al., 2020; Chang et al., 2020). This kind of building technology is seen as a promising solution for achieving smart city goals by optimizing four basic correlated elements: physical structure, systems, services, and management (Derek and Clements-Croome, 1997; Wong et al., 2005; Bach et al, 2010; Larios et al, 2013; Buckman et al., 2014; Ghaffarianhoseini et al., 2016; Moreno, 2016; Chang et al, 2020).

Table 4. According to the main groups of key performance indicators (KPIs) of smart city strategies, success factors addressed in the reports of NSCSAP and MSCEU from the perspective of building technology solutions.

Group of KPIs	Success factors	NSCSAP	MSCEU
Technological Indicator	Utilization of advanced embedded systems (a dedicated function within a larger system) for building components	n/a	√
	Incorporation of intelligent technologies and economic principles	√	√
	Intertwined with advanced sensors and artificial intelligence	√	√
	Application of advanced building systems and technological integrations	√	√
	Application of up-to-date adaptable and interoperable building control systems	√	√
	Implementation ICT-supported systems and innovative technologies	√	√
Economic Indicator	Consideration of economic repercussions	√	√
	Consideration of enhanced productivity and effectiveness of environments	√	√
	Application of efficient management of resources	√	√
	Application of integrated facility management	n/a	√
	Consideration of cost/time saving strategies	n/a	n/a
Socio-Cultural Indicator	Architectural considerations of the requirements and expectations of occupants and/or users	n/a	n/a
	Consideration of safety and security	√	√
	Adaptable to ever-expanding and changing human needs by using innovation and smart design process	n/a	n/a
	Responsive to social and technological changes	n/a	n/a
	Responsive to the needs for communication and globalization	√	√
	Consideration of health, well-being, user satisfaction, and enhanced creativity of users	n/a	n/a
	Use of self-support of user activity	n/a	n/a
Environmental Indicator	Application of sustainable smart design with regards to materials, waste, and durability	√	√
	Decrease of CO2 emissions and energy consumption in smart and green building technology	√	√
	Increasing the utilization of renewable energy sources	√	√
	Application of smart energy management systems	√	√

According to the SMART Model (Strategy, Multidisciplinarity, Appropriation, Roadmap, and Technology Model) (Letaifa, 2015), smart city strategies can be assessed with the group of key performance indicators (KPIs) involved technological, economic, socio-cultural, and environmental factors (Alwaer and Clements-Croome, 2010). In connection with the KPIs of smart city strategies, in this study, the reports of NSCSAP and MSCEU are examined to gain insight into the success factors addressed for building technology solutions. Based on the examination of the mentioned two reports, the findings are presented in Table 4.

The findings show that the main focus of two reports involving smart city strategies is based on the use of advanced technology in smart buildings. Particularly, it is mainly addressed building energy efficiency and the use of innovative technologies in all smart building systems as the factors affecting the achievement of smart city goals. The results also indicate that there is a lack of factors related to occupant oriented and flexible design, longevity, and cost-time effectiveness in both reviewed smart city strategy reports.

Conclusions

The study tried to provide a view of smart city strategies from the perspective of building technology solutions in smart cities. The definitions and characteristics of the smart city concept were firstly explained, and then smart city strategies were described in a general framework in order to gain a better understanding of smart city strategies. Finally, two smart city strategy reports (NSCSAP and MSCEU) were examined to explore their success factors in terms of building technology. The focus point of both the reports is mainly to seek efficient ways to facilitate smart city transformation. They assert that smart building is a promising building technology solution for smart city development. Based on the findings of this study, in both the reports, it is realized that the social dimension of smart buildings and cost/time-saving issues were not adequately identified while building energy efficiency and smart systems are mostly addressed.

Limitations of the study and some recommendations for future research are as follows: This study is limited to the review of only two smart city strategy reports. In future research, it can be focused on the evaluation of more smart city strategies by taking into account building technology solutions for increasing the reliability of the findings. Given the findings of this study, future works can question the social dimension of smart city initiatives, and also the effects of smart buildings on achieving smart city goals. Last but not least, there is a need to develop user/occupant-oriented smart city strategies because of the fact that the use of smart systems including innovative and advanced technological applications may not be adequately understood by citizens.

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BIM Implementations on Metro Projects and Suggestions on Digital Transformation: A Case Study of BIM on Istanbul Metropolitan Municipality Metro Projects

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Abstract

With the migration from rural areas to cities, urban transportation has started to become a major problem, and with the rapidly increasing urban population, central governments and local governments have started to increase their metro investments to solve increasing urban transportation problems. New approaches are being adopted to manage the construction and operation processes of subway projects where billions of dollars of investments are managed. Building Information Modelling (BIM) is one of the pioneers of these new approaches and an important concept in the digitalization of the construction industry. Within the scope of this study, BIM implementations and good practices will be examined with examples from ongoing constructions of metro lines where Istanbul Metropolitan Municipality (IMM) Rail Systems Department is the owner. In light of the applications examined, suggestions on how the processes can be evolved and the management of the digital transformation process based on the developing technology will be included.

Keywords: *building information modelling, digital transformation, metro project.*

Introduction

The world population, which was approximately 1 billion in the early 1800s, has now exceeded 7 billion. By the year 2100, the population is expected to exceed 11 billion. When we examine the distribution of this population based on urban and rural inhabitants, it is seen that the population of people living in cities in North America and Europe was more intense than in rural areas in the 1960s. It was observed that the population living in rural areas was more intense in developing countries in the 1960s. However, starting from the 1980s, a rapid increase was observed in the population living in the cities in developing countries. Today, it is stated that more than 4 billion people live in cities, and according to the data of the United Nations, the number of people living in cities for the first time in 2007 has outstripped rural areas. Another striking result of this rising trend is the expectation that more than two thirds of the world's population will live in cities by 2050.

With the increase in the population living in urban areas, urban transportation has become an important problem that countries must solve. For this reason, countries have tried to quickly find solutions to urban transportation problems and especially increased their metro investments, which has high capacity and is more eco-friendly amongst other urban rail systems. As a solution to urban transport problems increased in Turkey, it has begun to be concentrated to metro investments also. Especially in Istanbul, which is the most populous city of the country and one of the most important metropolises of the world, metro investments are increasing rapidly. Istanbul Metropolitan Municipality (IMM) aims to put a hundreds of kilometers metro network into operation in order to solve transportation problems quickly.

These investments targeted by IMM also bring great risks. Starting from the design phase, it is essential to identify risks and take precautions in order to finish the work on time and at a reasonable cost. In addition to the generally accepted risks in infrastructure projects, considering the factors such as Istanbul being a 1st degree earthquake zone, ground conditions, infrastructure density, construction works carried out close to the city's historical and residential areas, risks increase in metro construction. Taking an innovative approach to avoid from the effects of potential risks, IMM has made project management mandatory with Building Information Modeling ("BIM") in Rail System Construction Specifications. BIM was first included in the specification in Kabatas Mecidiyekoy Mahmutbey Line in 2014. BIM, which was included in the specifications in the construction works tenders for the Dudullu-Bostanci and Atakoy-Ikitelli Metro line constructions that started in 2016, continued to develop rapidly in the sector by taking part in the specifications in 6 construction work tenders and 8 project work tenders in 2017.

Within the scope of this study, Ataköy - Ikitelli Metro Line BIM activities and digital transformation steps, which are one of the metro lines under the employment of Istanbul Metropolitan Municipality Rail Systems Department, will be examined.

Atakoy – Ikitelli Metro Line

Atakoy-Ikitelli Metro Line is one of the most important transportation projects in Istanbul which is 13.4 km including 12 stations and is integrated with six other metro lines through five different districts of the city. In 2023, it is estimated that the line will carry 500.000 passengers daily. The metro line passes through the busiest main arteries in Istanbul and more than 6 district in Istanbul. Metro line is the second metro project in Turkey, which was tendered with BIM requirements.

Table 1. Atakoy – Ikitelli metro line.

Project	Atakoy Ikitelli
Location	Istanbul / Turkey
Project Size	12 Stations – 13.4 km
Project Cost	€ 338 Million
Owner	Istanbul Metropolitan Municipality
Engineer	EMAY International Engineering and Consultancy Inc.
Contractor	AGA Energy
Designer	PROTA Engineering Design and Consultancy Services Ltd.

BIM in Specification of Atakoy – Ikitelli Metro Line

When we look at the BIM targets in the Specification, there is a wide range of BIM usage covering all stages from design to business. In the Specification, 5 basic BIM targets are determined and these targets are listed below:

- Creating 3D models and ensuring interdisciplinary coordination
- Cost analysis
- Integration of the work program with 3D models and progress tracking
- Preparation of as - built projects in BIM model
- Delivery of models that can be used for operation / maintenance to the operating company

In the specification, the Contractor is planned to employ structural, architectural, electrical and mechanical BIM design experts, assistants and BIM manager. It is stated that CAD layouts cannot prevent the BIM model as a process in defining the BIM process design. With the exception of the exceptions defined in the specification, it is another important item that all 2D drawings will be obtained from 3D models. Although there are some provisions that may be exceptions to this article, all these exceptions are subject to the approval of the employer. With these items, it is clear that the whole design process will be carried out with BIM models. The level of detail for all disciplines has been determined in the specification, and the BIM Implementation Plan states that the detail level and modeling standards will be determined by the mutual decision of all stakeholders.

The specification stipulates that the work program should be integrated into the BIM model along with all its activities, but it also has clear provisions for achieving progress from these models. Although there are provisions in the specification regarding the cost analysis to be made from BIM models, it is stated that traditional progress payment files will be prepared together with BIM models. Details about the common data environment, which has an important place in BIM application, are also included in the specification, and there is a detailed definition of the common data environment, including the restrictions on the security and sharing of the data. The specification contains important details about the management of the project with BIM, but is lacking in the management of the construction site. In addition, considering that there are more than one metro line under construction at the same time, the formation of BIM modeling standards within the employer and sharing it with contractor companies will provide an important advantage for IMM to manage the projects.

Atakoy Ikitelli Metro Line BIM Applications

In Atakoy - Ikitelli Metro Line BIM Implementation Plan, main BIM targets are planned at three priority levels. High level BIM usage target is defined as 3D coordination, mid-level BIM usage targets phase planning (4D), record modeling, model based cost estimation (5D) and two-dimensional layout production, and low level BIM usage target is operation and maintenance studies (7D) is defined (Table 2).

Table 2. Project goal and potential BIM uses.

Priority	Project Goal	Potential BIM Uses
High	3D Coordination	Coordination and Clash Test
Medium	Phase Planning	4D Modelling
Medium	Record Model	Update of BIM Models According to As – Built Projects
Medium	Cost Estimation	BIM BOQ 5D
Medium	Design 2D Projects	2D Design
Low	Operation and Maintenance (7D)	Processing of related parameters to model objects for use during the operation phase

When we look at the software used by the line to realize the targets set by stakeholders, it is seen that Revit is used in parametric 3D modeling studies, and assistance is received from Dynamo in modeling specific objects such as tunnel. It has been observed that laser-scanning studies are actively carried out and even Recap software is used to process these data and Infraworks is used to create 3D terrain models. It is seen that during the coordination process, in the further stages where Navisworks is used, the entire coordination process is carried out over BIM 360. Clash test is carried out by means of Navisworks. It is seen that MsProject and Navisworks software are used in work program and progress tracking studies, and Quantification module of Navisworks software is used in progress payment tracking. It was observed that Navisworks software was actively used in the creation of operation and maintenance models (Table 3).

Table 3. BIM uses and software.

BIM Uses	Software
3D Modeling	Revit, Dynamo, Recap, Infraworks
Coordination	Navisworks, BIM 360
Clash Control	Navisworks
Planning	Navisworks, Ms Project
5D Cost Control	Navisworks
7D	Navisworks

3D modeling and coordination processes specified as high targets in the BIM implementation plan are carried out in cooperation with all stakeholders. In the coordination workflow described in the BIM implementation plan, representatives from all disciplines of the employer, consultant, contractor, designer and operation firm attend the BIM coordination meetings held in two-week periods. 3D models which are shared a week before the meeting are examined by the employer, consultant and operation firm. Within the coordination model examined, each discipline representative conveys his/her comments to the contractor and designer. These comments are not only about clashes but also to prevent problems that will be encountered during construction and operation. Each comment can be reached by all disciplines and stakeholders, and the whole process is carried out transparently. According to these comments conveyed within the BIM model, the design firm revises the models. However, some issues may arise between parties or disciplines. Such situations constitute the agenda of BIM coordination meetings (Fig. 1).

Figure 1: Bahariye station BIM coordination model.

The items that form the agenda of the meeting are examined technically with the participation of all parties and the decision taken as a result of the meeting is also processed in the BIM model. The BIM model in which the decisions taken at the meeting are processed is uploaded to the data sharing system and recorded. These records are both a source of reference for the parties against any possible disputes and are used as knowhow in the metro lines that will start within the IMM. Within the scope of the line, a total of 1009 comments were reported, and the vast majority of these problems were resolved during the design phase thanks to the BIM model. Another important achievement of BIM coordination meetings is that, with the joint decision of the stakeholders, without coordination and clash tests, the construction phase cannot be started. In this process, which is carried out simultaneously by all disciplines unlike traditional methods, the problems that may be encountered during the construction phase are minimized and the risks arising from design errors are largely prevented. These findings corroborate that BIM applications in construction projects reduce claims arising from inaccurate design as El Hawary et. al. (2015) argued. In the case of the Ataköy - İkitelli metro line, no inconsistency due to design errors were reported and results are obtained that support this argument.

The problems caused by the Covid-19 pandemic, which has affected the whole world since the beginning of 2020, have had significant impacts in the construction industry as in all other sectors. According to the Deloitte (2020), due to Covid -19 pandemic, executives and board of directors should be asking some key questions such as “How can we use technology to gain operational leverage?”. Atakoy – Ikitelli Metro Line BIM experts also ask these questions for to overcome the challenges posed by the Covid-19 pandemic. Before Covid-19 pandemic, coordination processes are carried out with the Navisworks software, however; in this period, BIM 360, a cloud-based software, has been used to adapt to new working conditions. Thanks to this rapid adaptation, coordination efforts was able to be continued continuously throughout the Covid-19 pandemic.

One of the most critical features of the line is that the route is in irregular residential areas with high building stock. An accurate examination of the interaction of the metro line, which passes through the most crowded areas of the city, with the surrounding buildings, is an important challenge for stakeholders. In order to overcome this difficulty, laser scanning studies were made through drones, and point cloud data and station / tunnel models were integrated, and interaction with surrounding structures could be examined through current data (Fig. 2).

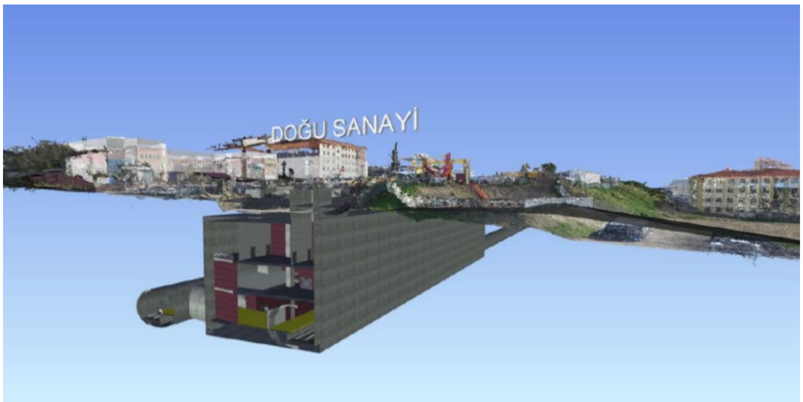

Figure 2: Dogu Sanayi station laser scanning site model.

In hazardous areas, laser scanning data has been used to examine tunnel structure interactions. Within the parametric 3D models, details such as environmental structures, infrastructure lines, roads, bus stops are modeled, and thanks to these models, risks were identified before production and precautions were taken before the construction phase. In addition, building parametric models are linked to these parametric models to provide access to the features of each building within the model (Fig. 3).

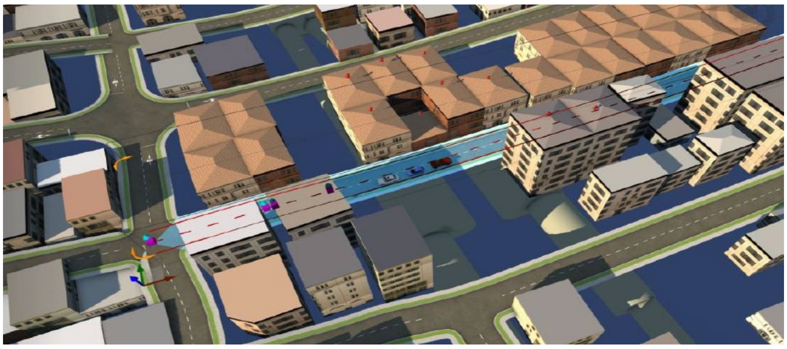

Figure 3: Site BIM model.

Laser scanning method is not only used for site interaction. It was also used to create as built models of structures whose rough construction is finished. With the as-built models created, again, an overlap test is performed with electromechanical / architectural models (Figure 4). Clashes that can be encountered during construction are largely prevented by performing the clash tests with laser scanning data (Fig. 4).

Figure 4: Bahariye station laser scanning model.

The progress tracking of the tunnel, rough construction and rail assembly of the line is carried out with bi-weekly progress models. Electromechanical and finishing works are carried out through more detailed models that are shared weekly. These models which are integrated with the work program, provide making the delay analysis (Fig. 5).

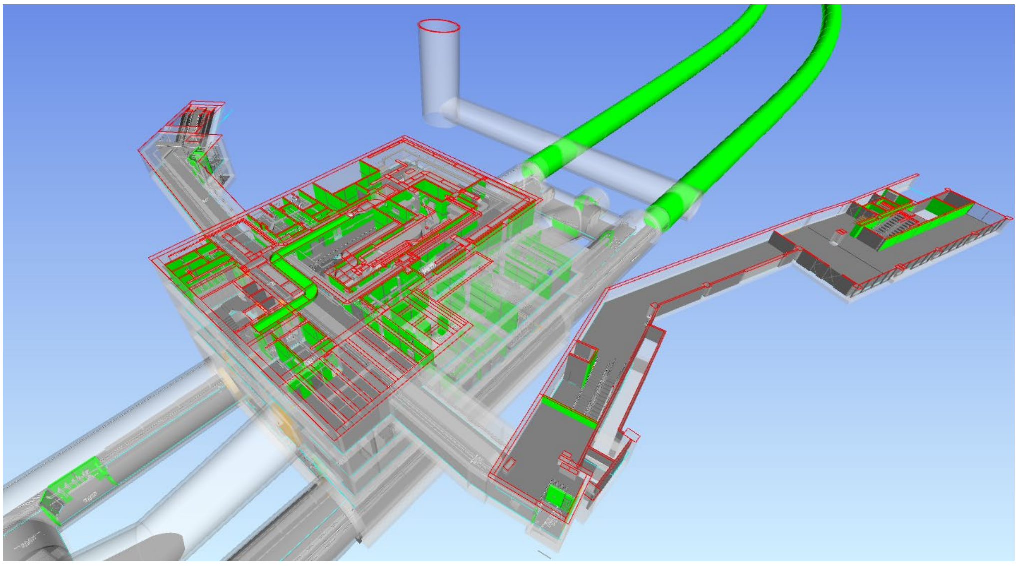

Figure 5: Masko station 4D progress tracking model.

Another study carried out within the scope of the line is to follow the cost analysis and progress payment through 3D models. In this study, firstly, the unit price descriptions defined in the contract have been defined in Navisworks Quantification module with all the details. In each manufacturing item, the model elements that are the basis of that production are integrated and then, as the manufacturing takes place, the progress parameter is filled and cost calculations are made. The prepared models are updated monthly and shared with the employer It is also used to quickly optimize the cost impact of systematic alternative design decisions. It has been determined that the stakeholders who are trying to reach the limited delivery times prevent fast decision making and time / cost losses. (Fig. 6).

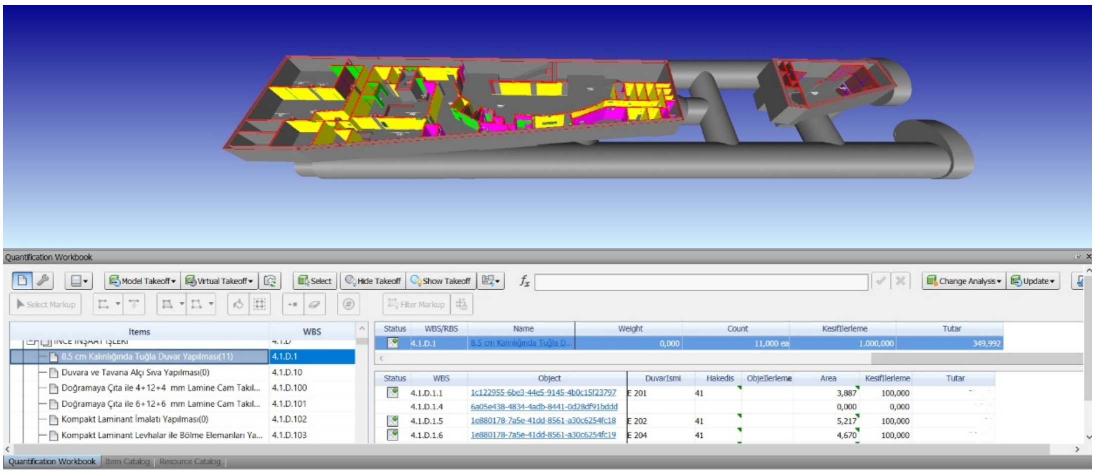

Figure 6: Bahariye station 5D BIM modeling for project cost estimation.

Studies to create 7D models, which are defined as low targets in the BIM implementation plan, are carried out through signaling documents, which are very important especially in testing and commissioning works. Within the signalization models created, all documents that may be required for operation, maintenance and repair are linked to the related equipment and accessibility is provided (Fig. 7).

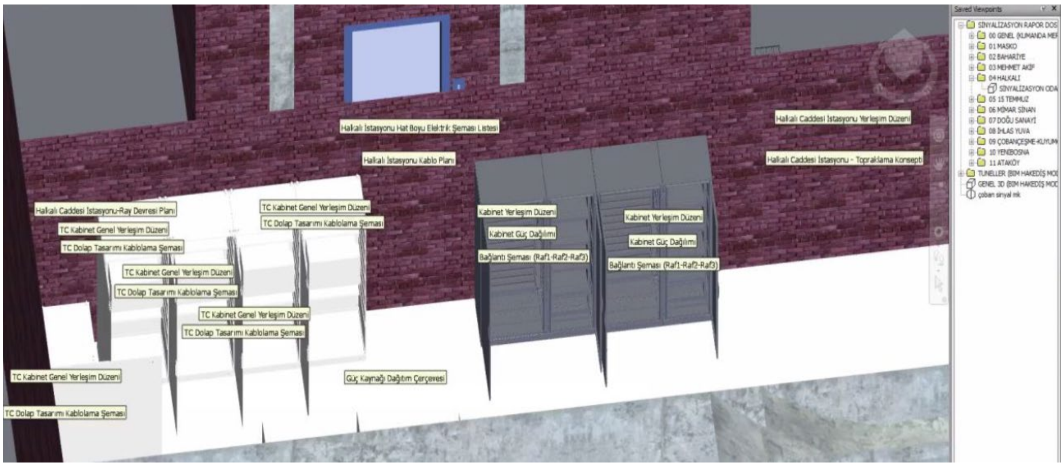

Figure 7: Operation and maintenance model.

Lessons Learned

The following lessons were learned from the investigated case studies:

- The fact that the stakeholders did not have sufficient BIM experience at the beginning of the project and the transition of IMM to BIM without creating a corporate culture It wasted a lot of time in designing BIM processes. IMM should prevent the loss of time caused by inexperienced contractors by creating standard documents.
- Although Atakoy - Ikitelli Metro Line is the 2nd metro project of IMM that is being carried out with BIM, it has been observed that it provides BIM adaptation in accordance with the terms of the contract. In particular, in coordination and clash test, it was observed that studies with high BIM maturity were carried out by stakeholders.
- During the Covid-19 pandemic period, BIM played an important role in the continuation of design and coordination processes. The transfer and dissemination of these experiences is important for the industry.
- The experiences gained from the coordination processes should be transferred to other projects and as a know-how. These experiences will be instructive not only for new jobs but also for new graduate engineers.
- The application of technologies such as laser scanning that has not become widespread in the construction sector and the experiences gained from these applications are of great importance for the development of the sector. Efforts should be made to implement these studies in other public projects.
- The traditional method cannot be abandoned in progress payments due to the legal limitations. Improvements in progress payment methods and arrangements should be made to integrate with BIM. IMM needs to realize this development with engineers with an innovative perspective.

- Transferring experiences to new lines during the transition to BIM and creating corporate memory will help IMM achieve its goals. Preparation of special documents such as BIM Implementation Plan by IMM will pave the way for standardization.
- It is seen that there are big deficiencies in terms of mobile use of workers and field engineers in BIM applications and the specification is not at the level of sufficient detail. Necessary software and hardware should be described in the specifications to make BIM models available on site.
- Although the studies for the business phase are of great importance in terms of development, the business firm needs to clearly determine its demands. In line with these demands, standards should be established and earnings should be increased in the long term.

Discussions

Atakoy - Ikitelli Metro line BIM studies and the lessons learned as a result of these studies were examined within the scope of the research. When the results obtained within the scope of the study are compared with the findings of the NBS National BIM Report 2020, which is published regularly by the National BIM Standards (NBS), it is seen that the BIM adaptation and the difficulties encountered are similar. In the NBS report, the lack of in-company experts and experience ranks first among the main obstacles and is similar to the significant findings highlighted within the scope of the research. However, it was determined that important obstacles such as lack of collaboration and no client demand highlighted in the report were overcome in the case examined. Another important issue is that the applications which prove the idea that the use of BIM has increased with the Covid-19 pandemic stated in the report, was seen within the scope of the case.

Hamma-Adama et. al. (2020) argued that lack of standardization and protocols are most important barriers for BIM adoption. However, this argument is not entirely acceptable for the case under consideration. Even though IMM protocols contain detailed explanations for the design phase, it is seen that they are not sufficient for the digitalization of the construction site and deficiencies have been identified in the application of the work done on the site.

This case includes examples of use of BIM applications in rail systems in a large project. Atakoy - Ikitelli BIM studies greatly benefited from the advantages of BIM in rail systems and contain elements that support similar studies. The case study shows that BIM integration into railway projects provides collaboration, time and cost saving, better facility management, dialogues between different disciplines and better quality work as Bensalah et. al. (2018) stated. Also, like Bensalah argued, it demonstrates that this integration causes not only a technological improvement but also a revolutionary approach for construction industry.

Also, the findings of this case study shows that BIM provides benefits such as generating accurate 2D plans at any stage, early accurate visualization, improvement of clash detection, reducing correction problems in design like stated in the research by Al-Zwainy et. al. (2017).

Conclusions

In this study, Atakoy - Ikitelli Metro Line BIM applications were examined. Despite the fact that the first implementation of BIM in public projects in Turkey, BIM maturity level was found to be high. In particular, BIM coordination processes facilitate the adaptation of stakeholders to BIM, as well as increase interdisciplinary communication and improve design quality. The fact that disciplines carry out processes with the awareness of collaboration is another finding that plays an important role in making critical decisions as well as preventing clashes in the field. Active use of new generation technologies such as laser scanning technology is expected to contribute to the improvement of the quality of the studies and the development of the sector. The use of BIM will become widespread by making progress payments with BIM mandatory and regulating legislation in this direction. In this way, progress payment management will be more reliable than the traditional method. The studies carried out on the metro line examined are examples that can set an example in this regard and will support the practitioners. Another work of IMM Rail Systems that will contribute to the development of BIM will be the creation of a common family database that can be used in all lines. This created database will not only contribute to the design and progress payments, but also to the operating company. It has been determined that there are shortcomings in the studies regarding the use of BIM applications of the project in the construction site, and it was observed that the inexperience of the stakeholders and the inadequacy of the specification caused this result. The BIM applications examined within the scope of this study are intended to be sources for other projects and the lessons learned will be guiding public and private institution managers' BIM processes.

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Evaluation and Comparison of the Public Construction Legislations of Turkey and the Netherlands in the Context of Project Planning and Control

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Abstract

Completion of public-owned construction projects successfully is quite important for Turkey as a rapidly developing country. However, schedule delays and budget overruns are frequently encountered in such projects. One of the major reasons of this situation is the nonexistence of legislative provisions enforcing project parties to utilize advanced project planning and control methods in their projects. This paper firstly introduces the results of an investigation conducted on the public construction legislation in force in the Netherlands and related practices. Secondly, the results of a review on public construction legislation in force in Turkey are given to reveal the deficiencies in the regulations from the perspective of project planning and control. Subsequently, a number of legislative amendments are proposed to eliminate these deficiencies. Finally, to give some international context to the study, the two countries were compared. The findings showed that the legislation of the Netherlands also does not contain obligatory terms towards the implementation of advanced project planning and control methods. However, the usage of these methods are ensured through the quality control systems applied tightly based on the regulations put into force within the scope of contracts. Future research could focus on including more countries in the comparative study.

Keywords: *project control, project planning, public construction legislation, the Netherlands, Turkey.*

Introduction

The basic objective in any construction project is to complete the project within time, cost and scope along with the expectations and requirements in terms of quality, safety, environment, and stakeholder satisfaction (Atkinson, 1999; Bakker et al., 2010; Toor & Ogunlana, 2010). Complex, uncertain and dynamic conditions of today's construction sector require the usage of advanced planning and control methodologies in projects in order to increase the possibility of achieving success (Oberlender, 2014; O'Brien & Plotnick, 2015). Particularly using techniques such as the Critical Path Method, Line of Balance and Earned Value Management seems essential in order to properly manage the construction projects (Hinze, 2011; Newitt, 2008; Oberlender, 2014).

In Turkey, public institutions, which are liable to public law and using public resources, are subject to Public Procurement Law No: 4734 and Public Procurement Contracts Law No: 4735. In case public resources are to be consumed to purchase goods and services or realize construction works, the state institutions in Turkey are obliged to act in compliance with these laws and related regulations (Legislation Information System, 2020a; Legislation Information System, 2020b). Completion of public-owned construction projects successfully is quite important for Turkey as a rapidly developing country. However, schedule delays and budget overruns are frequently encountered in public-owned construction projects in Turkey. One of the causes for these delays and overruns is that projects are started without a proper planning and executed without using (advanced) project planning and control methods. The studies conducted on this issue point out the main reasons of this problem being the nonexistence of appropriate and sufficient provisions in the current regulations that will enforce the project parties to utilize the required project planning and control methods in their undertakings (Zalmai et al, 2016) and lack of awareness on such methods in the Turkish construction sector (Yurdakul, 1998; Gerger, 2006). Besides, Belirgen (2005) showed the existence of a meaningful statistical relationship between project planning and project success in engineering projects realized in Turkey based on an empirical analysis.

This paper firstly introduces the results of an investigation conducted on the public construction legislation in force in the Netherlands and related practices. Secondly, the results of a review on public construction legislation in force in Turkey are given to reveal the deficiencies in the regulations from the perspective of project planning and control. Subsequently, a number of legislative amendments are proposed to eliminate these deficiencies. Finally, to give some international context to the study, the legislation and related practices in the two countries were compared and conclusions were drawn.

Public Construction Legislation and Related Practices in the Netherlands

The Netherlands, which is composed of 12 provinces, does not have a strictly centralized state tradition. There are 3 levels of independent Dutch governments; 1 central government based in The Hague, 12 provinces, and 355 municipalities, respectively. Furthermore, there is an independent layer of 21 regional water management authorities (boards), who deal with the local polder systems, water safety, sewer water treatment and water quality. A more complicated setting is arranged for the Caribbean Islands, which is also another part of the Netherlands (Rijksoverheid, 2020). All of these Dutch governments have their own jurisdiction, can make their own decisions, and have their own political representatives. Also for the role as an employer to the civil engineering market, these governmental administrations have their own policies and responsibilities. Only on some issues, the central (national) government enforces rules by law. However, in general, the policies and applications of the National Ministry of Infrastructure and Water Management (Ministerie van Infrastructuur en Waterstaat) are followed. Rijkswaterstaat is a part of this Ministry, being the executive agency that operates and explores the national networks for canals & rivers, highways, and water defense works (Rijkwaterstaat, 2020). ProRail, which is the public organization that takes care of the national railway network (ProRail, 2020), is a bit more remote and independent from the Ministry of Infrastructure and Water Management, but it also reports to this Ministry. On the other hand, the Water Management Authorities, municipalities, and provinces report to their own political representatives, and are only supervised by the national government remotely (Rijksoverheid, 2020).

In this study, public construction legislation and related practices in the Netherlands have been investigated by gathering and studying the Dutch standardized contract formats and specifications used by the Rijkswaterstaat, ProRail and Water Management Authorities, respectively, and by interviewing planning practitioners expertized on the Dutch construction sector. In the Netherlands, the procurement legislations and contract legislations in force have been regulated separately. The national procurement law entitled as the Aanbestedingswet 2012 (Procurement Law, 2012) has been constituted in compliance with the European Union's public procurement directives and it contains quite strict regulations. The governments at all levels and all of the public authorities are obliged to implement these regulations in their procurements. Regarding the contracts used in public construction sector, the Netherlands follow a different route when compared to the procurement legislation. The governments are entirely free in determining the formats and contents of the contracts they utilize and in making any arrangements on the relevant specifications in accordance with their needs. However, in order to enhance efficiency in the public construction sector, some standardized contract forms have been created mutually between the public owners and the contractors' associations at the national level. These standardized contracts are used widely.

The Quality Control System (QCS) is the main tool generally utilized in managing the Dutch public construction contracts. QCS is a very systematic and a certified approach and the contractors are responsible for delivering the products in a project in compliance with the requirements of this quality system along with the quality control certificates. Prior to rewarding the contract, the contractors are obliged to submit a Certified Quality Certificate, which was formed according to NEN-EN ISO 9001, as a proof of a functioning QCS within his/her company. Before the contractor starts the execution of the project, a "Project Quality Plan" has to be submitted to the owner and this plan must be approved by the owner. However, this plan does not transfer any responsibilities to the owner. During the construction, the QCS becomes an important issue at all meetings held on site between the contractor and owner. The owner may also implement some quality tests on the site as well. The issues regarding the project planning and control are an important part of this Project Quality Plan along with all the other descriptions about the construction processes. The financial sustainability of a contractor depends on the cash flows realized by the payments made by the owner, i.e. these are all based on the QCS, reported progress or completed intermediate project products including their quality certificates. As all payment depend on the QCS, this automatically ensures the usage of detailed project planning methods and advanced planning tools by the contractor. Forward payments by governments are never included in the contracts. Furthermore, in some of the infrastructure projects, which may have a large impact on traffic flow, strict timeslots are given to the contractor. Failing to use these timeslots will result in huge penalties. Therefore, the contractor comes to a position that he/she has to prevent possible delays though applying a proper planning and control mechanism and an effective risk management. Generally, the level of specifications regarding the project planning and control are not very elaborated in the Netherlands except for some major projects. In general, the details of the requirements regarding the project planning and control already are ensured through the QCS within the contracts. Enforcement by law is considered to be too inflexible.

Rijkswaterstaat (Rijkwaterstaat, 2020) has quite limited planning specifications applied for the simple projects. However, all quality assurances need to be included, and a contractor will generally formulate several products in the planning to ensure his/her cash flow. Supervision on the construction site is sometimes needed for some critical processes, but this is generally limited. For the larger Design & Construction contracts, a work breakdown structure (WBS) is required, including the tests and approvals by the owner. Also, the critical paths have to be highlighted by the contractor. A more elaborate Monte Carlo Simulation (MCS) based schedule or probabilistic scheduling may be requested in case of larger projects. *Water Management Authorities* (Rijksoverheid, 2020) generally realize smaller and local projects, but still count for a total expenditure of about 1.5 billion euro/year. Project planning and quality control are closely connected topics also in the projects of the Water Management Authorities. Before the start of the works, a general planning has to be submitted by the contractor. However, at intervals, a more detailed working plan is prepared. An IT tool for adequate communication between the contractor and supervisors named “VISI” is also used, and the requirements regarding the project planning and controlling are included within this system. *ProRail* (ProRail, 2020) applies the tightest contractual clauses regarding the project planning and control among the owners of the public construction sector of the Netherlands. The requirements are embedded in a general tight level of specifications and safety specifications implemented for all the projects in the railway construction sector. Works and temporary stops in rail services are generally scheduled in advance, long time ahead, and therefore the timeslots established are scarce. A detailed WBS is generally required, as well as a probabilistic approach to the planning. Critical Path Method, Linear Scheduling Method, Earned Value Management, S-Curve (Progress) Analysis and MCS based scheduling are among the project planning and control methods generally utilized by the contractors in the projects of ProRail.

Evaluation of Public Construction Legislation in Turkey in the Context of Project Planning and Control

The laws and regulations in force in Turkey, which are reviewed in this study (Legislation Information System, 2020a, 2020b, 2020c), are the Public Procurement Law No. 4734 (4734 sayılı Kamu İhale Kanunu) (*A1*), Public Procurement Contracts Law No. 4735 (4735 sayılı Kamu İhale Sözleşmeleri Kanunu) (*A2*), Annex to the Implementation Regulation for Construction Works Tenders – General Conditions of Construction Works (Yapım İşleri Genel Şartnamesi) (*B*), Implementation Regulation for Construction Works Tenders (Yapım İşleri İhaleleri Uygulama Yönetmeliği) (*C*), Public Tender General Communiqué (Kamu İhale Genel Tebliği) (*D*), and Annex to the Implementation Regulation for Construction Works Tenders - Contract Template for Construction Works (Yapım İşleri İhaleleri Uygulama Yönetmeliği eki Yapım İşlerine Ait Tip Sözleşme) (*E*). The legislation in question has been scanned through a number of keywords related to the scope of the study as shown in Table 1. These keywords are *planning/scheduling/control, activity criticality/float times, time extensions, work increase/decrease, delays/delay penalty, delay analysis/float time usage entitlement, advanced or detailed planning and scheduling*, and *advanced or detailed controlling/monitoring*. The results of this investigation (Table 1) show that the legislation designated in the form of A1, A2, B, C, D, and E above hardly contains provisions in terms of advanced project planning and control methods, the names of which are mentioned below. Therefore, it can be concluded that it is not possible to enforce the usage of such methods in public-owned construction projects with the current legislation in force.

The methods investigated during the review of the legislation up to now and to be referred in the legislative amendments that will be proposed in the following sections are the Critical Path Method (CPM), Line of Balance Method (LOB), and Linear Scheduling Method (LSM) as the planning and scheduling methods (Harmelink & Rowings, 1998; Ammar, 2013;

Ökmen, 2013; O'Brien & Plotnick, 2015; Ioannou & Yang, 2016; PMI, 2017); the Earned Value Management (EVM) and S-Curve Analysis (SCA) as the project control methods (McConnell, 1985; Marzouk & Hisham, 2014; PMI, 2017); and the Time Impact Analysis (TIA) as the delay analysis method (Arditi & Pattanakitchamroon, 2006; Al-Gahtani & Mohan, 2007; Braimah, 2013). The reason of using these methods in this study is that relevant literature extensively states their advantageous features and effectiveness in construction project management. However, it should be mentioned that new methods and advanced extensions to the current methods are continuously under development by researchers, therefore following the new developments in this field and quickly reflecting them to regulations and sectoral practice is needed.

Table 1. Evaluation of Turkish Construction Legislation.

Legislation	Planning/ Scheduling/ Control	Activity Criticality/ Float times	Time Extension	Work Increase/ Decrease	Delay/ Delay Penalty	Advanced or Detailed Planning and Scheduling	Advanced or Detailed Controlling/ Monitoring	Delay Analysis/Float Time Usage Entitlement
A1	✓	X	X	X	✓	X	X	X
A2	✓	X	✓	✓	X	X	X	X
B	✓	X	✓	✓	✓	✓	X	X
C	✓	X	X	X	X	X	X	X
D	✓	X	✓	X	X	X	X	X
E	✓	X	✓	✓	✓	X	X	X

Amendment Proposals for the Elimination of Deficiencies in Public Construction Legislation of Turkey

This section introduces a number of amendment proposals to eliminate the legislative deficiencies identified in the previous part. The proposals have been set up in the form of legal regulations either as a modification or an addition to the current legislation. In case a modification is proposed, the old text is over-lined and subsequently the new text is written under-lined. In case a new provision is added, the added text is given completely under-lined.

Amendment Proposal 1

In the clause (r) of the article no. 27 of the "Public Procurement Law No. 4734" titled *"Content of the tender, prequalification document and the mandatory points to be included in the Administrative Specification"*, the subjects that are required to be specified as a minimum in the Administrative Specification, which is one of the main documents prepared and delivered to bidders before the tenders by the Contracting Administrations, are the start and end date of work, the location of construction site, the delivery terms, and the penalties in case of delay. The following amendment is proposed for the article no. 27 in question. By this amendment, the project duration specified within the Administrative Specifications would be an estimated value determined by the Contracting Administrations. In current practice, completion date of the work is declared by the Administrations to the Contractors as an irrevocable constraint, thereby preventing optimum solutions for scheduling. Moreover, this amendment mandates the specification of the delay analysis method that will be used to find out the responsibilities of the parties in case a delay occurs.

Article 27- (r) The date of commencement of the work subject to the tender, estimated date of completion, the place of delivery, the conditions of penalty in case of delay and the method to be followed for delay analysis.

Amendment Proposal 2

The article no. 24 of the "Public Procurement Contracts Law No. 4735" titled *"Additional work, reduction of work and liquidation of the work within the scope of the contract"* is proposed to be amended by adding the following provision to the article no. 24. Although no specific method is prescribed in the present state of law, Contracting Administrations generally extend the duration of the work as much as the time calculated by applying "the rate of work increase to the contract value" onto the completion date of the work specified in the contract. Unfortunately, this approach causes improper time extension decisions. In this respect, the proposed amendment paves the way for determining the time extension amounts more realistically in case of a work increase through updating the work programs prepared with advanced project planning methods such as CPM.

Article 24- ... In the event of a work increase due to unforeseen circumstances, the work that is subject to the increase; ... within the framework of the provisions of the contract and the tender document, yet excluding the period, the same contractor shall have the work done. The additional duration due to any increase in the amount of work will be determined by updating the work program in accordance with the work increase.

Amendment Proposal 3

The definition of the "Work Program" in clause no. 1 of the article no. 4 of the "General Conditions of Construction Works", which is an annex to the "Implementation Regulation for Construction Works Tenders", is proposed to be amended as follows in accordance with the proposals offered so far. This amendment will ensure meeting the requirements such as preparing the work programs on a daily basis taking into account the estimated project duration and the annual allowance amounts stipulated by the Administration in the contract, arranging the work program in such a way that a more appropriate solution is reached, and allocating the allowances to the months accordingly in the work program. In other words, the Contractor is given the opportunity to prepare the optimum work program taking into consideration his / her available resources and financial situation together with the foresights provided by the Administration.

Article 4 – (1) Work program: Taking into account the estimated duration of the work specified in the contract and the estimated expiry dates of the work, if any, and the estimated annual payment amounts, work program is the schedule that shows the work items/ groups of the construction work, the ~~monthly~~ daily production and work quantities, the foreseen amount of material that is allowed to be paid in case be prepared on site in advance, the annual appropriation slice of the production in accordance with the proposed production rate and procedure, and their distribution to months.

Amendment Proposal 4

The clauses no. 1 and 5 of the article no. 17 of the "General Conditions of Construction Works" titled *"Work Program"* are proposed to be amended as given below and a new clause, the clause no. 8, is recommended to be added to the end of the article. The amendment proposed for the clause no. 1 mandates the work program to be prepared in the detail required by the Administration. The disputable term "comprehensive work" existing in the current legislation has been eliminated by the amendment proposed for the clause no. 5. Furthermore, through this amendment proposal, it is also obliged to prepare work programs in all kinds of construction projects by using advanced project planning methods such as CPM through the means of licensed computer programs. Besides, the amended clause no. 5 contains provisions about how and in what detail the work programs will be prepared and it mandates the utilization of the advanced work programs effectively during managing, controlling and tracking the progress of the projects. On the other hand, the clause no. 8, which is the newly added clause, ensures the usage of advanced project planning and control methods effectively during the execution of the work, the regularly updating of the work programs in order to reflect the latest situation in the project, the evaluation of the progress by an advanced approach such as "Earned Value Management" instead of the traditional "physical and financial realization" approach generally used in the current application, the demonstration of the precautions taken by the Contractor clearly and detailed if it is understood that the work will be delayed, the implementation of the delay analysis whenever required by using the "Time Impact Analysis" with taking into account the rights of float time usage, and the determination of the amount of responsibilities of the parties in case of a delay.

Article 17 –
(1) The Contractor shall prepare a work program in accordance with the examples given by the Administration and in sufficient detail compatible with the nature of the work, and shall submit it to the Administration for approval within the period specified in the contract or its annexes.

...

(5) ~~In a comprehensive work, the administration may require that the work program be organized using a package software work program or computer-aided work program that is prepared according to the feature of the work instead of the bar diagram.~~ *The work program should be organized through licensed software using one or more of the Critical Path Method, Line of Balance Method or Linear Scheduling Method according to the nature of the work. The method and software to be used will be specified in the contract. The information such as the relationships between work items or activities, criticalities of activities, float times of non-critical activities, start-up and completion dates, etc. should be clearly indicated in the work schedule using tables, bar diagrams, network diagrams or production graphs in the details requested by the Administration. Managing, controlling and progress tracking will be realized from the beginning until the end of the work effectively through using the work program.*

...

(8) The Contractor is responsible for conducting the work effectively by using the work program which has been prepared in accordance with the points specified in the clause no. 5 and approved by the Administration and responsible for providing the latest progress in construction to the Administration with the results of S-Curve Analysis and Earned Value Management on a regular basis and whenever required. Due to time-outs in critical activities or the use-outs in float times of non-critical activities, the amount of elongation at the planned completion date should be communicated to the Administration at regular intervals and, if

necessary, by updating the work program. The notifications must also include sufficient explanations on how to control the time-outs that have occurred and how to finish the work in the planned period. Apart from these, the Administration may ask the Contractor to carry out a study based on Time Impact Analysis for finding out which party is defective to what extent if time extension is requested or if the work is delayed. If there are any provisions in the contract related to the float time entitlement, these issues shall also be taken into consideration in the analysis.

The contents of Table 1 would change as shown in Table 2 if all of the amendments proposed in this study are implemented. Table 2 also includes the results of the amendments proposed for the "Implementation Regulation for Construction Works Tenders (Yapım İşleri İhaleleri Uygulama Yönetmeliği) (*C*)", "Public Tender General Communiqué (Kamu İhale Genel Tebliği) (*D*)" and "Annex to the Implementation Regulation for Construction Works Tenders - Contract Template for Construction Works (Yapım İşleri İhaleleri Uygulama Yönetmeliği eki Yapım İşlerine Ait Tip Sözleşme) (*E*)" although the amendments in question were not discussed in the paper due to size limitation. As can be observed in Table 2, the subjects shown in the columns occupy place in at least one of the arrangements mentioned in the rows. This can be considered as a sufficient criteria to eliminate the legislative deficiencies detected in this study when the principle of "hierarchy of norms" of law is taken into account.

Table 2. Re-evaluation of Turkish construction legislation after amendment proposals.

Legislation	Planning/ Scheduling/ Control	Activity Criticality/ Float times	Time Extension	Work Increase/ Decrease	Delay/ Delay Penalty	Advanced or Detailed Planning and Scheduling	Advanced or Detailed Controlling/ Monitoring	Delay Analysis/Float Time Usage Entitlement
A1	✓	X	X	X	✓	✓	X	✓
A2	✓	X	✓	✓	✓	✓	X	✓
B	✓	✓	✓	✓	✓	✓	✓	✓
C	✓	X	X	X	✓	✓	X	X
D	✓	✓	X	X	✓	X	✓	✓
E	✓	✓	✓	✓	✓	X	✓	✓

Discussion of the Findings and Conclusions

Ensuring the usage of advanced project planning and control methods such as CPM, LSM, and EVM through legislation emerges as a priority for the public construction sector in Turkey. This study has revealed that almost no obligation exists in regulations regarding the usage of these methods. This situation yields to ineffective project management from the contractors' perspective and ineffective progress monitoring from the owners' viewpoint. In turn, cost overruns and schedule delays frequently occur in public-owned construction projects. This study aims to create an awareness on this issue and introduces an approach that can be followed to resolve this problem.

In this study, the public construction legislation in force in the Netherlands and the related practices also have been investigated in terms of project planning and control. The results of this investigation have shown that, in the Netherlands, the usage of advanced project planning and control procedures in public-owned construction projects are ensured mainly through the adoption of a comprehensive quality control system, the details of which are determined within the contracts through negotiations conducted between the public owners and contractors. In other words, although the legislative regulations do not contain obligatory terms towards the implementation of advanced project planning and control procedures in the public construction legislation of the Netherlands similar to the situation in Turkey, the usage of such methods is ensured through the quality control systems applied tightly based on the regulations put into force within the scope of contracts. Although different corporation cultures among the public-owner organizations in Turkey already provide the conditions of realizing procedures similar to the current practice in the Netherlands, generalization of the usage of such a model is also possible in Turkey. In other words, a similar approach may also be followed in Turkey besides the implementation of legislative amendments as proposed in this paper so that the problem could be solved in a multi-dimensional manner, i.e. from legislative, application and contractual points of view. Furthermore, it can be argued that legislative amendments similar to the ones proposed in this study may be applicable and required also for the legislation of the Netherlands to provide the aforementioned multi-dimensional solution also to the case of the Netherlands. Obviously, schedule delays and cost overruns in the public-owned construction projects also occur in the Netherlands. Future research could focus on the opportunities of legislative amendments in the Netherlands, but also in the other European countries.

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Applicability of the Six Thinking Hats Technic to the Eco-Charrette Meetings

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Abstract

Eco-charrette meetings are important pillars and enablers of sustainable building design and its construction project management. Eco-charrette meetings are performed with the participation of interdisciplinary teams and various stakeholders (e.g. owner, contractor, architect, engineer, consultant, etc.) to discuss project specific trade off decisions (quality, time, cost) and technical aspects. The six thinking hats technic emphasises the necessity of presenting knowledge, experience and thinking in a systematised way. Each hat has been symbolised as a though. This technic can enable decision makers to approach the topic from different perspectives. This paper aims to investigate applicability of the six thinking hats technic to eco-charrette meetings. With this aim, following an in-depth literature review, and expert opinions have been gathered with the participation of experts having eco-charrette meeting experience. This research is expected to be useful to eco-charrette meeting participants, effectiveness of eco-charrette meetings and to the value creation in the sustainable building projects.

Keywords: *eco-charrette meeting, effective team work, six thinking hats, health and safety.*

Introduction

Enhancing effectiveness of the thinking and discussion atmosphere of a meeting can be supported enabling the meeting participants to think and talk. Even experts and professionals may not always think in a systematic and rational way (Olson, 1997). As thinking processes are complicated, thinker needs to know what to follow and focus on (Dominowski and Bourne, 1994). Critical thinking covers assessment, analysis, synthesis and commenting of a thought to reach to a conclusion (Villalba, 2011). Critical thinking identifies why and how an idea needs to be chosen (Villalba, 2011). Even if critical thinking and problem solving can be considered as main skills necessary for the success, there is limited focus on the way the thinking methods can be effectively implemented solution methods (Kivunja, 2015). This can enable them to gain thinking skills (De Bono, 2005). The six thinking hats technic (STHT) aims to enable meeting participants to think at the same time (De Bono, 2009). As there is generally no one way for solving a problem, assigining different colours to the hats can help understanding critical thinking and problem solution (Kivunja, 2015). STHT establishes six contexts corresponding to objective, subjective, critical and creative thoughts shaping the thought in a detailed framework (John, 1996). STHT prevents individuals to perceive the thoughts and events from a single perspective (Toraman and Altun, 2013). This method supports finding optimum solutions as it can provide thinking opportunities and new outputs in problem solving sessions (Aithal et al., 2016). STHT is important as it can enable multi dimensional thinking approach in complex organizations (Aithal and Kumar, 2017). This research aims to investigate applicability of the STHT to eco-charrette meetings. With this aim, following an in-depth literature review, and expert opinions have been gathered with the participation of experts having eco-charrette meeting experience. Furthermore, STHT's potential for enhancing efficiency of eco-charrette meetings has been investigated.

Eco-charrette Meetings

Eco-charrette is a 4-8 hours long interactive brainstorming and team establishment activity (Law Insider web site, 2020). Eco-charrettes are intense sessions ranging from a few hours to a day, where customer representatives, architects, engineers, other consultants and often users come together to define sustainability principles to guide the design and define potential synergies among different disciplines (Mccomb, 2013). Eco-charrette meetings can serve to investigate the synergies and cost advantages of various project-specific design strategies and to engage each player in this collaborative effort while at the same time realizing the full potential of the building (Green Step web site, n.d.). A charrette is defined as a dense workshop with the participation of various stakeholders and experts to address a particular design problem (Todd, 2016). Eco-charrette is a tool for adapting the well-known architectural design charrette to the challenges of high-performance buildings to achieve high-level results using the LEED performance evaluation system (Yudelson, 2009).

Thinking and Problem Solving

Various definitions of the word 'thinking' have been made. The word 'thinking' is defined as "an independent and distinctive state of mind, apart from sensations and impressions" (Turkish Language Society, 2019). Thinking is also "the ability to make comparisons, divide, join, and grasp connections and forms" (Turkish Language Society, 2019). Thinking is expressed as a mental process that results in generating ideas (Istanbul İşletme Enstitüsü Istanbul Business Institute, 2020). The main cause of most of the problems and disagreements in the world is not thinking enough (De Bono, 2009). Thinking is related with appreciation, reasoning and distinguishing between false and correct (Başerer and Duman, 2019). The act of thinking can be improved throughout the life (Akkılıç and Koçyiğit, 2019). Thinking and thinking skills are important from this aspect.

The role of thinking on a problem and problem solving skills can be important. Problem building is one of the first steps in creative problem solving and research has shown clear links between problem building ability and creative output (Vernon and Hocking, 2016). Problem finding is an important skill demonstrating that education can support performance using structured thinking technics (Hocking and Vernon, 2017). Modern workforce needs/necessitates competent communicators, good problem solvers and effective employees (Vijayaratnam, 2012). Even if teams share common goals, different ways of thinking can often obstacle the creativity process (Obront, 2018). The best decisions might be taken by changing the way problems are thought and perspectives from which problems are examined (Mind Tools web site, n.d.). Changes in the way of thinking can contribute to problem solving.

The Six Thinking Hats Technic

The STHT, developed by Edward de Bono, is used as a tool for communication and reasoning (IIE, 2020). For example, the white hat can encourage the individual to focus on facts and information, helping them ask questions about what information is available and how relevant information can be obtained (Vernon and Hocking, 2014). Main thoughts symbolized and represented by the six types of hats are given in the Table 1.

Table 1. Main thoughts symbolized by the 6 types of hats.

	Explanation
White hat	Way of objective thinking (IIE, 2020) Information hat (Obront, 2018) Focus on data and analysis of past data (Mind Tools web site, n.d.)
Red hat	Anger, emotional perspective, evocation of emotions (De Bono, 1985) Calling on all participants to express their feelings (De Bono, 2009) Ability to predict the reactions of other people (Mind Tools web site, n.d.)
Black hat	Addressing sad and negative/adverse aspects (De Bono, 1985) Focus on critical thinking (De Bono, 2009) Protection against excessive optimism (Obront, 2018) Highlighting weak points in a plan (Mind Tools web site, n.d.)
Yellow hat	Logical positivity, applicability and utility (De Bono, 1991) Optimism (De Bono, 2009) Optimistic evaluations/assessments (Obront, 2018) Seeing the value in the decision (Mind Tools web site, n.d.)
Green hat	Evocation of vegetation and fertile growth (De Bono, 1985) Crossing borders to achieve the impossible (IIE, 2020) A typical representation of creativity (Obront, 2018)
Blue hat	The coldness of the blue and the evocation of the sky (De Bono, 1985) Discovery and organization of the implementation process of an idea (Obront, 2018) Representation of process control (Mind Tools web site, n.d.)

Studies have been carried out on which situation the usage of which hats can be emphasized more. For example, Göçmen and Coşkun (2019) stated that those who use the green hat idea can put forward more value-added thoughts under time pressure and that educators and students may consider the use of yellow thinking hat framework as helpful in developing and improving their habit of generating ideas. While the yellow hat can allow students to identify causes and suggest explanations, the red hat can allow them to criticize and provide counter arguments (Lin, 2019). Some hats can be used more effectively in some cases.

Advantages of the STHT and Its Applicability to Meetings

The STHT has many usage areas and advantages. Companies (e.g. IBM, Chevron Oil, Du Pont, American Standard, Siemens, NTT) have also used the STHT in various fields (e.g. training programs of companies) and received advantages (De Bono, 1991). Potential advantages of the technique have been given in Table 2.

Table 2. Potential advantages of STHT.

Advantages	Authors
Possibility of avoiding potential pitfalls before taking a decision; allowing emotion and skepticism to become a completely/entirely rational process	Mind tools web site, n.d.
Its being easy to learn and apply	De Bono, 1991
Encouraging cooperation among stakeholders; not punishing disagreement	Ribeiro et al., 2014
Improving students' creativity	Göçmen and Coşkun, 2019
Enhancing meeting productivity and efficiency	De Bono, 2005
Simplicity of the method	De Bono, 1991
Helping groups to work on different thinking styles Ability to protect rights and claim	Lin et al., 2020
Providing opportunity to the parties to reduce/avoid conflict Enabling each party in the meetings to take full advantage of their knowledge and experience	Pinto et al., 2015
Ability to identify opportunities where others only see problems Controlling egos Maximizing efficient collaboration and productive interaction	The De Bono Group web site, n.d.
Having significant impact on students' learning	Lin, 2019

The STHT can made it possible for the team members to communicate more constructively and effectively with each other (De Bono, 1998). The advantages of the technique can support that its usage in meetings can add value.

Research Method

This paper investigates applicability of the STHT to eco-charrette meetings. Following an in-depth literature review, opinions of the four experts (architects and civil engineers) having experience in eco-charette meetings were taken based on semi-structured interview questions. These experts participated at eco-charette meetings with different job descriptions during different periods of their professional lives (e.g. as architects, civil engineers, project managers, site supervisors).

Findings and Discussion

Experts were asked about the colour of the hat they usually wore in the eco-charette meetings they participated. They have provided different answers. One expert stated that when he was at the technical side, he wore green and white hats respectively whereas when he was at the administrative side, he wore blue and black. He further stated that he wore yellow and blue hats in case he has a request. An expert stated that she used the white, black and blue hats more frequently based on the character and area of responsibility. Another expert stated that he usually wears a white hat due to his executive position as he needs to report based on objective facts and numbers. Furthermore, he stated that he mostly uses the red and blue hats when he does business with people at the lower hierarchy levels and when he is asked for evaluation. One of the experts has further expressed that he wears white hats for the analysis of a situation, black hats for taking measures and precautions, blue hat for meetings without a manager. All experts have mainly agreed on the usage of white hats and all experts have expressed that they use other hats in various situations.

Experts were asked about the colour of the hat corresponding to the most frequently encountered thoughts in the eco-charrette meetings. The experts' statements are that meetings tend to start with yellow hat, whereas highly responsible staff tend to wear green and white hats. Furthermore, the experts stated that the red and black hats can be reciprocally observed and that the blue hat can be observed throughout the progress in the process. The experts highlighted that weekly meetings have been stated to be accomplished with broad participation enabling hats of all colours attend to the meeting. Furthermore, they indicated that even if participation of the department heads not related with the topic discussed attend to these weekly meetings can be criticised, their participation can enable all hat types to be covered in these meetings. An expert stated that most of the time white, green, black and blue hats are effective. Contrary to these answers, an expert stated that the yellow hat was frequently applied to the meetings she attended.

Experts were asked about the missing hat colour in the eco-charrette meetings they attended. Majority of the experts indicated that the yellow hat is not frequently applied apart from its application at the beginning of the meetings. An expert mentioned that all hat types are available in the meetings whereas there is a lack of application of black hat compared to others due to the his/her companies' strategic management levels' risk taking attitude. Another expert also supported the lack of black hat application.

Experts were asked about the hat type necessary to be applied in the eco-charrette meetings they participated. They indicated that the white and blue hats need to be applied more. One expert indicated that in her company the top manager gave priority to the application of the green hat, whereas he had to adopt the blue hat. Another expert indicated that as the yellow hat is the least applied hat type, it should be applied more whereas the other expert indicated that the black hat should be used more due to the lack of its application in the meetings.

Experts have indicated the positive and negative consequences which can appear due to the application of the STHT. They indicated difficulty in adopting all 6 hats in the meetings where all stakeholders participate. For example, the demanding party can tend to adopt the yellow hat at the beginning of the work and can adopt the blue hat for efficient planning. Furthermore, this demanding party can tend to adopt the white hat occasionally whereas this party can expect the green hat adoption from the other party. This demanding party might not apply the black hat throughout the project. Teaching the characteristics of a specific hat to a person and expecting that person to act accordingly can cause irrational consequences at the individual level. Another expert stated the risk of prolonged meetings and confusion in case all participants express their opinions. For this reason, the experts indicated that it may not always be suitable for all topics to make STHT meetings frequently. They expressed their opinion that the application of the STHT can cause delay in construction as time and fast decision making are very important at the construction sites. Based on his experience, one expert indicated that the data gathering and analyses can result in decisions to be taken in an unexpected way. He further expressed that it may not always be possible to have analyses results in the meeting where the need for these results may not be recognized. Experts have expressed advantages of the STHT as the ability of the meeting participants to assess the situation from different aspects resulting in endorsement of empathy and enhancement of the value of the meeting outcome shortening the meeting duration. Representation of all hats and their thoughts can be useful in understanding presence/availability of different ideas. Furthermore, it has been expressed that approaching to a topic from the subjective and objective aspects can be a richness. Experts indicated, however, that even if multi voice participation can enhance richness, it can cause difficulty in taking a common decision and it can prolong the decision taking process.

Experts have encouraged and supported the application of the STHT to the eco-charrette meetings. They recommended that potential hats complying with parties' role requirements can be identified and other hats' thinking style and approach can be considered. They indicated that even thinking through changing the roles can be an effective start to adaptation as a participant's hat as a customer can be different than that participant's hat as a designer. They expressed that the STHT can be beneficial to the eco-charrette meetings as it can enable the participants to assess the situation from different angles and to maximise collective intelligence. They further indicated that STHT can enable different thoughts to be expressed and that enabling participants having different opinions to express their views in these meetings, can support their adaptation to the project and strengthen the team spirit. Furthermore, they expressed that as the STHT can enable the topic to be assessed deeply from different angles, various factors (e.g. human and environment related factors) can be assessed in detail in the eco-charrette meetings.

Experts have provided recommendations for wide spreading the usage of the STHT in the construction industry. They recommended case study based training on the usage of these technic to enhance professionals' awareness. One expert indicated that companies can test the performance of these meetings and assess whether or not these meetings should be carried out at regular intervals. Experts recommended these meetings to be held with the participation of a moderator trained in this technic so that these meetings can be achieved more systematically. All experts indicated that STHT can be effective in the design phase of buildings. One expert suggested that STHT can be used for health monitoring of buildings. Another expert emphasised that STHT can enhance assessment of the life cycle aspect of a building in its design phase.

Experts provided their suggestions on the potential application areas of the STHT in construction industry. They indicated that STHT can increase efficiency of the meetings at the project's initial phases. Furthermore, the experts suggested that STHT can be used for determination of customer needs and approach, identification of technically and administratively possible or impossible topics, establishment of mutual understanding among the contracting parties, reduction/minimization/elimination of uncertainties and revisions in the construction phase, accomplishment of the project successfully.

They recommended STHT to be presented to the companies' top level managers as dynamics of each construction project and company can be different. Furthermore, they suggested that decision makers can prefer application of STHT to the meetings. Design and construction phases can be analysed in details. Experts indicated that STHT can be used for occupational health and safety policies in the construction industry. Potential accidents which can be prevented through proactive precautions taken. Furthermore, they indicated STHT can enhance employees' motivation through: consideration and assessment of their motivation and performance relationship; improvement of the work environment's comfort; empowerment of the employees.

Experts were asked about their further comments and opinions. Experts indicated that sharing thoughts representing all hats can be useful as STHT can enable different thoughts to be listened to. They have also stated that some of the participants can hesitate in and avoid expressing their opinions in the meetings. Experts have indicated that STHT can be covered at the undergraduate level so that future professionals can know STHT.

Conclusion

This paper investigated applicability of the STHT to the eco-charrette meetings. Following an in-depth literature review, expert opinions have been gathered with the participation of experts having eco-charrette meeting experience. The findings supported that the STHT's can have potential for enhancing efficiency of eco-charrette meetings and project management processes. The findings further revealed the indication that STHT can be applied to the eco-charrette meetings and enhance value creation for sustainable building design and construction project management. The findings further revealed potential advantages, positive and negative aspects of usage of STHT in the meetings as well as the hat types which are used relatively less in the meetings. Potential advantages of the STHT have been stated as potential of STHT's usage for enhancing motivation, team spirit, efficiency in the meetings and processes. The findings revealed tendency for potential further application areas of the STHT in the construction industry as follows: The STHT can be considered to be used for the meetings at the initial phase of the project to reduce potential variation orders which can arise in the contract execution phase as well as to reduce their potential adverse impacts on duration, cost and quality. Furthermore, this technic can be considered to be used for occupational health and safety performance through its potential contribution to the identification of potential risks for accidents, and near-misses. Additionally, usage of STHT can have potential in enhancing lean performance of the companies and their project management processes. This research can be useful for eco-charrette meeting participants. The findings can be considered for enhancing effectiveness of eco-charrette meetings to enhance value creation for the sustainable building projects.

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Safe Work Method Statement for Construction Activities

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Abstract

The method statements are crucial documents that describe construction jobs and give details of implementation on site for establishment of project management and organization. The best practices reveal that all steps of the construction activities should be described in detail and important information such as man/machine-hour, equipment and tools, material to be used in the activity should be included in method statement. In order to carry out occupational health and safety (OHS) activities at a professional level in a construction project, it is necessary to harmonize method statements with OHS activities. In this study, an approach has been developed to create a safe work method statement (SWMS) in construction projects. Firstly, hazard analysis for common construction activities was described in detail with practical recommendations. Afterwards, Job Safety Analysis (JSA) was carried out for these activities to reveal related occupational risks during a construction project. Finally, the risk control hierarchy was used to control the risks identified for the activities. From case studies, on site observations and literature research a practical and feasible construction safe work method statement model was established. As an output of the study a sample template and checklists were formed to create SWMS's for common construction works in the projects.

Keywords: *construction industry, method statements, occupational health and safety, safe work statement.*

Introduction

Millions of people worldwide die every year because of work accidents and occupational diseases. In addition, millions of workers are injured every year due to occupational accidents and occupational diseases (ILO, 2020). The construction sector is in the top rank among all sectors with its bad score in work accidents. The construction industry is considered one of the most hazardous industries (with mining especially) in almost all countries. Although many legal regulations have been made in the construction industry in recent years, there is no concrete evident upon the prevention of accidents as seen in the statistical figures. Although the construction sector has increased the examples of good practice in the field of occupational health and safety in recent years, it is thought-provoking that there is no significant change in the stated situation (Yilmaz, 2014). This is a valid reason to think that there is a management-oriented problem to prevent accidents. Although many studies have been carried out to eliminate the mentioned method problem, the studies for reducing occupational accidents are still one of the most studied fields in the construction sector (Zhou et al., 2015). To reduce / eliminate occupational accidents in the construction sector, an integrated approach should be developed with the project management mechanisms compatible with the sector's own production style. To put the systematic point of view into practice for a successful OHS management in the construction industry, many instruments are needed during the implementation phase of the projects. These instruments are tools that enable planning, documentation, and communication of the management system's work. Effective use of these tools is very important for project management. However, most of the time, these tools are not used effectively in construction projects. Planning, implementation, and supervision deficiencies cause work accidents (Hallowell et al, 2013). In this study, a practical tool is proposed for the elimination of the mentioned problems. To reduce occupational accidents and to perform high-risk activities safely, the “safe work method statement (SWMS)” has been developed. SWMS will benefit from providing the expected planning and communication in the activities.

Project Management and the Method Statements

The aim of construction industry is to end the project at the expected time, quality, cost, and in a way that workers and the environment are not harmed. Achieving this desired goal in project-based construction works is only possible with an effective project management mechanism. The role of planning activities, which have an important place in project management, is important in achieving the above-mentioned aim of the construction industry. One of the most important topics that should be addressed in the planning phase of a construction project is occupational health and safety practices (Gurcanli et al., 2015). OHS measures should be evaluated in the planning phase of the project. It is necessary to determine the high-risk activities to be carried out in the project and the measures to be taken in these activities should be determined at the planning stage of the project. This activity is a legal and practical necessity in many countries (HSE, 1974; Queensland, 2011). Method statements are an effective tool for project management, and it can be considered as an indication of how an organization organizes its resources and processes.

Method statements are studies conducted to evaluate the risks related to an activity and convey the requirements of the safe working system to the employees (Borys, 2012). Although it is often referred to as a method statement, in some of its uses, safe work method statement (SWMS) is also seen. Essentially, a method statement combines information gathered about various hazards and ways to check them for a particular activity from the results of risk assessments. For this reason, in a construction method, the manpower, material, equipment, etc. needed for the realization of the activities. Parameters (resources) need to be planned effectively (Pearl et al., 1998). Creating a realistic construction method can only be possible by gathering sufficient information about the activity and analyzing this information. The measures to be taken regarding the activity should be determined after this stage. All these activities should be carried out with the participation of the relevant departments in project management.

The Method Statement are often prepared by the contractor who will carry out the activity and submitted for the review of the project management (Queensland, 2011; Borys, 2012; HSE, 2006; HSE, 2011). Project management ensures that all topics of the relevant activity are fully and adequately described. If the project management decides that the described work is not safe, it may request that the required contractor change / improve the method statement. No activity should be initiated by the project management, whose method statement has not been approved and whose compliance with the MS has not been checked.

Developing a Method Statement with JSA

The Method statements provides the opportunity to determine occupational health and safety principles by evaluating the risks related to the activity. As this study will be carried out and published with a team, it also opens the opportunity to provide informational collaboration between employees. The Method Statement is an application that also offers the opportunity to inspect all the ongoing activities on the construction site based on the approved method statements. The processes for creating a safe working method are shown below as a flow chart.

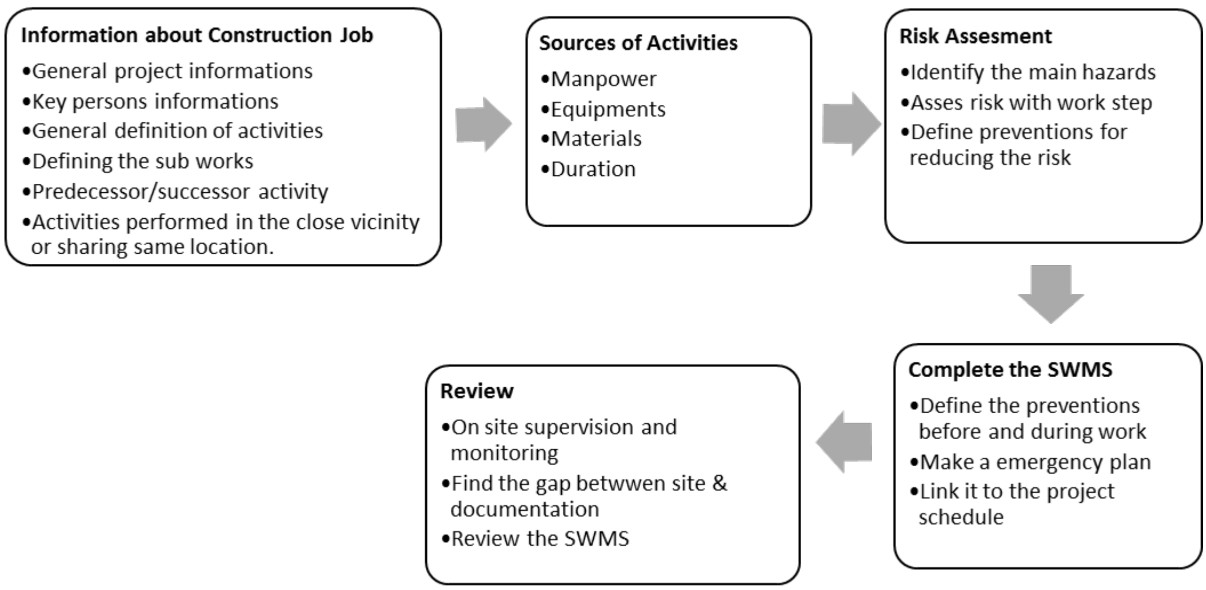

Figure 1: Developing SWMS processes.

As can be seen in Fig. 1, in the first stage, basic information about the project, contractor and activity is obtained. The most important part in this section is to define the activity in general and detailed (reserved for work order). In the second step, information about the “Sources of Activities” should be obtained completely. With this information, the risk assessment of the activity should be carried out in the third step. In the fourth step, the risk control hierarchy was used in reducing the analyzed risks. In this step, the approved method statement must be integrated into the project schedule. The last step is the publication of the declaration of the statement, the start of the activity and the supervision of the activity in the field. As a result of these activities, if necessary, the method statement should be reviewed. Among these steps, the most important issue is the evaluation of the risks and the decision on the control measures. There are many different methods to evaluate risks. It is possible to benefit from those methods that are suitable for the activity to be carried out (ISO, 2019). It is known that each of these methods has its advantages and disadvantages.

In this study, JSA method, which has a similar structure with the method statement, was preferred. JSA is a typical and effective method for assessing risks JSA focuses on identifying risks and control measures by focusing on each of the sub-steps of an activity. This unique aspect of the method allows for detailed analysis of each of the sub-steps already present in the method statement. This provides an opportunity to describe measures to make all details of the activity “safe”.(Holt, 2001; Chao & Henshaw, 2002; Rozenfeld et al., 2010; Collins, 2010; Glenn, 2011; Kjellen & Albrechtsen, 2017, Albrechtsen et al., 2019).

The “hierarchy of control” should be used when deciding on the control measures to be taken at each step of the activity. The first and most important step in this hierarchical approach is to eliminate the activity. The second is to replace the hazard with the less dangerous if the hazard cannot be eliminated. If this is not possible or sufficient, the next step is to isolate the hazard by engineering and administrative measures. In addition, it is recommended to use protective equipment to increase effectiveness in the last step (Uzun et al., 2018) At this point, it should be remembered that some control measures to be taken according to the risk control hierarchy may replace the steps of the activity completely or partially. The process of JSA includes three main stages: (1) Identification – choosing a specific job or activity and breaking it down into a sequence of stages, and then, identifying all possible loss-of-control incident that may occur during the work. (2) Assessment – evaluating the relative level of risk for all the identified incidents. (3) Action – controlling the risk by taking sufficient measures to reduce or eliminate it (Chao & Henshaw, 2002).

As mentioned earlier, in the method statements, the general and detailed descriptions of the activity and the sources of the activity (man/power, materials, and equipment) are defined. In this study, a practical way to identify hazards and assess risks is proposed using this information. In order to identify hazards, a checklist has been created from dangerous activities / situations that often cause accidents in construction (Gurcanli & Mungen, 2013; Mungen, 2011). This checklist is placed in the attached template, which is the concrete output of the study. It is easier to assess the risks once the hazards in each sub-step of the activity are identified. At this step, risk levels should be found (Gopinath & Johansen, 2016). It should be noted that these risk levels/rankings or scores must not be conceived as a arithmetical numbers but they are giving an overview on any activity from the perception of an expert (Gopinath & Johansen, 2016). Hence, there are plenty of methods or approaches (fuzzy, neural networks etc.) on risk assessment (Gurcanli & Müngen, 2009). In order to make this assessment, the evaluation matrix including probability and severity explanations has been added to the relevant template. Explanations about the risk level determined because of the risk assessment of the activity can also be found in Table 1.

As can be seen in Table 1, the necessary measures are divided into two as "before the activity starts" and "during the activity". The main reason for this is to ensure that all collective protection measures are taken before the activity starts. This approach is also important in terms of the intersection of these declarations of methods to be integrated into the work schedule with other activities. Other information that should be included in a method statement is also shown on the template. These are shown in the template where many necessary information about the activity can be easily placed. Some of those; responsible persons, workers, resources, emergency plans, pictures and technical drawings etc.

Table 1. Safe work method statement form.

Project Name:					**Project Ref:**				
Main Contractor					**Sub-Contractor**				
Description of the Task/Activity:									
Description of the Existing Activity									
Site Address/ Location:					**Start Date/Time:**				
					Finish Date/Time:				
Personnel Involved	**Name**				**Role/Trade**			**Quantity**	
Works Supervisor:					**Telephone**				
Role:					**Mail**				
Detailed Activity Definition (Step by step/max 10 sub step):	**Sub Activity Number**	**Sub Activity Definition**							
Key Plant and Tools Required:	**Types of Tools**				**Unit**		**Quantity**		
Key Materials Required:	**Types of Tools**				**Unit**		**Quantity**		
Other Essential Requirements									
Hazardous/Applicable	**Highly Flammable**	**Oxidizer**	**Explosive**	**Toxic/ Very Toxic**	**Corrosive**	**Harmful/ Irritant**	**Longer Term Health Hazard**	**Gas Under Pressure**	**Dangerous to the Environment**

<table>
<tr><td rowspan="14">Hazard Analysis(Follow the activity steps, if the defined hazard exist selected yes)</td><td colspan="3">Hazardous Activity</td><td>Yes</td><td>No</td><td colspan="2">Hazardous Work Environment</td><td>Yes</td><td>No</td></tr>
<tr><td colspan="3">Working at height</td><td></td><td></td><td colspan="2">Dust</td><td></td><td></td></tr>
<tr><td colspan="3">Lifting heavy materials</td><td></td><td></td><td colspan="2">Noise</td><td></td><td></td></tr>
<tr><td colspan="3">Working with electricity</td><td></td><td></td><td colspan="2">Lighting</td><td></td><td></td></tr>
<tr><td colspan="3">Working with heavy equipment</td><td></td><td></td><td colspan="2">Unsuitable weather conditions</td><td></td><td></td></tr>
<tr><td colspan="3">Excavating</td><td></td><td></td><td colspan="2">Harmful gases</td><td></td><td></td></tr>
<tr><td colspan="3">Working with chemicals</td><td></td><td></td><td colspan="2">Unsuitable ergonomic condition</td><td></td><td></td></tr>
<tr><td colspan="3">Working on fragile surfaces</td><td></td><td></td><td colspan="2">Radiation</td><td></td><td></td></tr>
<tr><td colspan="3">Working with hand tools</td><td></td><td></td><td colspan="2">Asbestos</td><td></td><td></td></tr>
<tr><td colspan="3">Driving</td><td></td><td></td><td colspan="2">Inappropriate psychological working environment</td><td></td><td></td></tr>
<tr><td colspan="3">Confined Space Works</td><td></td><td></td><td colspan="2">Rough work environment</td><td></td><td></td></tr>
<tr><td colspan="3">Hot works</td><td></td><td></td><td colspan="2">Other</td><td></td><td></td></tr>
<tr><td colspan="3">Other</td><td></td><td></td><td colspan="2">Other</td><td></td><td></td></tr>
<tr><td colspan="9"></td></tr>
<tr><td rowspan="6">Job Safety Analysis (Risk Assessment Techniques)</td><td>Probability/ Severity</td><td>Disastrous (1)</td><td>Critical (2)</td><td>Frontier (3)</td><td>Minor (4)</td><td rowspan="6">Level of Risks</td><td rowspan="2">High</td><td colspan="2" rowspan="2">The activity must be stopped to reduce risk and if risk reduction is not possible, the risk source should be restricted and the device banned.</td></tr>
<tr><td>Repeated (A)</td><td>High</td><td>High</td><td>High</td><td>Serious</td></tr>
<tr><td>Likely (B)</td><td>High</td><td>High</td><td>Serious</td><td>Medium</td><td rowspan="2">Serious</td><td colspan="2" rowspan="2">The activity must be stopped to reduce risk and prompt action taken to eliminate the risk.</td></tr>
<tr><td>Occasionally (C)</td><td>High</td><td>Serious</td><td>Medium</td><td>Medium</td></tr>
<tr><td>Very little (D)</td><td>Serious</td><td>Medium</td><td>Medium</td><td>Low</td><td>Medium</td><td colspan="2">Efforts to reduce and risk control are essential.</td></tr>
<tr><td>Unlikely (E)</td><td>Medium</td><td>Medium</td><td>Low</td><td>Low</td><td>Low</td><td colspan="2">No additional control is required, protection of the source of risk is mandatory.</td></tr>
<tr><td rowspan="3">Risk Assessment (Follow the activity steps)</td><td>Sub Activity Number</td><td colspan="2">Sub Activity Short Definition</td><td colspan="2">Hazardous Situation/Behavior & Risk Definition</td><td>Exposed Person</td><td>Probability</td><td>Severity</td><td>Risk</td></tr>
<tr><td></td><td colspan="2"></td><td colspan="2"></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="9"><u>Note:</u> Think about the other activities risks which will be affect the examined activity. If it is exist, add the risk and assessment process to the table</td></tr>
</table>

	General Activity Risk Level (Before Prevention)						**High/Medium/Low**
Actions Before To Start	**Refer to Sub Activity Number**	**Definition of Prevention**					**Responsible Person**
Actions During Activity	**Refer to Sub Activity Number**	**Definition of Prevention**					**Responsible Person**
	General Activity Risk Level (After Prevention)						**High/Medium/Low**
PPE/Applicable/When	**Safety Boots**	**Hard Hats**	**Safety Gloves**	**Hearing Protection**	**Respiratory Protection**	**Eye Protection**	**Other**
	Yes	Yes	Yes	Yes	Yes	Yes	
Emergency Procedures							
First Aid Facilities:	**Name of On-Site First Aider:**						
	First Aid Box Location:						
	Location of Nearest Hospital:						
Other Information & Comments:							
Technical Drawings							
Reference Documentation							
Note: All work will be undertaken by qualified competent persons with experience of the type of work described above, and in all cases in full accordance with the company's Health and Safety Policy.							
Created By				**Checked By**			
Date				**Date**			
Signature				**Signature**			
Deliver to	**Main Contractor Project Management Team**						
	Sub-Contractor Management Team						

SWMS in Project Scheduling and Time Management

As previously stated, construction planning and control is important in preventing health and safety risks. Therefore, occupational health and safety risks should be evaluated during the preparation of project schedule in construction projects. It is very common that, many activities are carried out simultaneously in the construction industry. The risks transferred by these simultaneous activities to each other should be evaluated in the construction schedule. Method statements of all high-risk activities in the project should be evaluated in the planning of the activities. To perform this evaluation, SWSM needs to be integrated into the project schedule. This can be solved by describing SWSM in the resource descriptions of the activities in the project schedule. Various evaluations should be made to describe the effects of predecessor-successor (or parallel) relationships of construction works on construction risks as well as communication between different sub/trade contractors. Some of these according to the type of activity are start to start, start to finish, finish to start and finish to finish, etc. As it is known, measures to be taken in most activities (collective protection measures) must be taken before the related activity starts. For example, before working at heights, collective protection measures such as temporary edge protection systems and safety nets should be taken. The resources to be used for the measures described in SWMS and which must be taken before the activity starts should be included in the work schedule. With this approach, the necessary abundances and delays in the project schedule can also be defined from a "safety" perspective.

Apart from collective protection measures, some administrative measures should be reviewed before the activity starts. For example, checking workers' training documents, checking health reports, examining maintenance and inspection reports for work equipment, etc. many studies must be completed before the activity begins. On the other hand, the measures to be taken during the activity should be planned in accordance with the end of the activity. Changes to the construction time schedule may also require SWMS to be changed. For this reason, the relationships between activities and safe method statements should be closely followed and reviewed.

Conclusions

In this study, a "safe method declaration" template was created by using practical methods. This template is for the construction industry and can be adapted for different sectors. The approach proposed in the study will have the following benefits:

- Detailed evaluation of high-risk field activities and determination of measures
- Integrated assessment of project management team
- Preventing problems arising from the work schedule
- A defined tool in contractor OHS management / communication
- If the method statement approach specified in the study is taken for each activity in a project, it will be possible to create a large “method statement library”. Organizations that prefer this method will be able to benefit from this library in their later projects

These benefits provide many opportunities to improve successful health and safety management in a construction project. In order to evaluate these opportunities, construction site should be simulated while the construction project is still in preparation phase and method declarations should be prepared based on this simulation. Method statements can be integrated with some software (MS Project, Primavera, Revit etc.). It is thought that it is possible to provide effective coordination and cooperation in project management with this approach.

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Potential of Biosensors as Indicators of Safe Behavior in Construction Sites

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Abstract

Maintaining the safe behavior of construction workers is one of the major aspects of safety management in the AEC industry. Unsafe behavior in hazardous places like construction sites could lead to severe consequences. Meanwhile, measuring and controlling safe behavior is an ambiguous task. Unsafe behavior can have various reasons. It is a very complex issue that includes many hard-to-measure variables. Yet still, most of the time, understanding and analyzing these reasons are done merely based on the insight of the safety managers and statements of the workers. This paper investigates the potential of psychophysiological information gathered via biosensors to be used in safety management in the AEC industry. Two types of biosensor systems, electroencephalogram sensors (EEG), and electrodermal activity sensors (EDA), are reviewed. Basic information about the sensor systems is provided. The biological mechanisms behind the psychophysiological reactions that the sensors measure are briefly explained. The sensors are examined in terms of usefulness of the information they provide, invasiveness, and affordability. The opportunities they could provide to the academia and the industry, and the challenges they pose are discussed. Suggestions are made for utilization of the potentials and coping with the challenges.

Keywords: *biosensors, construction safety, EDA, EEG, safety management.*

Introduction

Severity of the construction site accidents is very well known. It is a situation that requires urgent intervention. An enormous amount of workplace accidents in the AEC industry is caused directly by human mistake (Abdelhamid & Everett, 2000). Therefore, understanding and controlling the mental and physiological conditions of the construction professionals would make precious contributions to the occupational health and safety efforts.

With the increased availability of the biosensors, their usage gets more and more feasible. Biosensor systems are getting cheaper, less invasive, and more reliable every day. They allow real-time data and wireless acquisition (Goumopoulos & Menti, 2019). Artificial intelligence systems could help filtering and analysis of the data gathered via biosensors (Bhuvaneswari & Kumar, 2015; Gurudath & Bryan Riley, 2014). There are sensor systems that are as small as a single ring which allow measurement of multiple biological responses such as electrodermal activity, heart rate, and skin temperature (Mahmud et al., 2019). Moreover, since controlling psychophysiological responses is rather hard, it is fair to tell that data gathered via biosensors would be less biased.

Background

Basic Information About EEG

Electroencephalogram is a methodology that is used to investigate electrical activity in the brain. It is a non-invasive method in which electrodes are attached to the surface of the upper part of the head. Two typical examples of the EEG sensor systems can be seen in Fig. 1. The electrical activities of the brain measured by these sensors are generally categorized under five bands according to their signal frequencies. These are Delta (0.5-4 Hz), Theta (4-8 Hz), Alpha (8-13 Hz), Beta (13-30 Hz), and Gamma (30-49 Hz) waves (Kumar & Bhuvaneswari, 2012). More detailed categorizations are also possible (Chen et al., 2015). These wavebands can be associated with different mental states. For example, cognitive and memory performance can be associated with alpha and theta frequency bands (Klimesch, 1999).

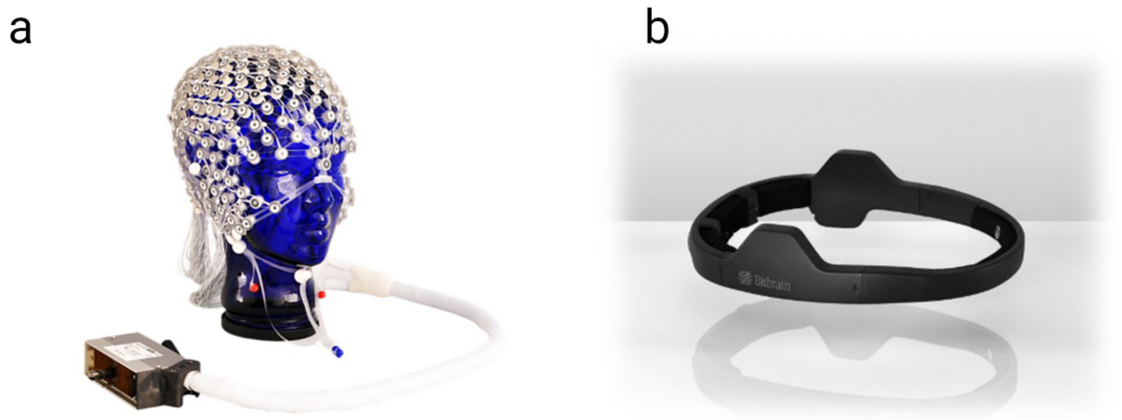

Figure 1: A full scale, clinical level EEG sensor system by PHILIPS on the left (a); a wearable, 8-electrode EEG sensor system by Bitbrain on the right (b).

By examining these wave types, the general state of the brain can be understood to detect any mental illnesses such as schizophrenia (Akar et al., 2015). More importantly for the AEC industry, the temporary state of the brain can also be examined from the electrical activity of the brain. Mental states like low vigilance, drowsiness, mental fatigue can be detected via results from EEG sensors (Gurudath & Bryan Riley, 2014; Wang et al., 2019; Xing et al., 2019).

Another wide-spread usage of EEG is the measurement of event-related potentials (ERP). ERP is the response of the brain that can be directly linked to a specific stimulus (Luck, 2005). This is a widely used technique in neuroscience, cognitive science, and psychology (Buzsaki, 2011). In this technique, a particular event or a stimulus is introduced to the subject while an EEG sensor is measuring the electrical activity in the areas of the brain that is expected to be affected by the stimulus. The exact timing of the stimulus is time-stamped on the measurements of EEG sensors. The time of the stimulus and the signals are compared to detect any correspondence (Luck, 2005). It is also stated that, since there are thousands of neurons in the brain firing simultaneously, it is not easy to isolate the effect of a single stimulus. Usually, repeated instances of the same stimulus are introduced to the subject so that the average of the responses can be calculated, and random brain activity can be separated from the response to the stimulus (Rugg & Coles, 1995).

Basic Information About EDA

Electrodermal activity can be described as the changes in the electrical conductivity of the skin (Boucsein, 2012). Since it is very easy to measure these changes, EDA has a long research history in different branches of science. Therefore, different names for the same phenomena can be encountered in different sources. These names include but are not limited to; galvanic skin response (GSR), skin conductance level (SCL), sympathetic skin response (SSL). However, EDA is the most widely accepted term (Critchley, 2002). The changes in the electrical conductivity of the skin is a result of the activation of eccrine sweat glands. Eccrine sweat glands are activated by the sympathetic nervous system which is directly related to the so-called *fight-or-flight response* (Jansen et al., 1995). Therefore, EDA can be used as an indicator of arousal, situational stress, and emotional response. But it should be noted that it is argued whether EDA can be used to understand the direction of the emotions (positive or negative); therefore, if the direction of the emotion is important it is advised EDA sensor systems to be used together with other indicators such as hearth rate (Turpin & Grandfield, 2007).

EDA is usually measured via sensors placed on the hand of the subject, as it can be seen in Fig. 2, because eccrine sweat glands are the densest in the hands and feet, more specifically palms and soles. Placement of the sensors is very critical because eccrine glands are not only reactive to phycological stimulus but also responsible for thermoregulation (regulation of the body temperature). It is indicated that palmar surfaces of hands as well as the index finger and the middle finger of the non-dominant hand are the most suitable places to attach sensors to measure psychologically-reasoned EDA changes (Turpin & Grandfield, 2007). It should be noted that EDA is affected by many variables such as age, sex, time of the day, stage in the menstrual cycle, time from the last exercise, personality, etc. (Boucsein, 2012). Therefore, it is useful to determine a base conductivity level specific to the subject and the time of the measurement. This base conductivity level, which is generally referred to as electrodermal level (EDL), but also can be seen as skin conductance level, is one of the two main types of electrodermal responses. The other is the electrodermal response (EDR), or sometimes referred to as skin conductance response. While EDL is a base level, EDR is the response to the stimulus (Boucsein, 2012). Because that EDL is a continually changing level, it is one of the main challenges of any information-gathering process via EDA is the determination of the correct EDL and separation of EDL and EDR (Boucsein et al., 2012).

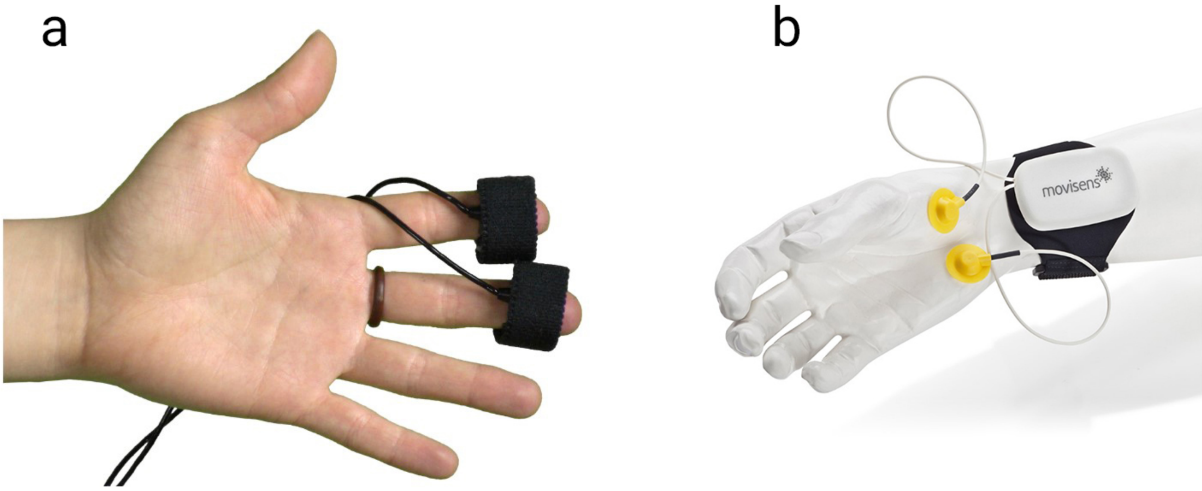

Figure 2: EDA sensor system by Biopac attached to index and middle finger on the left (a), EDA sensor system by Movisens attached to the palm on the right (b).

Discussions

Discussion on Potentials of EEG

As stated earlier, EEG can be used as an indicator of mental workload. As shown in the famous "invisible gorilla" experiment, a high level of mental workload can cause an unintentional blindness towards some objects or events, even if they are absurdly obvious (Chabris & Simons, 2010). This is also applicable to workplace hazards. A high level of mental workload may result in a dangerous blindness towards hazardous situations. However, there is a fundamental problem with the detection of high mental workload. Most of the time, it is a direct requirement for the job to be done. As a result, even if it is detected, it may not be possible to lower the mental workload. Nevertheless, detecting it would still be useful in terms of understanding who is under a higher risk and when. It might also be possible to set thresholds for mental workload and call for intervention when they are passed.

The thing that must be questioned is that if it is worth the resources and effort. Detecting the mental workload of construction professionals in real-time would require a lot of resources. The prices of the EEG sensor systems that are suitable for professional usage usually start around 1000 USD and can be as high as 25000 USD (Farnsworth, 2019). Though, it must be noted that a lower-end system would probably be sufficient for AEC industry applications since higher-end systems are usually used in medical applications. Nevertheless, considering the financial and human resources spared for safety management is already scarce, spending this much resource for EEG sensor systems and their implementation might not be feasible.

A more feasible option might be designing experiments that would test AEC activities in terms of mental workload via EEG sensors. These experiments would reveal which types of activities result in a higher mental workload. This information can be used to understand who and when are more prone to unintentional blindness. That way, more specialized and efficient precautions, and spot-on safety training can be implemented. Considering how inefficient the current safety training is on improving hazard recognition skills (Perlman et al., 2014), the importance of this spot-on safety training can be understood better.

Another possible usage of EEG is the detection of mental fatigue before starting to work. Current pre-work fatigue detection methods are mostly based on expert judgment of the site manager or safety manager. This method is even less reliable for mental fatigue. It can be argued that this very subjective and inefficient method can be replaced with an EEG sensor-based more reliable method (Li et al., 2019). Using the EEG sensors not during but before the work would be easier and more feasible. This way, excessive mental fatigue that is caused by nonwork-related causes can be detected. Quick and straightforward interventions such as progressive muscle relaxation or trigeminal nerve stimulation as it is suggested in a study (Xing et al., 2019) could be implemented to lower to mental fatigue level of the construction professionals when an excessive mental fatigue that could cause safety issues is detected by EEG sensors.

Practicality is one of the major problems with the usage of EEG sensors in the AEC industry. Measuring EEG signals is a very complicated process, and it requires electrodes to be attached to the head very precisely. The number of EEG electrodes is a critical limitation. It can be as high as 30. It is not practical to attach that many electrodes correctly and precisely in real-life conditions. Even if using a lower number of electrodes is possible, as it can be seen in some previous studies (Chen et al., 2015; Jebelli et al., 2018), fewer electrodes means less data and less reliability of the acquired information.

Wearable EEG systems generally have 7-15 electrodes, but it can be as low as 4. This trade-off between the number of electrodes and reliability of the acquired information requires careful allocation. An off-the-shelf device would probably not be ideal for the AEC industry, though adequate solutions are definitely possible. For example, it is possible to integrate an EEG sensor system that measures the mental workload of a worker via brain activity into a safety helmet in a non-invasive way (Chen et al., 2015).

Moreover, excessive movement of the user, popping of the electrodes, environmental noise, or the noise caused by the measuring equipment can cause spikes called “artifacts” in the measured data. While it is possible to filter out these artifacts, it is not an easy task, especially for AEC professionals or AEC researchers. This situation makes the usage of EEG sensor less practical and their adaptation less likely in the future. On the other hand, there are attempts to make this process more manageable in the AEC industry via hybrid kinematic-EEG (Wang et al., 2019). Moreover, considering the pace of the progress in capabilities of artificial intelligence applications in signal processing; it might be fair to expect fully automated and streamlined systems that are capable of reasoning of the data from EEG sensors without much human expertise in the future. There are examples of such efforts in different fields (Bhuvaneswari & Kumar, 2015; Gurudath & Bryan Riley, 2014), which can lead the way for AEC industry applications.

Discussion on Potentials of EDA

It is possible and feasible to process the data from EDA sensors to measure the risk perception of AEC professionals in an unbiased way (Choi et al., 2019). Risk perceptions of AEC professionals is one of the major considerations in safety management, and it has a strong effect on safety behavior in hazardous conditions (Taylor & Snyder, 2017). It is also reported that risk perception of the professionals could be a reliable and accurate indicator of the real risk when individual biases are minimized (Hallowell, 2010). Risk is generally calculated by multiplying the severity of the outcome of the event with the possibility of the occurrence of the event (Wol et al., 2019). However, this is a cumbersome process. Considering unbiased measurement of the risk perception is accurate enough to measure the real risk, and EDA sensors are capable of tracking the risk perception of AEC professionals as stated above, these sensor systems could be used as a practical and reliable method for measuring risk in real-time. Naturally, this claim requires extensive research to be confirmed. There is a potential for initial academic research and a follow-up real-life application.

It is also shown that using an off-the-shelf wearable EDA sensor system that is attached to the wrist is suitable and feasible even during intense construction jobs (Choi et al., 2019). That indicates off-the-shelf EDA sensors are non-invasive enough to be used in a construction site without much intervention. Moreover, they can be water-resistant and dirt repellant. This means that unlike EEG, EDA sensor systems can be used by the AEC industry without extensive R&D that would be needed to make the systems suitable for the unique conditions of the industry. Moreover, EDA sensors are more accessible than most of the other sensor systems. A wearable EDA sensor system usually costs between 100 USD and 1600 USD (Mahmud et al., 2019). Thus, it can be said that the feasibility of adopting the EDA sensor systems for safety management is considerably high.

The possibilities as a result of the difference between EDL and EDR are also worth discussing. A research that tests changes of EDA of the subject during everyday activities shows that a rise in the EDL is an indicator of a continuous stressful situation such as watching a horror movie (Poh et al., 2010). That means detection of long-term high stress-level that is independent of a quick stimulus such as a particular single hazard could be possible with tracking EDL. This information would be valuable for safety management, considering the negative effects of high stress-level on safety behavior. However, a social condition like a conversation could also cause changes in EDL (Boucsein et al., 2012); therefore, some kind of filtration system should be used. A secondary sensor, coupled with the EDA sensor, could be a solution to this problem.

On the other hand, EDRs are caused as a response to specific stimuli. As expected, the experiments indicate that hazardous situations cause EDRs in AEC professionals (Choi et al., 2019). The information on when a hazardous situation is perceived would be very valuable for safety management in the AEC industry where time and location of the hazards are rather hard to guess (Swuste et al., 2012). However, there is also a type of EDR which is called non-specific EDR that is not caused by stimuli but occurs randomly (Boucsein, 2012). This type of EDRs can cause false-positive situations. As also suggested for the problems with EDL, another sensor that would be used in tandem with EDA sensor systems could be a solution to this problem. Considering most of the modern sensor systems already have multiple types of sensors incorporated in them (Jebelli et al., 2019), the feasibility of this solution could be assessed better.

The study mentioned above (Poh et al., 2010) is also interesting in terms of showing the high non-invasiveness of the EDA sensor because none of the participants reported any kind of discomfort during very long term (multiple days) continuous usage. The EDA sensor system used in the study is wrist-worn. Examples of wrist-worn EDA sensors can be seen in Fig. 3.

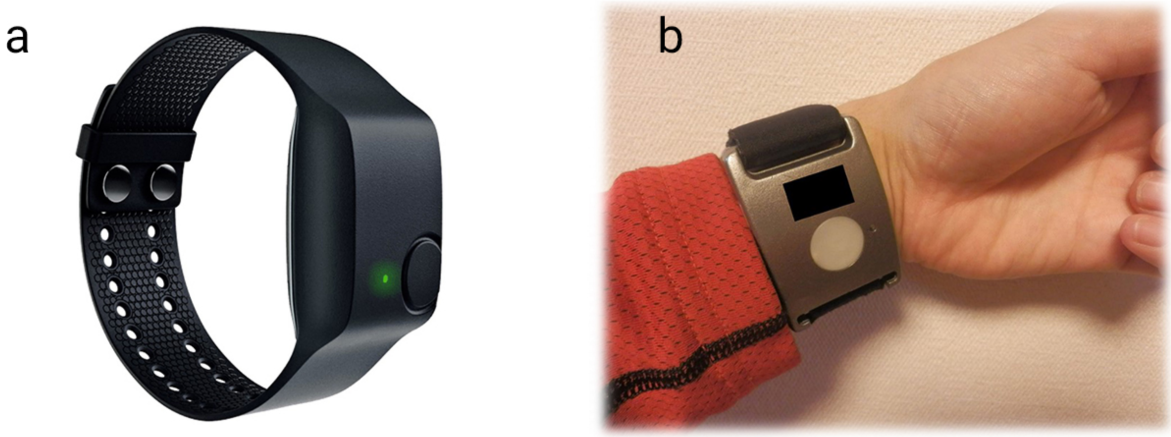

Figure 3: Wrist-worn EDA sensor systems, Empatica E4 on the left (a); Q Sensor by Affectiva on the right (b) (Adapted from: Tamura et al., 2018).

Conclusions

A large number of construction site accidents could be prevented by improving the safe behavior of AEC professionals. Therefore, understanding, monitoring, and controlling safety behavior is a crucial aspect of safety management. Current methods of doing so, such as self-reporting or personal judgments based on past experience, are exceedingly subjective and unreliable. This paper discusses potential uses for two biosensor systems, EEG and EDA, for better assessment of the safety behavior of AEC professionals.

Both EEG and EDA sensors systems may have various utilizations directly on the construction sites. EDA sensors seem more feasible to use on the field because of their relatively low cost, high non-invasiveness, and usefulness of the information they provide. On the other hand, even though they are less suitable to be used directly on the field, EEG sensors would be very valuable if they can be implemented. Unique challenges and requirements of the conditions in the AEC industry disables majority of the off-the-shelf devices and the off-the-shelf techniques and asks for unique approaches. Besides being a challenge, this situation is also a natural call for research and development in the field.

Moreover, usage of biosensors directly on the field is not the only option. Designing experiments that would include data acquisition in physically or digitally simulated construction environments via biosensors is also a possibility for academia. Data acquired this way would be valuable because they might reveal information that is invisible to other types of measurements. Variables which are not easily measured such as level of stress, mental workload, or arousal could be measured via biosensors rather easily. Moreover, biosensors are much less prone to bias than most of the other methods. It is hard and unexpected for subjects to control their biological responses such as galvanic skin response or electrical activity in the brain. Therefore, data acquired via the biosensors are expected to be more reliable.

Considering the pace of the development in the sensor and data processing technologies, it would be reasonable to expect the biosensors to have applications in the AEC industry in the future. Occupational safety is one of the major issues in the AEC industry, and utilization of the biosensors have a considerable potential that should not be overlooked. Research and development in the field might enable precious solutions to construction safety issues.

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Payment Considerations in Turkish Building Construction Contracts vs. FIDIC Contracts

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Abstract

Contract administration is one of the most important pillars of a construction project. Its effect starts at bidding and lasts until the end of the guarantee period. A common mistake made by construction owners is structuring the construction contract in a way that minimizes the owner's risks by relaxing the timing of owner payments, including heavy penalty clauses, requesting bank guarantees with indefinite durations, etc. However, a well-balanced construction contract may protect the work against any unexpected events, avoid potential disputes between the parties, and provide contract clauses that are fair to both parties. In this study, the payment-related clauses of 304 contracts undertaken in the Turkish building construction market are analyzed and compared against standard FIDIC conditions. The timing of the payments is similar to those in FIDIC general conditions, but recommendations are made to structure a more balanced building construction contract relative to retainage, advance payments, and cost escalation clauses, hence creating the groundwork for more successful construction project management in Turkey.

Keywords: *contract administration, delays, FIDIC, payment terms, risks.*

Introduction

The construction industry is one of the most important industries in any economy because the annual value of construction put in place is very large, the industry employs a very large number of workers as it is very labor-intensive, and it affects the activities of many side industries such as materials, manufacturing, chemicals, etc. All private and public investments are directly or indirectly related to the construction industry. The success of construction projects can be assured if a professional project management approach is adopted. Efficient project management covers different aspects of project management including scope, time, cost, risk, quality, procurement, stakeholder, communication, human resources and integration of all participants' work (PMBOK, 2017). An integrated project delivery system is also very important for construction projects (Xie & Liu, 2017). The nature of construction is such that each project is unique because of its unique conditions such as soil conditions, climate, location, material quality, and even the skills of the labor used. This situation makes a construction project more difficult to handle than any project in any other industry. While manufacturing industries are more automated, and the production lines are more stable, the construction industry carries more risks due to its structure where the human effect is very strong. In that sense, it is difficult to standardize the construction industry, especially in terms of developing and applying professional project management standards. Nevertheless, the Project Management Institute (PMI), the Construction Management Association of America (CMAA), the American Institute of Architects (AIA), the International Federation of Consulting Engineers (FIDIC), and many other trade and professional associations developed project management and contract administration standards for the construction industry (Pettit, 2012). While some of these contracts are efficient in design-bid-build types of projects, some of them are more suitable for design-build, Engineering-Procurement-Construction (EPC) or Public-Private-Partnership (PPP) projects. Depending on the project's requirements, but mostly based on the project owner's choices, these standard documents are amended by creating particulars of the general conditions.

Turkey, a G-20-member emerging economy, has been developing in the last few decades mostly based on the construction industry. Many public projects including highways, bridges, tunnels, as well as hospitals have been constructed and many private real estate investments have been completed including residential, commercial, retail, tourism and logistics projects. While some of the public projects used international contracts such as FIDIC, most of the private projects were completed by using the contracts prepared by project owners. These contracts take into consideration the common local applications as well as the local cultural issues. Good construction project management is one of the most important pillars of a successful construction project. Its effect starts at bidding and lasts until the end of the guarantee period. A common mistake made by construction owners is structuring the construction contract in a way that minimizes the owner's risks by relaxing the timing of owner payments, including heavy penalty clauses, requesting bank guarantees with indefinite durations, etc. (Lee et al., 2020). Furthermore, heavily amended clauses of standard contract forms or bespoke contracts cause some problems to contractors, especially in tight-scheduled projects (Youssef et. al, 2018). However, a well-balanced construction contract may protect the work against any unexpected events, avoid potential disputes between the parties, and provide contract clauses that are fair to both parties (Abotaleb & El-adaway, 2017).

In this study, the payment-related clauses of 304 bespoke contracts undertaken in the Turkish building construction industry are analyzed and compared against similar clauses in the standard FIDIC conditions. Recommendations are made to structure a more balanced contract that could lead to a more successful management of a building construction project in Turkey.

Literature Review

Construction project management covers all phases of a project from inception and feasibility to operation and demolition. The contract draft is included in the bid documents, and the contractors provide their proposals under the contract conditions such as the scope of works, the type of the contract, the payment terms, the duration of the project, the bonding requirements, the dispute resolution methods, the applicable laws, etc. The literature about contract administration has focused on different aspects such as conflicts, claims, and disputes. Fawzy and El-adaway (2012) investigated the FIDIC books and World Bank contracts and developed a guideline for contract administration to better manage World Bank-funded projects. Hamie and Abdul-Malak (2018) analyzed three American-based, two British-based, and one international contracts (AIA, FIDIC, Joint Contracts Tribunal (JCT), Engineers Joint Contract Documents Committee (EJCDC), New Engineering Contract (NEC3), and Consensus Docs) relative to the language used to prioritize the contract documents, and to minimize the disagreements that may result in legal disputes. El-adaway et al. (2016) and El-adaway et al. (2020) underlined the importance of the wording of delay and time extension clauses in construction contracts and developed guidelines by evaluating different international contracts including AIA, Consensus-Docs, EJCDC, JCT, NEC, and FIDIC contracts. Another comparative study conducted by Abotaleb and El-adaway (2017) compared international contracts from the payment perspective and developed a checklist for payment conditions. The change order process of a construction contract is also an important study area where Syal and Bora (2016) compared different standard contracts by focusing on the change order process, direct costs, overhead costs, overhead and profit practices and percentages.

Although there are many research studies about different aspects of contract administration in Turkey, the studies that focus on the comparison of standard and bespoke contracts in the private sector are limited. Cakmak (2014) evaluated the Turkish Public Procurement Authority (KIK) standard contract documents and proposed a new model for the reconstruction of KIK standard contract documents. Yayla (2009) compared the FIDIC, AIA and KIK standard forms of contract and concluded that the KIK contract clauses about change orders are inadequate compared to corresponding FIDIC and AIA contract clauses. Cakmak and Tas (2010) analyzed the problems of standard contracts by comparing AIA and KIK contract conditions and concluded that lack of supplementary conditions, inadequate change order procedures, and weak mechanism of dispute resolution are the main problems of KIK contracts.

No comparison exists of bespoke contracts used by private building construction owners and standard contract conditions. This study aims to fill this gap. For the first time, this study compares bespoke contracts used by private building construction owners in Turkey against standard FIDIC contracts by analyzing 304 signed and implemented bespoke contracts in the Turkish building construction industry.

Data and Methodology

In this study, 304 bespoke building construction contracts signed in 18 different projects in Turkey were analyzed relative to payment terms. The distribution of the contracts by type of project indicates that most projects (65%) involved mixed-use buildings, with residential buildings in second place (22%), and the rest (13%) consisting of others (commercial, educational, healthcare, and industrial).

Of the 304 contracts analyzed, 8 were main contracts signed between an owner and a general contractor, whereas 193 were subcontracts and 103 procurement contracts. CM-for-fee (Agency CM) was the project delivery system used in the majority (72%) of the 304 contracts analyzed. It was also noted that 168 of 193 subcontracts (87%) and 67 of 103 procurement contracts (65%) were directly signed by the owner, a strong sign of the owner's interference in these contracts. Particularly procurement contracts exhibited high owner involvement in material and equipment purchases.

In Turkey, one of the main problems of the building construction industry is an incomplete design that prevents bidders to make an offer that may match the owner's budget, because the owner's requirements are not set precisely enough at the beginning of the project. It is for this reason that although owners prefer to sign lump-sum contracts, they are forced to award unit price contracts to allow for increases or decreases in the quantities that can be caused by design changes. By getting a commitment from the contractor in the form of stable unit prices for the entire duration of the project, they dump the risk of unit price volatility on the contractor. This situation was indeed reflected in the contracts analyzed. It was observed that 95% of the contracts investigated were fixed unit price agreements and only 4% of the contracts were lump-sum agreements because of an incomplete design caused by uncertainty in owner specifications.

Analysis, Results and Discussion

This study aims to analyze 304 building construction contracts relative to terms of payment and compare these bespoke contracts against the corresponding conditions in the standard FIDIC Red Book. Before making this comparison, it is important to present the general outlines of the standard FIDIC Red Book.

The FIDIC Red Book is one of the most commonly used international contract standards and also has a subcontract edition, both of which are used in this study. With the latest edition published in 2017, FIDIC Red Book contracts are built on 21 clauses as shown in Table 1.

Table 1. FIDIC Red Book Second Edition 2017.

Number	Clause	Number	Clause
1	General provisions	12	Measurement and evaluation
2	The employer	13	Variations and adjustments
3	The engineer	14	Contract price and payments
4	The contractor	15	Termination by Owner
5	Subcontracting	16	Suspension and termination by contractor
6	Staff and labor	17	Care of the works and indemnities
7	Plant, material and workmanship	18	Exceptional events
8	Commencement, delays and suspension	19	Insurance
9	Tests on completion	20	Owner's and contractor's claims
10	Owner's taking over	21	Disputes and arbitration
11	Defects after taking over		

The contract agreement, the letter of acceptance, the letter of tender, the general conditions, the supplementary conditions, the specifications and drawings, and the dispute avoidance and adjudication board agreement are the main components of a typical FIDIC Red Book (FIDIC Red Book, 2017). While FIDIC sets the main standard rules of the contract, it also enables the parties to negotiate the general conditions and amend them by creating supplementary conditions.

The bespoke contracts used in the Turkish building construction industry and the FIDIC Red Book are compared relative to terms of payment relative to (1) timing of payments, delayed payments, owner's financial status; (2) amount of retainage, amount and repayment terms of retainage; (3) advance payment amount, advance payment guarantee; and (4) cost escalation.

Timing of Payments, Delayed Payments, Owner's Financial Status

In the FIDIC Red Book, the timing of payments is set as 56 days (if not set otherwise) after the Engineer receives the Statement and Supporting Documents. This duration is 70 days in subcontractor agreements. (FIDIC Red Book, 2017; FIDIC Red Book Subcontract Form, 2017). On the other hand, according to the information in Table 2, 79% of the contracts analyzed allow for payments to be made in up to 56 days after the request is submitted to the owner which means that the timing of the payments in the bespoke contracts used in Turkey mostly agrees with FIDIC Red Book.

Table 2. The timing of the payments in bespoke contracts.

Payment Terms	Number of Contracts	Percentage
< 14 days	3	0.99
14-28 days	24	7.89
28-56 days	212	69.74
> 56 days	58	19.08
Not specified	7	2.30
Total	304	100%

Late payment is considered as the main reason for project delay (Kazaz et al, 2012, Culfik et al., 2014). The critical question in this matter is whether the owners stick to the contract conditions and make the payments on time or not. Another question is, does the contractor have any recourse to a legal remedy in case there is a delayed payment. The position of the FIDIC Red Book is very clear:

"14.8 – Delayed Payment: If the Contractor does not receive payment under Sub-Clause 14.7 [Payment], the Contractor shall be entitled to receive financing charges compounded monthly on the amount unpaid during the period of delay."

Unlike the alignment of the timing of the payments with FIDIC Red Book, none of the contracts considered in this study gave any legal rights that entitle the contractor to receive compensation for the losses caused by delayed payments. That is why the owners feel comfortable in these contracts even though late payment jeopardizes the success of the project.

Section 2.4 Employer's Financial Arrangements clause in FIDIC Red Book states that "The owner's arrangements for financing the owner's obligations under the contract shall be stated in detail in the contract documents." Even though in most FIDIC contracts this clause is open to negotiation by project owners, this is a very critical clause that provides contractors with proof of solid financing arrangements, relieving contractors from suffering the consequences of late payment on the part of the owner. This clause gives the contractor the right of termination in case proof of solid financing is not provided by the owner when requested by the contractor. Unfortunately, none of the contracts investigated in this study had such a clause.

Retainage and Release of Retainage

FIDIC does not specifically offer a percentage for the money retained from each monthly progress payment, but the re-payment of the retainage is clearly defined in clause 14.9 of FIDIC Red Book as releasing the first half after the owner issues the "taking over certificate" (substantial completion certificate) and the second half after the expiry date of the defect notification period. Substantial completion refers to the completion of the essential parts of the building that allows the use of the building by the owner for its original purpose even though there may be some inconsequential deviations from the contract that need to be completed or corrected (the punch list items). Final completion refers to the completion and correction of all items specified in the punch list issued by the owner after substantial completion. Final completion denotes the time when all contract requirements (including punch list items) are satisfactorily completed by the contractor, allowing the owner to take over the constructed facility, make the final payment, and return the retainage. Final completion marks the end of the contract. More than half of the contracts investigated in this study required retainage between 3% and 5% of the interim payments. In 111 (37%) of the 304 contracts considered in this study no retainage was withheld. In 85 (83%) of the 103 procurement contracts, no retainage was withheld either. Table 3 shows the retention rates. Almost 90% of the retained money was released by the owner either at substantial completion or at the latest 90 days after substantial completion. The retained money was returned to the contractor at final completion in only 10% of the contracts. It is noteworthy that in 79% of the contracts, retainage was withheld as cash, and in the remaining 21% of the contracts as debentures.

Table 3. Retainage rates in bespoke contracts.

Retainage Rates (percent of interim payment)	Number of Contracts	Percentage
< 3%	11	3.62
3%-5%	175	57.57
5%-10%	6	1.97
> 10%	1	0.33
Not Requested	111	36.51
Total	304	100%

Advance Payment and Advance Payment Guarantee

FIDIC Red Book recommends advance payment under clause 14.2 and leaves the parties to decide about how much the advance payment should be. In one third of the contracts considered in this study no advance payment was made. On the other hand, more than half of the contracts offered to make an advance payment of 20% or less of the contract value. Although the specialty contracts in Turkey are small and most specialty contractors face financial problems, 94% of the advance payments were made against an advance payment guarantee. The major problem of advance payment guarantees seems to be the expiration period of this financial instrument. FIDIC Red Book states:

"14.2.1. Advance Payment Guarantee: The Contractor shall ensure that the Advance Payment Guarantee is valid and enforceable until the advance payment has been repaid, but its amount may be progressively reduced by the amount repaid by the Contractor as stated in the Payment Certificates."

Unfortunately, 63% of the contracts which included an advance payment clause either did not mention an expiration date or mentioned an open-ended period. Another problem observed was about the repayment of the advance payment and the risk reduction of the advance payment guarantees. On this issue, while some of the contracts followed the same approach as in the FIDIC Red Book clause 14.2.1 stated above, some owners increased the monthly repayment installments to get the totality of the advance payment back before the project completion date, yet they did not reduce the amount guaranteed in the Advance Payment Guarantee by an amount proportional to the amount repaid by the contractor. This situation created a cash flow problem for the contractors because of unjustified fees paid to the bank. Indeed, the contractor pays a fee for the risk created by the totality of the guarantee even though the risks to the bank are declining as the contractor pays back portions of the advance payment to the owner.

Cost Escalation

Cost overruns have always been the subject of disagreements and disputes among project parties. Including provisions in the contract that define the rights and responsibilities of the parties in cost-related issues may reduce the number of disputes and enhance the overall performance of the project. Although Section 13.7 of FIDIC Red Book includes directions for handling changes in cost and duration in different clauses, 99% of the contracts investigated in this study did not have any cost escalation clauses. This situation resulted in losses for contractors because cost-related problems are resolved by owners. In Turkey, to transfer their financial risks, project owners tend to sign either fixed unit price or lump-sum contracts, which do not grant any cost escalation to the contractors even though the economic conditions and the project scope are not as ideal as project owners assume. Double-digit inflation, the devaluation of the Turkish currency against the U.S. Dollar and the Euro, only a partially completed design, and an ill-defined scope encourage contractors to submit frequent claims in order to recover the related losses incurred during the execution phase. In such circumstances, a project owner should formulate a contract that ensures that the risks of the project are distributed fairly between the parties and that incentivizes contractors to successfully complete the works rather than struggling with administrative and financial problems. The contract provisions should consider the joint impacts of payment-related issues because time and cost are interconnected.

Conclusions

Contract administration has always been one of the most important parts of project management. For this reason, many national and international institutions have issued general conditions for different types of projects. These books are regularly updated in response to the changes that take place in the building construction industry. The Turkish building construction industry is one of the drivers of economic growth. Many building projects were completed by contractors for private owners in the last decades. Turkish contractors are very familiar with international standards because many of them routinely undertake projects overseas. However, bespoke contracts are commonly used in local building projects by many private owners. This study investigated payment-related issues in 304 such contracts undertaken in Turkey and compared the findings with the relevant clauses in FIDIC Red Book, one of the most commonly used international standards.

The results of the study revealed that project owners wrote reasonable payment terms in the contracts but did not allow for any legal contractor rights in case of late payment or non-payment by the owner. Additionally, these bespoke contracts did not include any provisions regulating the presentation of the owner's financial status as is specified FIDIC Red Book. Also, no cost escalation was allowed under any circumstances in most bespoke contracts.

A good contract is prepared to be fair to both parties to ensure project success and avoid disputes. The findings of this study reveal that the Turkish building construction industry needs better contract administration standards for professional construction management. While the adaptation of international standards to Turkish local requirements may be a solution, a new set of standards that consider not only internationally recognized common practices, but also local cultural, social, and economic conditions may work well for the Turkish construction industry.

The following recommendations are made for Turkish contracts considering the observations made in this study.

- Contractors prefer to do business with project owners who have sufficient funds to finance the project and who make the interim payments on time. A new set of standards designed for Turkish practice could mitigate such concerns if they resemble the FIDIC standards.
- The funds retained by the owner from the interim payments constitute an important security fund for the owner as it allows the owner to take action at the contractor's expense if the contractor misbehaves. On the other hand, retainage is an important issue for contractors as it creates cash flow problems during construction, which sometimes forces the contractor to borrow money and pay interest. The timing of the return of the accumulated retainage funds to the contractor is critical for the simple reason that a late release of retainage costs the contractor more interest. A new set of standards could regulate the rate of retainage and the timing of its release in the light of project size and complexity.
- Advance payment is critical for contractors at the start of a project for mobilization as well as negotiating prices and making deposits with vendors, especially in fixed-price contracts. In Turkish practice, a project owner makes an advance payment only after getting a guarantee from the contractor that the advance payment will be fully paid back, just like a loan. This guarantee is an instrument that the contractor obtains from a financial institution for a fee based on the size of the advance payment. The owner tends to keep this financial instrument until the end of the project. However, If the risk reduction commensurate with the monthly re-paid amounts is considered in a new set of standards, the contractor's interest costs can be reduced, and their cash flow can be enhanced.
- Not being allowed to charge for cost escalation in any circumstance is a major problem for Turkish building contractors. The absence of cost escalation clauses in Turkish contracts is problematic and may cause disagreements and disputes. It would be a good idea to include a clause in the contract that clearly specifies whether the contractor can charge for cost escalation or not, particularly in the volatile economic conditions of Turkey.

In addition to the contract standards mentioned above, some additional standards may also be developed for a healthier building construction industry in Turkey. These standards may start by defining the minimum requirements for companies considered for performing contracting activities depending on the size, type, and complexity of the projects. Clearly specifying these requirements before bidding may help contractors with their bid/no-bid decision and may assist the owners with the selection of the winning contractor.

Although project owners often engage the services of construction management firms, they continue to frequently interfere in project decisions. This situation creates an authority problem and impedes the efficiency of the CM firms. The next step may be to initiate a shift in the project owner's habits from high interference in each phase of the project to a more professional project management approach.

This study covered the payment-related clauses of 304 Turkish bespoke building construction contracts. Future research may focus on a wider scope and may include other commercial and legal aspects of the contracts such as time considerations, dispute resolution methods, insurance requirements, guarantees, and penalties. Such research may provide a deeper understanding of Turkish building contracts and may result in additional recommendations for practitioners.

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Quality Concept in the Construction Sector

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Abstract

Although most of the quality studies in the construction sector are related to the cost part of the job, there is no clear definition of the concept of quality. In order to identify problems related to quality, it is necessary to understand the perspective of quality and what is quality means by companies. Based on this, some definitions and acceptances must be made in order to increase the quality. A Survey which includes 11 questions was conducted with 30 companies to determine the quality understanding of the construction companies. The surveyed companies are all private and they are from the large-scale residential and commercial sectors. This study was carried out with company managers and company officials (engineers, architects). It was also aimed to determine the reasons for poor quality, solution suggestions for poor quality situations, what is the most important stage in reaching quality, what is the quality management. With the findings and results obtained from this study, can be explained that understanding the importance of quality studies and eliminating the quality problems that may arise between organizations is only possible if each organization fulfills its duties fully.

Keywords: *construction industry, quality assurance, quality standards, total quality management.*

Introduction

Although many studies on quality understanding are in the construction industry have been related to the cost part of the structure, this research and the studies behind this research focuses on the total quality understanding in the construction industry. This research aims to develop the perspective of quality concepts and analyze the difference and similarities on the desired quality. Despite the importance of the quality issue, when there is a literature study about the collection, analysis of the quality data, and its definition in the construction sector, there are different approaches to the concept of quality. Therefore, the concept of quality often appears to be related to more than one concept under the name of total quality management. That's why the first issue to be discussed is why there is no definite approach and definition of quality in order to identify the problems related to the construction sector and what are the quality perspectives of the sector stakeholders.

Quality-related applications were started in the world construction sector since the 1970s and still continue today. However, it wasn't handled literally until the 1990s in Turkey because of, product characteristics, production process, workforce and organization differences and some cultural differences were prevented clarity in quality (Güner & Giritli, 2011).

In this paper, some definitions have been made about what quality means by companies, reasons for poor quality in the sector and what can be done to increase quality. In addition, a survey was conducted on these issues and analyzes obtained were tried to be explained with the help of tables.

The main concern of the managers of the companies that have been in the leading position for the last 50 years is about the meaning of quality and the effective and efficient use of quality control systems. Since the globalization of the economy and the rapid development of building and management technology, international competition has increased and the quality of both products and services has become one of the significant factors. This is the reason why modern quality systems develop, implement and spread systematically, comfortably and quickly (Zantanidis, 1998).

Some Definitions of Quality

Kanıt (2005) stated that the quality concept varies over time with increasing demands and expectations. Accordingly, customers will have an idea of "quality" or "poor quality" in terms of meeting their demands from the product or service (Çağlar & Kılıç, 2019). Briefly, quality studies are mostly about measuring service quality and varies from person to person.

According to Arditi and Günaydın (1997), quality can be defined as meeting the legal, aesthetic and functional requirements of a project. Requirements may be simple or complex, or they may be stated in terms of the end result required or as a detailed description of what is to be done.

Quality is simply the sum of effective feedback activities (Ekinci, 2008). Total Quality Management is a philosophy that aims to improve, the quality of management, the quality of the organization, the quality of the staff of the employees, the quality of the work and the products and services (Öztürk, 2009). Build quality is the achievement of clearly defined demands for people, processes and resulting products at the desired level of perfection (Yükçü, 1999).

In addition, it has been stated in some studies that quality should not be considered independent of customer perception. Perceived quality is named that satisfaction level felt by the customer for the quality of the building. It is a relative concept and this is because people's feelings of value differ from each other (Evans & Lindsay, 1991; Şeker, 2000).

The other two dimensions of the concept of quality in the construction industry are design quality and quality of conformity. The design quality is that customer expectations are included in the building design. Secondly; the quality of conformity is that the building meets customer expectations after construction (Gözlü, 1990).

Quality in the construction industry in line with the quality definition of Kaoru Ishikawa, it can be defined as "the most economical, most useful, designing the building and producing it, also giving after-sales services for satisfying to customers" (Ishikawa, 1991).

Besides these, one of the quality insights belongs to Garvin. Garvin has determined eight components of quality which are performance, features, reliability, suitability, durability, serviceability, aesthetics and perceived quality (Garvin, 1987).

In addition, customers should differentiate between 'quality in fact' and 'quality in perception'. A service or product that meets the customer's expectations achieves quality in perception (Arditi & Günaydın, 1993).

When the building, which is a product in the construction sector, is analyzed in terms of these quality definitions, the meaning of the concept of the quality building is revealed.

General Characteristics of the Construction Industry in Terms of Quality

The construction industry is the service and production sector. As a requirement of the sector, every stage of construction production is tried to be determined for the customer satisfaction. Products of the building construction industry, shows great variety in size, appearance, residential area, material and production technique. Another important feature of the construction industry is that the product is stable but the manufacturers are mobile. Each product is unique and because of the products are mostly made by the custom-made methods and are not easily replaceable products. The properties of the construction to be done are specified from the beginning by the customer. The products of the construction industry are generally very long-lasting. Investments and usage time are spread over a very long time.

It is possible to estimate how long the demands will be and how much sales can be made before the final production of the product will begin. Responsibility is distributed to a wide audience (customer, contractor, architect, engineer, material suppliers, financial providers, transporters, etc.). In addition, the sector requires that people in many different branches of business work together (Koontz, 1998).

The works of the construction industry are generally carried out in the open area due to their characteristics. Therefore, it is very quickly affected by environmental factors (temperature, daylight, rain amount, groundwater level, humidity, snow and wind). Bad weather can make construction work difficult in all seasons. Failure to do things regularly in all seasons may cause disruption of management functions.

It is very difficult to create an effective management system for the construction industry due to the characteristics mentioned above. The highly fragmented and scattered structure of the sector creates a variable and uncertain demand-supply relationship, which creates high risks. In addition, the construction industry has very important safety and health problems. Therefore, the concept of quality in the structure depends on many components. The reflection of the quality in the structure can be achieved with the efficient and effective work of all stakeholders. The important thing here is that the said enterprise accepts these issues as an indispensable principle as a business policy (Yıldıztekin, 2005).

Quality Assurance in the Construction Sector

Today, companies operating in both local and international markets must have internationally accepted quality assurance systems in order to continue their achievement. Also, it is important to standardize to produce the desired quality product. Being able to produce products with the desired properties is of course directly related to the precise determination of conditions and rules. However, standardization is a start for quality and its main purpose is to guarantee quality. Providing quality assurance in the construction industry is an indispensable condition for the industry. Now expressions such as quality control, quality assurance and quality management have taken their place in the construction terminology and these systems have started to be implemented in Turkey.

The development of the quality assurance system is in parallel with the manufacturing industry. There are some basic differences when development procedures are compared with production procedures, but these are mainly due to the different features of the construction process and other operational activities. The differences between products and production processes, the long construction production process, the prevalence of subcontracting use, the difficulty of evaluating those, are critical features that make it difficult for people in the project stage to implement quality assurance practices from a single source.

As in production systems, the basic elements of the quality assurance system in the construction industry are quality guides, quality plans, quality system operations, operating instructions and quality system documents (Zantanidis, 1998).

When quality assurance systems are applied effectively, it gives companies a significant advantage over their competitors. To achieve this goal, managers and quality assurance experts should objectively demonstrate their company's strengths and weaknesses and establish a quality assurance system that will address these shortcomings (Akın, 2002).

Poor Quality Problems and Reasons in the Construction Sector

It should be determined whether the quality assurance systems and TQM systems, which have given successful results in obtaining quality in the production sector, will be the solution to the poor quality problems in the construction sector. So, the poor quality problems in the sector should be identified. For this purpose, first of all, it is beneficial to determine the characteristic features of the sector that significantly affect the quality in the construction industry (Erdiş, 2001).

These are as follows:

- Production is project-based.
- Each project is unique with its design, construction and environmental conditions.
- Construction products are less resistant to external factors (economic, weather, etc.).
- The sector is divided into parts (such as architects, contractors and subcontractors)
- Project teams consist of groups with common goals and long-term projects may cause team employees to change from time to time.
- The standards used during production are excessive.
- Redoing a job is very expensive.

- The application of statistical quality measurement program (statistical process control) is very difficult (Erdiş & Laptalı, 2001).

Also Mokhtariani et al. (2017) predicated some characteristics of the sector as follows:
- Highly fragmented and multi-disciplinary
- Dynamic and cyclical industry
- The complexity of the environment and clients
- Project-based business
- Immobility and on-site production
- Bulk and expensive
- The difficulty of product differentiation
- Variability of quality

The aforementioned features of the sector make it difficult to implement systematic quality management practices in the construction sector in construction projects (Akkum, 1997).

Methodology and Analysis of Research Results

A survey study was organized to determine the quality understanding of Turkish construction companies, production and quality problems, implementation of quality control systems and problems arising from management. In the survey, construction companies were asked to answer the following questions.
- what they understand from the quality,
- what kind of quality standard they have,
- what is the most important stage in reaching quality,
- what quality policies are,
- solution suggestions for poor quality and poor quality in practice,
- reasons for poor quality,
- how the management and leadership system implemented

The survey consists of 11 questions in total and 7 of them are shown in the study. The survey was carried out by hand delivery or mail. The surveyed companies are all private companies and are from the large-scale residential and commercial sectors. This survey was conducted with the company managers or company officials (engineers, architects) of 30 companies that are sufficient and effective in terms of the construction industry. These companies still continue their activities.

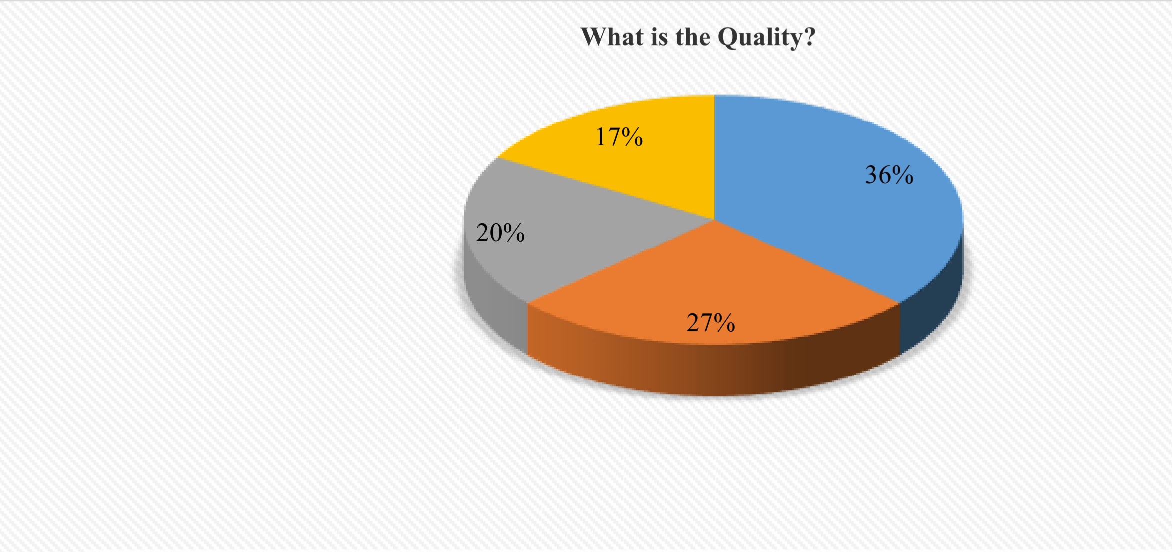

Figure 1: "What is the quality" according to companies.

Companies' answers to the question "What is quality" have been satisfactory. The aim has been to provide customer satisfaction and quality products. According to them, quality is based on producing quality products by prioritizing customer satisfaction. This approach is acceptable in this customer focused sector.

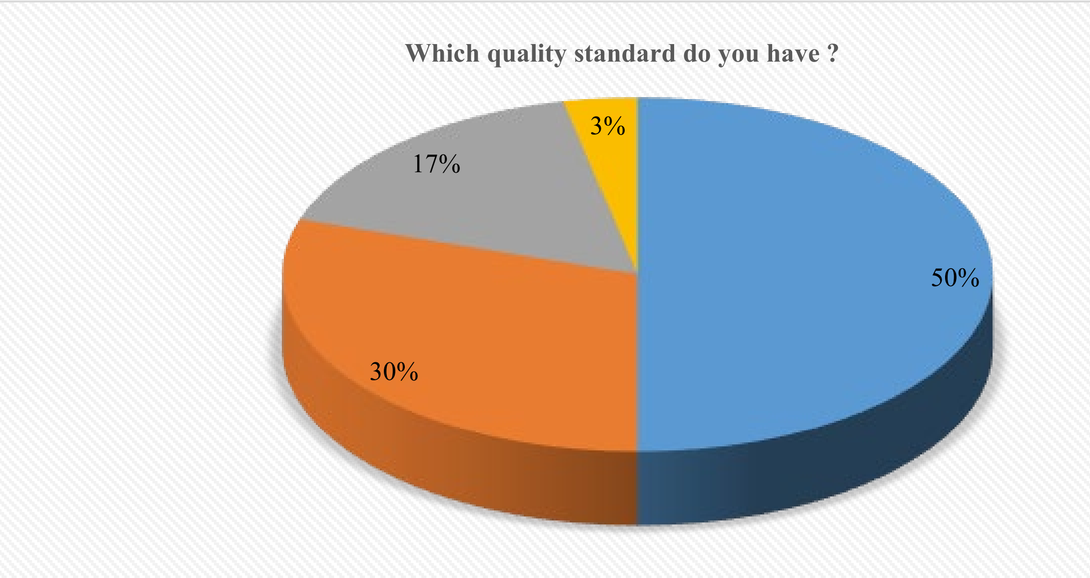

Figure 2: Quality standard certificates of companies.

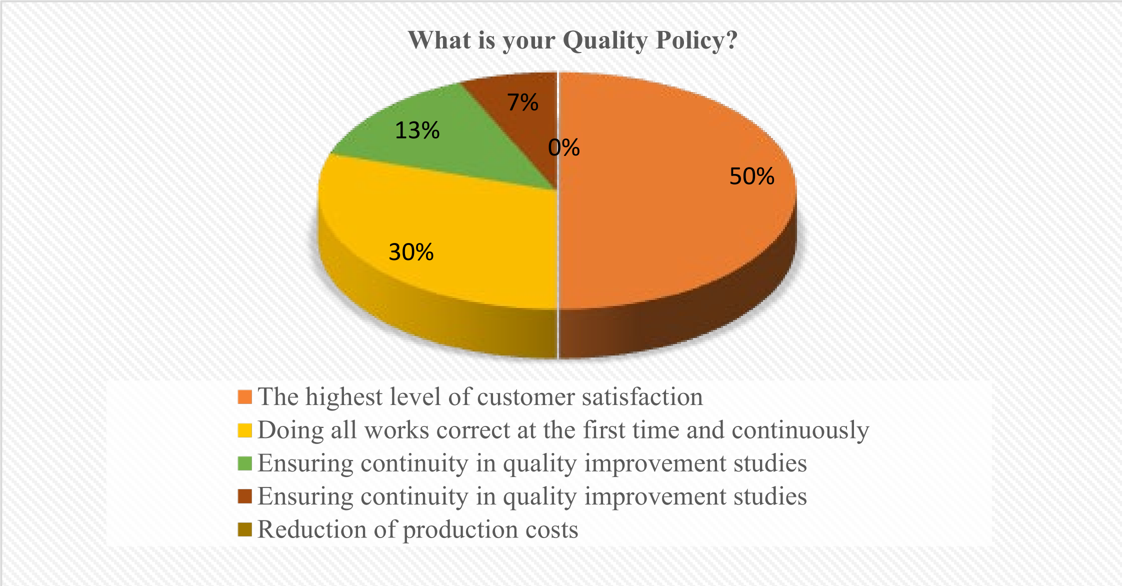

Figure 3: An overview of quality policy.

The first 3 figure includes a simple percentage method, for example, Fig. 3 shows that; 15 of 30 companies answered this question as "The highest level of customer satisfaction" so it is calculated as %50. Besides this, the percentage values of the graphics below, shows the importance level, depending on the number of options in the questionnaires.

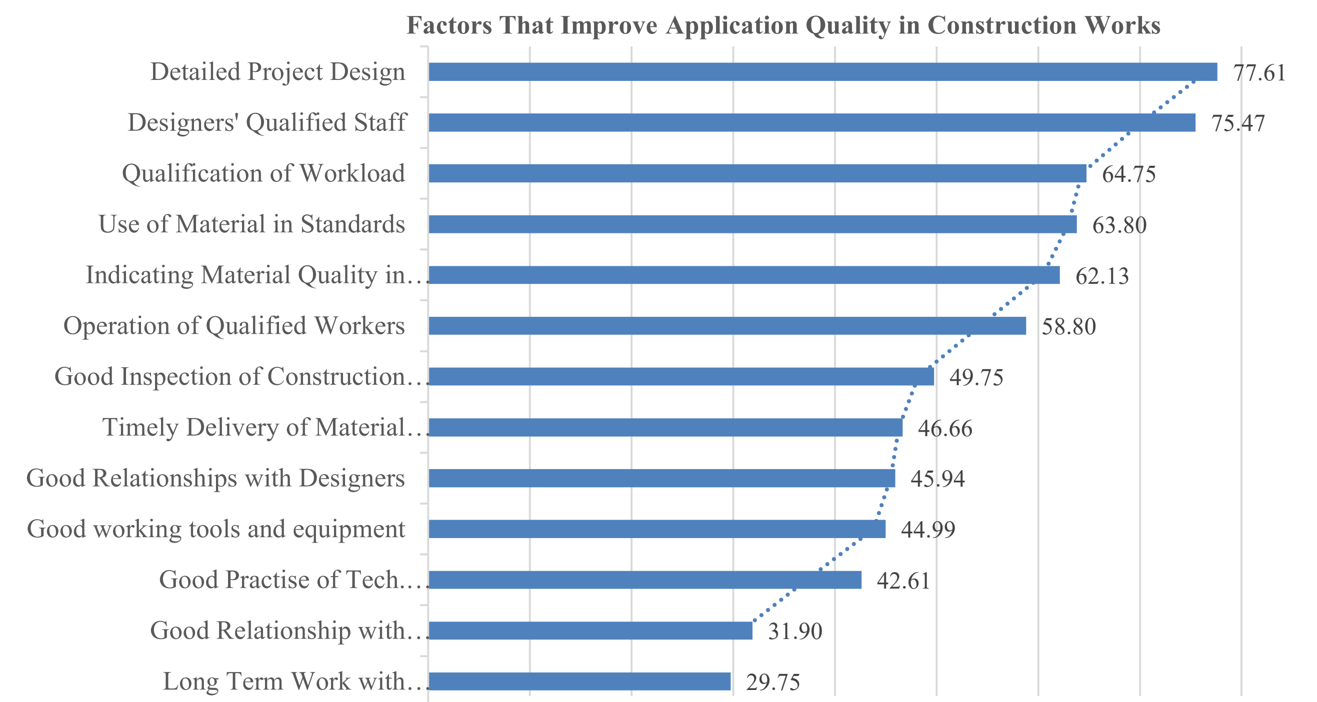

Figure 4: Which criteria improve application quality.

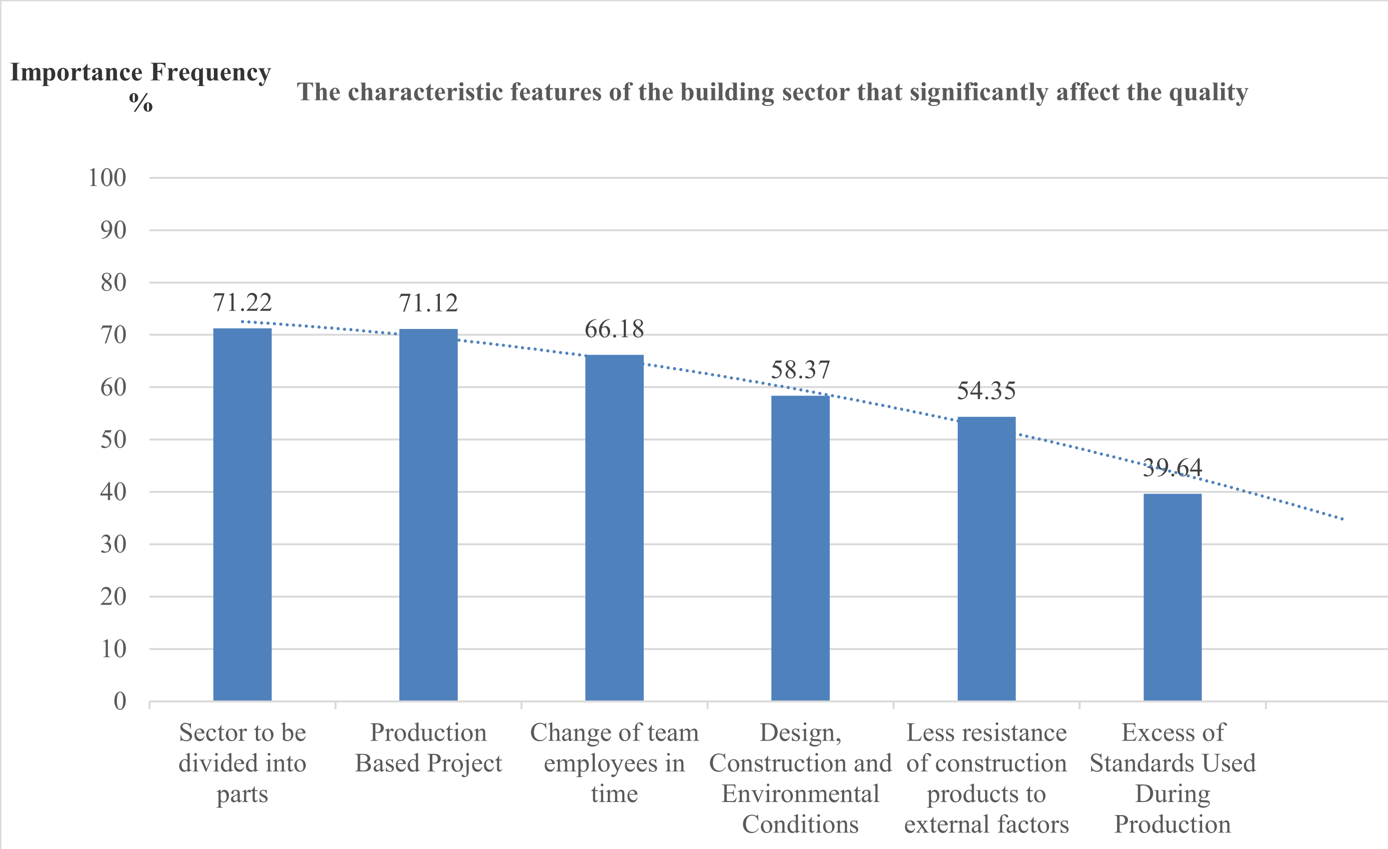

Figure 5: Industry-specific features and quality.

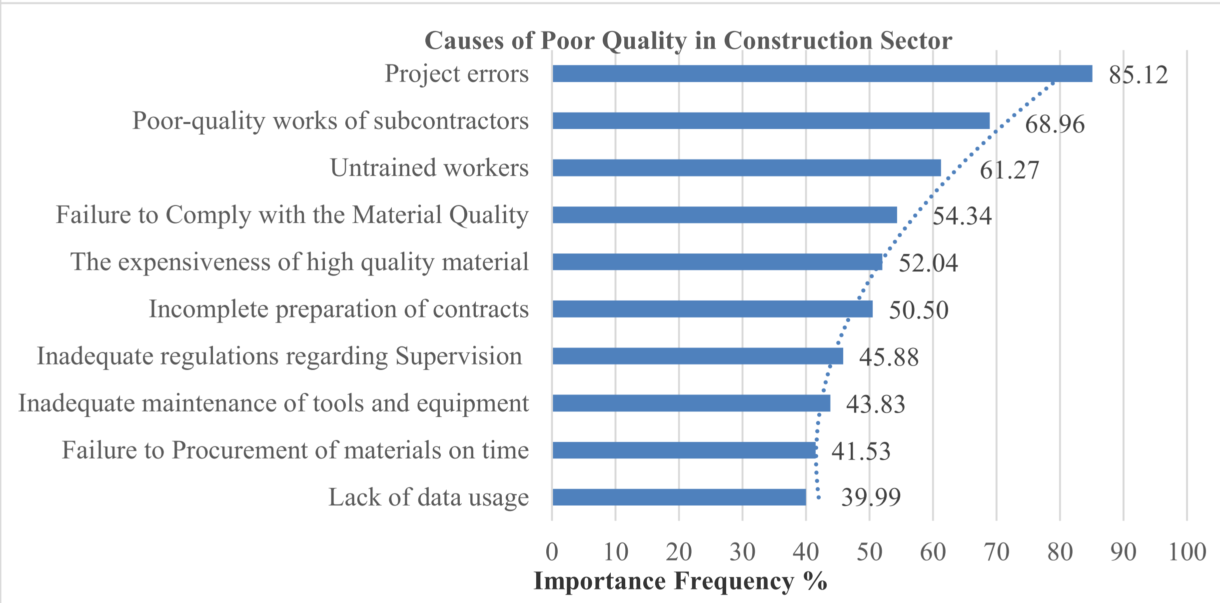

Figure 6: Causes of poor quality.

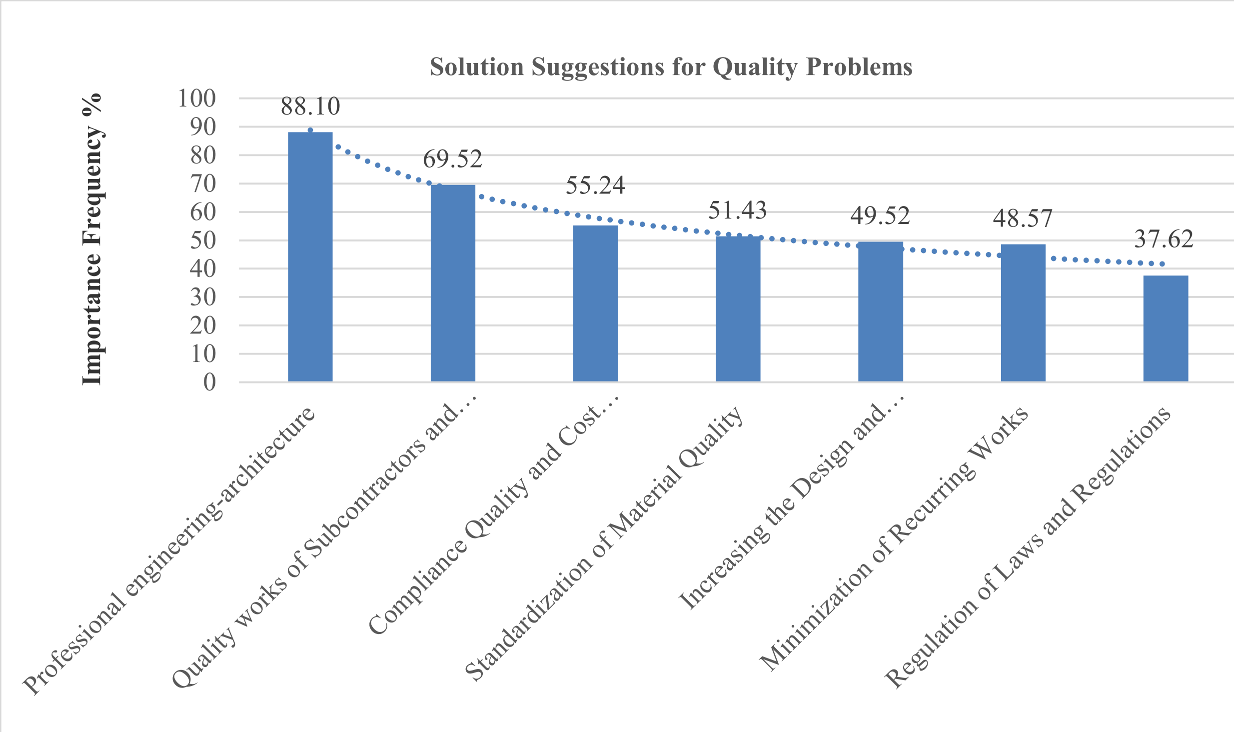

Figure 7: Suggestions to decrease quality problems.

When Fig. 4 is examined; it is clear that the detailed design of the project, the use of quality elements and the use of materials by the standards will increase the quality of application. It can be also seen that long-term working with subcontractors is not as important as others.

Fig. 5 shows, the fact that there are more than one stakeholder and business line in the construction sector naturally causes the sector to fragment and this situation affects the quality of implementation. In addition, project-based production has been the second parameter with a high level of importance that affects quality. Figures 6 and 7 show the causes of poor quality problems and solutions to these problems, respectively. While the projects were not prepared properly (85.1%) and the subcontractor did poor quality work were seen as the most important problems, the priority solution suggestions were mentioned as professional engineering-architecture (88.1%) and the quality works of subcontractors and suppliers.

Conclusions

Quality; have started to be reward with achievement, reputation and high profitability in recent years. Many businesses around the world have come to the idea that quality management is very important.

It can be seen that customer satisfaction is at the forefront of quality policies. Companies stated that they prioritize the product quality while keeping the cost in the background. It is thought that the efficiency and stability of the technical team will increase the quality and improve the quality of the works. They think that establishing a good relationship with subcontractors and working with the same supplier for a long time will not increase the quality in practice.

Within the scope of solving inter-organizational problems and reaching the common mission, communication should be provided on a sectoral and project basis. This will also ensure that resources (such as financing, workers, materials, equipment) are used effectively.

The respondents think that if the production consists of a single team, the quality will increase. Excessive quality standards during production can cause production disruption and to stay away from the desired quality.

If the projects don't prepare properly, it causes the production to be made wrong to be applied. Besides this, there are poor quality problems in the construction sector caused by project errors, inappropriate material use, application errors, disagreements between organizations, methods of conducting business, types of contracts, gaps in-laws and regulations or inadequacies. In the peculiar characteristics of the sector that affects the quality is the fact that the application and manufacturing are not managed from a single-center, in contrast, divided into sections such as contractor-subcontractor or architect-engineer-chef at the sector.

In order to eliminate the quality problems that may arise between the organizations, each organization must fulfill its duty completely. To minimize conflict between organizations, the responsibility of each organization should be clearly stated in the contracts and an organizational chart for the project should be created.

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Utilization of DSM in Design Phase of IPD Projects: A Case Study

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Abstract

IPD principles were explained in AIA's manual published in 2007 and it is stated that BIM is the tool that will best serve the needs of these principles. There are academic studies related to BIM in the national and international literature. However, there are no studies in national literature related linking BIM and IPD yet. According to literature Design Structure Matrix-DSM is the most suitable process management model for BIM - based construction projects. This paper will investigate associated with IPD BIM-based construction projects in Turkey. Since in the project life-cycle process design phase most critical decision taken during that phase. In semi-structured interview form A-295 general condition document were used and search that event were applied or not and by whom at that phase of project. According to the case study data obtained as a result of the applicability of the design process of the IPD; BIM-based construction project in Turkey will be discussed, it will be created DSM evaluation of the data obtained.

Keywords: *BIM, construction projects, DSM, IPD.*

Introduction

Different project delivery system are used in construction projects. These are design bid build-DBB, design-built-DB, construction manager as advisor-as contractor- CMa, CMc and finally Integrated Project Delivery-IPD systems. IPD is the last project delivery system published by AIA in manuals and documents. According to AIA'' Building Information Modeling (BIM), a digital, three-dimensional model linked to a database of project information, is one of the most powerful tools supporting IPD.'' (AIA, 2007). Since IPD is the most suitable delivery system to BIM-based construction project; BIM and IPD should apply together in a construction project.

In order to provide time-cost-quality balances of construction projects, these projects need a process management model that is suitable for construction projects multi-part-participant nature. Considering these needs of the construction projects, the process management models in the national and international literature were examined. As a result of the examinations, it was observed that the DSM process management model effectively met the needs of the construction projects. At the end of this case study, a semi-structured interview form was conducted to investigate IPD usage in BIM-based construction project in Turkey. Finally DSM model proposed for Turkey, BIM- based construction project.

IPD, BIM Definition and IPD-BIM Relations

IPD is the last project delivery system published by the AIA. The main purpose of IPD is to bring key participants together from the project phase of idea. Integrated Project Delivery (IPD) is a project delivery method that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to reduce waste and optimize efficiency through all phases of design, fabrication and construction (AIA, 2014).

In IPD projects; generally speaking, the project team includes two categories of team member: the primary participants, and key supporting participants. The primary participants are those participants that have substantial involvement and responsibilities throughout project, from beginning to end. For example, in a traditional project the primary participants are the owner, architect and contractor (AIA, 2007). The key supporting participants on an integrated project serve a vital role on the project, but perform more discrete functions than the primary participants. In a traditional project, the key supporting participants include the primary design consultants and subcontractors (AIA, 2007).

There are several different definition of BIM in international literature. However according to AIA, BIM is ‘’Building Information Modeling (BIM), a digital, three-dimensional model linked to a database of project information, is one of the most powerful tools supporting IPD. Because BIM can combine, among other things, the design, fabrication information, erection instructions, and project management logistics in one database, it provides a platform for collaboration throughout the project’s design and construction. Additionally, because the model and database can exist for the life of a building, the owner may use BIM to manage the facility well beyond completion of construction for such purposes as space planning, furnishing, monitoring long term energy performance, maintenance, and remodeling’’ (AIA, 2007).

When IPD and BIM relations investigate in international literature, investigation result indicate that BIM-IPD application in construction project supply to reducing the waste and time saving. The use of BIM as an information sharing tool used in conjunction with an IPD system is one of the more promising advances in the construction industry lately. BIM seeks to facilitate the exchange of information between all parties to a construction project, with the goals of reduced cost, error, and redundancy (Bell, 2004). BIM also supports the concept of IPD which is a novel project delivery approach to integrate people, systems, business structures and practices into a collaborative process to reduce waste and optimize efficiency through all phases of the project life cycle (Glick and Guggemos, 2009). Finally, BIM-IPD applications bring new needs to conventional process management approaches and process management models in construction projects.

Definition of DSM

Design Structure Matrix-DSM was introduced by Don Steward in 1981 as a management model. A two-dimensional matrix representation of the structural or functional interrelationships of objects, tasks or teams. N-square matrix, Dependency structure matrix concepts are also used synonymously for design structure matrix. As a figure, the actions that take place in the process are written so that the rows and columns are equal. The relationship of the actions on the matrix with each other, which action needs information in which action, repetitive actions and risks are easily read and followed through the matrix. DSM can be created as object-based, team-based, parameter-based and action-based (Weck, 2012).

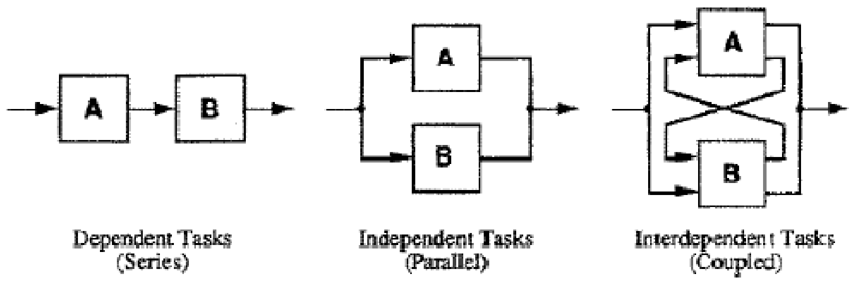

Figure 1: Three possible sequences for two design tasks (Eppinger et al., 1994).

In DSM proces manegement model; there are, in fact, three basic types of relationships that tasks can have with each other. An example of the different possible relationships between two activities, A & B, is shown in Figure 1. If Activity B requires information from previously completed Activity A, then they typically ocur sequentially, and are referred to as dependent. If Activity A and Activity B can be done in parallel without information from each other, they are referred to as independent and can potentially be done at the same time (or different times in any order). If successful completion of Activity A requires information from Activity B and Activity B also requires information from Activity A, the activities are interdependent or “coupled”. Interdependent tasks are iterative due to feedback relationship the tasks share. The first two types of relationships are relatively straight forward to model and manage in practice and are prevalent in the construction and manufacturing industries, where tasks can be completed in a prescribed sequential order. Modeling and managing coupled tasks, which describes much of the real estate development process and product development industries, is much more challenging because this arrangement implies iteration and feedback loops (Eppinger et al.,1994). In the DSM, N units are listed identically in the rows and columns of a matrix to represent the design tasks. The marks represent the information flow between tasks. Revisiting the example from Figure 1, the same three patterns of relationships between two tasks are shown in the N-square matrix below (in this case 2x2) in Figure 2.

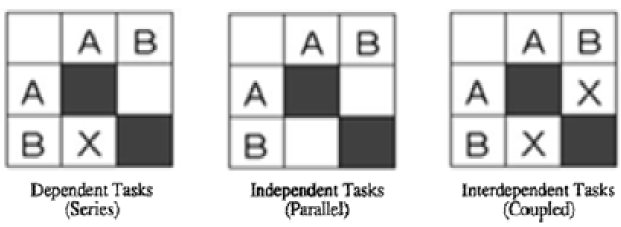

Figure 2: Possible sequences for two design tasks (in DSM) - (Pektas and Pultar, 2006)

Figure 3(a) depicts a hypothetical DSM scenario for designing a suspended ceiling system in a commercial office building. In order to design task B, “Floor to Ceiling Height”, you will need information from task A (Floor Area) and task G (Plenum Depth). Reading down the columns shows where the task provides information to. Task D (Air Duct Depth), for example, generates information that is required for tasks E (Beam Integration) and G (Plenum Depth) to be completed (Sullivan and Bulloch, 2009).

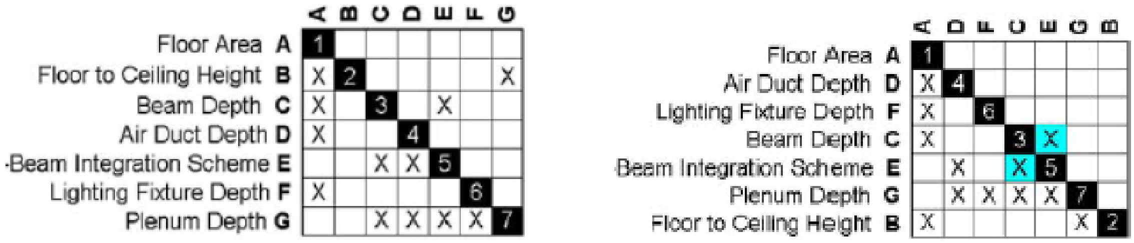

Figure 3: Suspended ceiling design-Initial DSM & Partitioned DSM (Pektas and Pultar, 2006)

The matrix also reveals where iteration takes place. All X’s below the diagonal line represent feed-forward information flows, where information created in earlier tasks can be used in later tasks. This is a classical sequential process. When X’s are above the line, however, there is a feedback where information from later tasks may require rework or refinement of work done or decisions made in previous tasks. In the example above, task B depends on information from task G, which is completed after B. Therefore, the designer must make assumptions in order to complete B, without G being completed. If these assumptions are subsequently found to be incorrect when task G is completed, rework will be required to fix the problem or adverse consequences may ensue. This would require the process to move back to task B and repeat itself, which could prove to be costly and time consuming (Eppinger, 2001). With the matrix completely filled in, the initial sequence of tasks can be reorganized to minimize the amount of potential rework; a process known as partitioning. To optimize the process, tasks are organized in a way in which the most number of X’s as possible are below the diagonal, minimizing feedback. In the development process, with known iterations, it is impossible to move all of the activities below the diagonal. In this case, tasks are ordered to get the X’s to as close to the diagonal as possible. By partitioning the example shown in Figure 1, we can see a new process, with less iteration in Figure 3(b) (Pektas and Pultar, 2006).

Investigation of the structures of BIM-Based Project Design Process with Turkey IPD Relations and DSM Adaptation

BIM, which is widely used in the construction sector in other countries of the world, has also started trials in our country in recent years. Although consciousness about using BIM has developed in our country, this awareness is not at the desired level. There are different forums and organizations establish to meet all participants together. Since these organizations and forums support the BIM application, there is no regulation about BIM application in Turkey. Lack of regulatory about BIM application cause that limited usage BIM-based construction project.

Since there are several project delivery system for construction project, IPD is the most suitable delivery system to support the integrated working. Although there are publications about BIM, there is no publication about BIM-IPD. In Turkey BIM-based construction project mostly completed via traditional project delivery system. Because of that, the application of BIM cannot be provided effectively in BIM based construction projects.

On the other hand, the application of IPD and BIM together has changed the traditional process management of construction projects. Construction projects are multi-part and multi-participant. In addition, iteration occur while completing tasks throughout the process. In the literature review of the paper, it is stated that the DSM process management model is the most suitable process management model for construction projects. There is no model for process management, project delivery systems in Turkey. The fact that BIM is a new concept and IPD has different principles than traditional project delivery systems requires the process management model associated with IPD for BIM based construction projects. Therefore, the process management model will be proposed using the DSM model. To propose the DSM model a case study was conducted to investigate DSM data. There are 51 tasks are given in A-295 general condition document for conceptualization, detailed design, implementation, and construction document phase. First of all with this case study it was investigated whether 51 specific tasks were implemented. Secondly if tasks are being implemented, which stakeholders have been implemented have been investigated. Finally, the relationship of tasks with each other was investigated. DSM matrix is created with the help of this data. During the investigation, semi-structured interview were completed in 2 hours with 11 participants. While preparing the semi-structured interview form, AIA 295 general conditions that published by AIA were used. Design teams whose using BIM in Turkey construction sector have been identified as target groups. The survey study scope design processes in which vital decisions of the project life cycle are made. In semi-structured interview form, these phases were investigate. There are 51 tasks are given in A-295 general condition. First of all, these tasks that listed in A-295 general condition document application in construction projects in Turkey, BIM was asked whether applied or not. Secondly, if tasks are implemented; the owner, design team or contractor participants were asked which of them completed the task. Finally, in order to complete the tasks, it was asked which of the other actions in the table needed from the other tasks information. According to the survey results, separate DSM tables were created for conceptualization, design criteria, implementation and construction document phases. These DSM tables were merged in Figure 4. Participant roles and responsibility legend are shown in the Table 1 via color. For indicating participant roles and responsibility with colors were used that shown in Table 1. Blue used for representing to owner, red for design team and yellow for constructor. Purple used for design team and owner. Green used for owner and constructor. Orange used for owner and constructor. Finally, grey used for owner, design team and constructor all together. Task relationships are also shown in Figure 4 as well.

Table 1. Participant association and coloring legend table.

Participants	Single Participant Task	Double Participant Task	Triple Participant Tasks
Design Team	Red		
Owner	Blue		
Constructor	Yellow		
Owner + Design Team		Purple	

Table 1 (cont'd). Participant association and coloring legend table.

Participants	Single Participant Task	Double Participant Task	Triple Participant Tasks
Owner + Constructor		Green	
Constructor + Design Team		Orange	
Owner + Design Team + Constructor			White

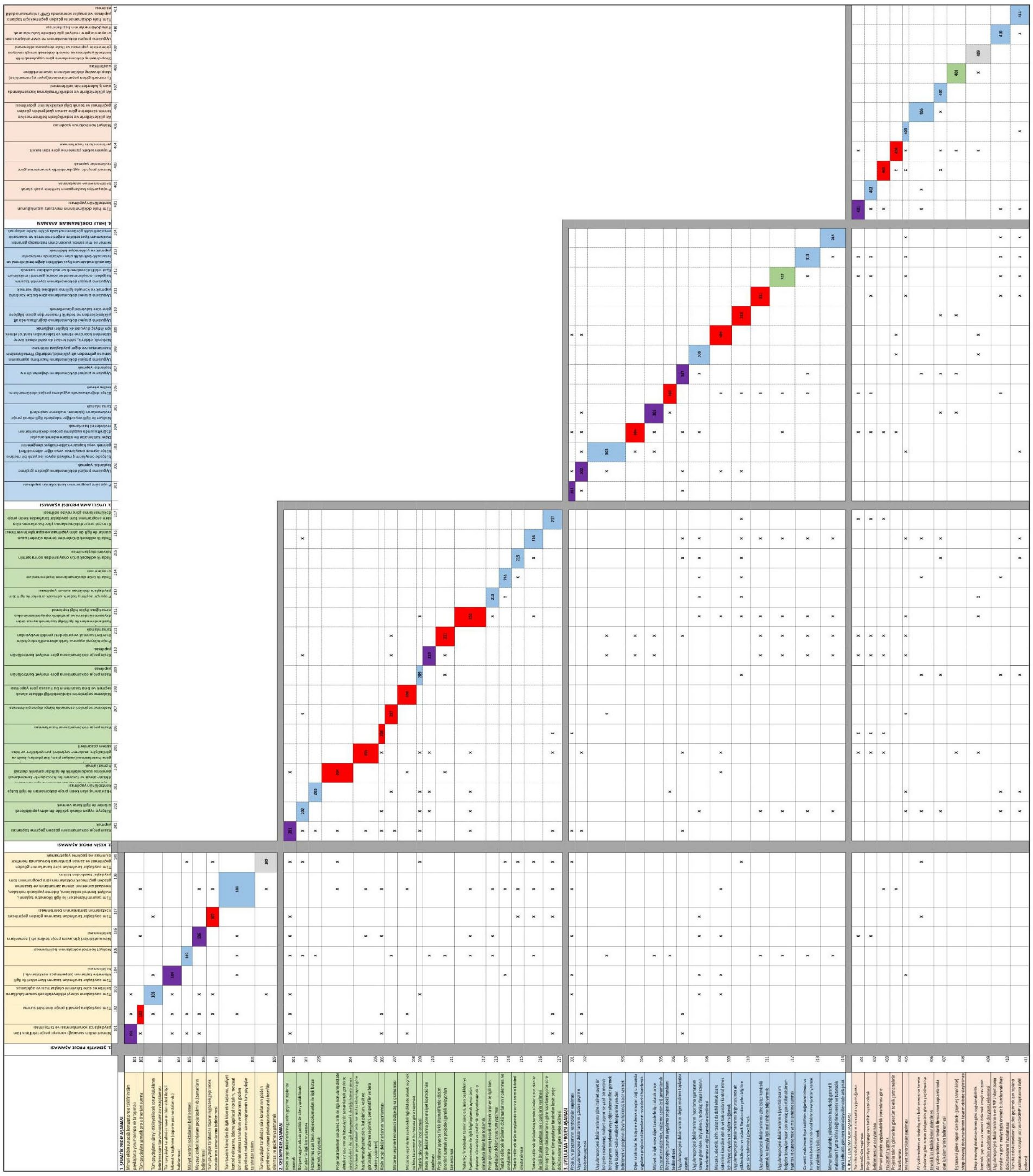

Figure 4: DSM created according to survey result.

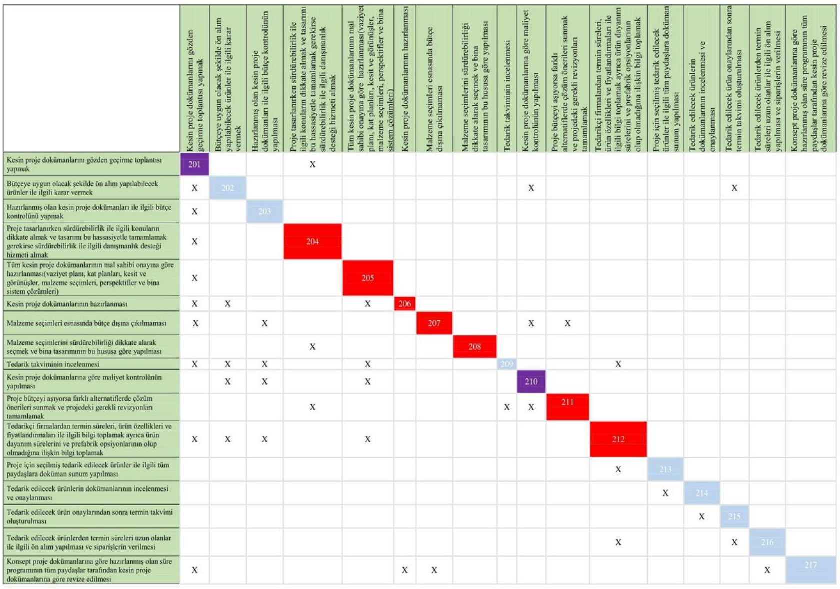

Figure 5: Criteria Design Phase DSM created according to survey result.

In Figure 5 indicate that criteria design phase DSM created according to semi-structured survey form data result. According to DSM definition; when task relation were evaluated the task is finalization meeting for detailed design document. Considering the sustainability issues while designing the project and completing the design with this sensitivity, obtaining sustainability consultancy support services tasks relation is interdependent relation. In other words, feed-forward tasks relationships. To decide on products that can be pre-purchased in accordance with the budget task and finalization meeting for detailed design document tasks relationship has dependent task. The same to decide on products that can be pre-purchased in accordance with the budget task, cost control according to the detail design documents, creating a deadline calendar after the approvals of the products to be supplied task have interdependent relationship.

Case Study

The case study has been completed in order to determine the DSM data via using semi-structured interview form. The results of the survey are shown in Table 2.

Table 2. Comparison of case study data and A-295 general condition.

	AIA, A-295 General Conditions Information		Case Study Result
Participant Roles and Responsibility	Conceptualization Phase	2 task design team 3 owner, design team 4 task owner, design team and constructor	4 task owner 2 task design team 3 task owner, design team and constructor
	Detailed Design Phase	4 task design team 5 task constructor 1 task owner 4 task design team and owner, 2 task owner, design team and consturctor	8 task owner 8 task design team 1 task owner and design team

Table 2 (cont'd). Comparison of case study data and A-295 general condition.

	AIA, A-295 General Conditions Information		Case Study Result
Participant Roles and Responsibility	Implementation Phase	3 task design team 5task constructor 3 task owner 4 task design team and constructor 2 task design team, owner and constructor	5 task owner, 7 task design team, 1 task design team and owner 1 task design team and constructor
	Construction Document Phase	1 task design team 5 task constructor 3 task design team and constructor 2 task design team owner and constructor	6 task owner 2 task design team 1 task design team and owner 1 task design team and constructor

When differences in the following points were determined based on survey data formed by Turkey DSM compared to AIA A-295 general condition document information;

- 3 out of 51 tasks determined by AIA were marked by less than 50% of the respondents according to survey data in Turkey. This result shows that according to participant of that case study these three tasks are under-implemented or not.
- The participant or participants who completed the tasks are different; When the case study data is compared with AIA especially in the design stages, it is seen that one of the key participant contractor has a very little role. As you can follow from Table 2 when DSM created according to case study result is examined, unfortunately, there is no action that the owner, design team and contractor completed by working together in the conceptualization, detailed design, implementation stages. Only in the construction document phase, 2 tasks are completed by the cooperation of the owner, the design team and the contractor.
- One of the most important principles of IPD is to bring key participants together from the early stages of the project. As you can follow from Table 2 key participant in BIM-based construction projects in Turkey, they cannot complete tasks according to IPD principle. Key participant complete BIM-based construction projects in Turkey, mostly they working alone most of the tasks during the design phases of project life cycle.

Conclusion

In Turkey, BIM is supported only by rail system projects by the government, which does not support its widespread use. There are no officially published guides or official documents about BIM. The lack of guidance or official documents causes confusion about the roles and responsibilities of participants involved in construction projects using BIM. This cause that BIM manager, BIM coordination manager, etc. it leads to the emergence of many participant roles and responsibilities. All disciplines that take roles and responsibility in construction sector in Turkey; need of qualified personnel to use BIM. Due to the lack of information about adaptation to BIM and the lack of official publications, companies taking part in the construction sector have difficulties in transition to BIM. Due to the absence of official guides and documents, every company that changes to BIM determines its own process management rules.

When the case study results are evaluated; in the design processes of the project life cycle, it is seen that the participants mostly complete the tasks by working single. Especially constructor's roles and responsibility is limited in design phase. This is critical point.

According to this result, BIM-IPD awareness does not develop even though BIM awareness is improved in Turkey. This is because when the situation in the construction sector in Turkey has not yet explored by the participants said that all disciplines have qualified personnel may use BIM. The 'X' sign, which shows the task relations in the DSM created according to the case study results, mostly remains under the diagonal axis. This indicates that task relationships are linked, and tasks are often completed by a linear workflow. The presence of a linear workflow indicates that BIM-based construction projects are still acting with the traditional project delivery system logic. Adding the need for qualified personnel in order to meet mandatory schedule of university courses in BIM software is required to monitor the effect of the use of BIM in Turkey. In order to ensure the adaptation of BIM-IPD, companies that take part in the construction sector by the public institutions should suggest road maps and publish guides or documents. Finally, the main idea should clearly understand that BIM can be used to facilitate IPD and DSM can be used in the design phase of an IPD project as an effective decision support method.

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Using the MACBETH Method to Solve the Construction Site Manager Selection Problem

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Abstract

Construction site manager is one of key personnel staffs to serve in construction projects in order to satisfy several required criteria such as project duration, cost and quality. In construction sector, personnel contracting depends on project. And after project termination, the contract with personnel may be not continued unless there is another project is planned to be started. So that before each project start, a new construction manager is required. In this study, a generic selection methodology based on MACBETH multi-criteria method is proposed with a case study that includes selection of a construction manager from four civil engineer candidates who have applied to a construction company.

Keywords: *construction management, MACBETH, multiple criteria decision making.*

Introduction

Construction companies are increasingly adopting project management skills in their design and build processes to their projects. A key issue for the management of the construction projects is to ensure skilled individuals are allocated as effectively as possible to cope with the other construction companies' projects. A construction manager is a key personnel that companies the use of the construction management project requirements on a construction project. Selection of a site manager for construction projects and hiring the right candidate is a multi-criteria decision making problem (Ceran & Dorman, 1995).

In literature, some of the Multi Criteria Decision Making Techniques have been applied to solve many problems also recruitment problem of a company. Afshari (2017) proposed a method combines the Delphi method and the fuzzy linguistic evaluation to enhance the selection of construction project manager. Ensslin et al. (2013) identify human resource allocation in a project management model, based on knowledge demand and using a multi-criteria decision aiding method as an intervention instrument. Torfi and Rashidi (2011) select project managers of a construction company by implementing AHP and Fuzzy TOPSIS decision making methods. Balentis et al. (2012) proposed a model by using Fuzzy MULTIMOORA decision making method to solve project manager problem. Sadeghi et al. (2014) improved goal programming and TOPSIS decision making method to select a project manager.

Multi-criteria Decision Making (MCDM)

The complexity of real-world problems, which involve the achievement of multiple and often conflicting objectives (criteria), is raised with the use of MCDM methods to guarantee the validity and reliability of the final decision (Figueira et al., 2009). The advantages of MCDM methods include their ability to take into consideration conflicting criteria, structure the management problem, provide a model for discussion, and lead to rational and explainable decisions (Belton & Stewart, 2002).

The main steps of multi-criteria decision making methods are (Anbarcı et al., 2016):

(1) Problem identification,
(2) Establishment of evaluation criteria
(3) Development of alternative systems
(4) Evaluation of alternatives according to criteria
(5) Application of a normative multi-criteria analysis method
(6) Acceptance of an alternative as highly favored
(7) If the final solution is not accepted, to collect new information to the next iteration for multi-criteria optimization.
(8) Model building and use,
(9) Development of action plans.

MACBETH Method

MACBETH is an approach to multi-criteria decision aid whose development was set in motion in the early 1990's by C.A. Bana e Costa and J.-C. Vansnick. MACBETH, the name (Measuring Attractiveness by a Categorical Based Evaluation Technique) is:

i. User-friendly for decision-makers to discuss their value systems and preferences.
ii. Interactive from a practical viewpoint, this suggests that such interaction would greatly benefit from an extremely efficient decision support system, as it is actually the case of the M-MACBETH software.
iii. Constructive because MACBETH rests on the idea that full-bodied convictions about the kind of decision to make do not (pre-) exist in the mind of the decision maker, nor in the mind of each of the members of a decision advising group (Bana e Costa et al., 2002).

MACBETH has been applied to solve problems in different subjects for instance (Demesouka at al., 2016);

- Research and development
- Human resources management
- Career choice problems
- Portfolio management
- Natural phenomena
- Medical science

- Drinking water utilities
- Public investments
- Politics
- Project development

The steps of the MACBETH method are as follows (Bana e Costa et al., 2002):

1. Step: The Decision Maker has to select carefully the decision criteria, according to which the alternatives' performance is to be measured, forming the problem's value tree and the Decision Maker has to define the upper reference level and the lower reference level for each criterion.
2. Step: For measuring the attractiveness of alternatives belonging to a finite Set A to create of quantitative models
3. Step: Establishing cardinal value functions based on a questioning procedure.
4. Step: To ask Decision Makers' to verbally express differences in the attractiveness of two actions (criteria and/or alternatives), based on the seven semantic categories shown in Table 1, forming a (n× n) matrix in case of n actions by achieving the quantification process.

Table 1. Attractiveness scale.

Semantic Categories	**Quantitative Scale**
No	0
Very Weak	1
Weak	2
Moderate	3
Strong	4
Very Strong	5
Extreme	6

5. Step: Arranging the consistent judgements in decreasing order according to the preferences of the Decision Makers.
6. Considering p_i^k the performance of the alternative k to the criterion i, and the fact that the Decision Makers' prefer the alternative k to the alternative l for this criterion, they should denote the level of strength of performance (h) between these two alternatives according to the predefined scale of Table 1 as follows:

$$p_i^k - p_i^l = h\alpha \tag{1}$$

   where $\alpha = coefficient$ necessary to meet the condition that p_i^k,$p_i^l \in [0,100]$,and $h \in \{0,1,2,3,4,5,6\}$.
7. Step: Evaluation of the alternatives is obtained by applying the additive aggregation model [Eq. (2)], where $V(a)$ measures the overall attractiveness of $a \in A$; $v_j(a)$ quantifies the per-criterion local attractiveness of the actions of A; and wj is the scaling constant (weight) of the ith criterion for the k criteria of the analysis (Demesouka at al., 2016);

$$V(a) = \sum_{i=1}^{k} w_i x v_i(a) \tag{2}$$

   with

$$\sum_{i=1}^{k} w_i = 1 \; and \; w_i > 0 \; (i = 1, \ldots, k) \qquad (3)$$

Case Study

In this study, a generic selection methodology based on MACBETH multi-criteria method is proposed with a case study that includes selection of a construction manager from four civil engineer candidates who have applied to a construction company.

The experience, their performance in the job interview and references of the candidates were taken into account in the selection of the most suitable candidate among the four civil engineer candidates who applied for the construction manager position of the company. The decision criteria for recruitment were determined by the company's general manager, technical affairs assistant general manager and assistant general manager responsible for human resources.

At first, the value tree of the determined criteria has been created as shown in Fig. 1.

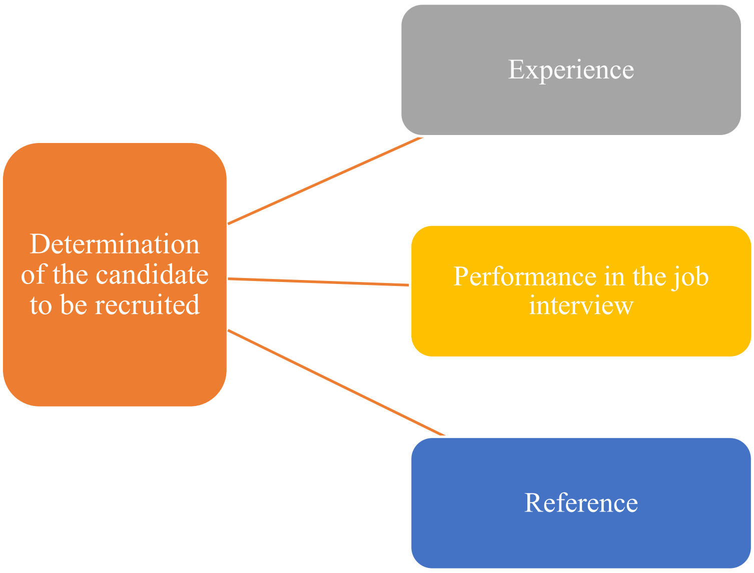

Figure 1. Value tree of the determined criteria.

In order to determine the effect levels in the preference to be made after the decision criteria are determined, a comparison matrix that shows the importance levels among themselves should be created. The decision maker is expected to make binary comparisons between the criteria, creating a non-dispute comparison matrix. It is proposed to use the semantic categories specified in Table 1 in the creation of comparison matrices. Experience was the most important criterion for decision makers in this study, while the least important w the reference. The comparison matrix was determined for the solution of the problem is as in Table 2.

Table 2. Comparison matrix.

	Reference	Performance in the job interview	Experience
Reference	No	Very Weak	Very Strong
Performance in the job interview	Very Weak	No	Strong
Experience	Very Strong	Strong	No

After the preparation of the comparison matrix, a linear programming model has been used for the determination of the criterion weights. The purpose of the linear programming model created was to minimize the largest of the specified criteria. It is necessary to establish the required linear programming to create the constraints. Ordinal conditions ensure the accuracy of the preference ranks of the specified criteria, while semantic conditions ensure that preference levels are appropriate. Ordinal conditions and semantic conditions are shown in Table 3.

Table 3. Constraints.

Constraints
Ordinal Conditions
Experience (Very Weak) Job Interview Performance
Experience (Very Strong) Reference
Job Interview Performance (Strong) Reference
Semantic Conditions
(Experience-Job Interview Performance)<(Experience-Reference)
(Experience-Job Interview Performance)<(Job Interview Performance-Reference)
(Experience-Reference)>(Job Interview Performance-Reference)

After entering the related constraints into the Solver add-in of Microsoft Excel program, linear programming problem has been solved. When the Solver plug-in was run, the values to be taken by other criteria were determined so that the criterion with the lowest score is "1". The results are shown in Table 4.

Table 4. Calculation and results of the linear programming.

	Results/Calculations		
Aim: Minimizing the highest option	6		
Criteria			
Experience	6	0,5	
Job Interview Performance	5	0,42	
Reference	1	0,08	
Constraints			
Ordinal Conditions			
Experience (Very Weak) Job Interview Performance	6	≥	6
Experience (Very Strong) Reference	6	≥	6
Job Interview Performance (Strong) Reference	5	≥	5
Semantic Conditions			
(Experience-Job Interview Performance)<(Experience-Reference)	-4	≤	-4

(Experience-Job Interview Performance)<(Job Interview Performance-Reference)	-3	≤	-3
(Experience-Reference)>(Job Interview Performance-Reference)	1	≤	1
Reference	1	=	1

The results prior to use in deciding by the decision-maker has been checked whether satisfies all specified limitations. Failure to achieve any one of these conditions is indicative of a mismatch in the comparison matrix. The decision maker should make the necessary corrections in the comparison matrix based on the constraint not provided. As a result of the model, “6”, “5” and “1” values were found for experience, job interview performance and reference criteria, respectively. After these values are found, they are proportioned to have a total of "1" to determine the weight of the criteria in percent. Thus, the weight of the experience criterion was calculated as "0.50", the weight of the job interview performance criterion was "0.42" and the weight of the reference criterion was "0.08". The results showed that the experience and job interview performance were significantly effective in recruitment, while the reference was of low importance. After the criteria have been determined, the relative preference levels of the candidates have been determined for each criterion. Comparison matrices for each criterion has been created. The comparison matrices of the criteria are shown in the Table 5 below.

Table 5. Comparison matrix for criteria.

Experience	*1.Candidate*	*2.Candidate*	*3.Candidate*	*4.Candidate*
1.Candidate	No	Very Weak	Very Weak	Weak
2.Candidate	Very Weak	No	Weak	Moderate
3.Candidate	Very Weak	Weak	No	Weak
4.Candidate	Weak	Moderate	Weak	No
Job Interview Performance	*1.Candidate*	*2.Candidate*	*3.Candidate*	*4.Candidate*
1.Candidate	No	Strong	Strong	Very Strong
2.Candidate	Strong	No	Moderate	Weak
3.Candidate	Strong	Moderate	No	Moderate
4.Candidate	Very Strong	Weak	Moderate	No
Reference	*1.Candidate*	*2.Candidate*	*3.Candidate*	*4.Candidate*
1.Candidate	No	Very Strong	Very Weak	Very Strong
2.Candidate	Very Strong	No	Very Strong	Very Weak
3.Candidate	Very Weak	Very Strong	No	Very Strong
4.Candidate	Very Strong	Very Weak	Very Weak	No

After the comparison matrices were created, the scores of the alternatives were calculated according to the criteria. One of the issues that should be considered before establishing the Model is to equalize the candidate with the least preferable according to the criteria to the value of "0". The MACBETH method scores the least preferred option in the criteria so that it equates to "0". As a result of calculations using the Solver plug-in of Microsoft Excel, the values obtained for the preference of candidates were 3, 4, 2, and 0, respectively. Values were extended to the maximum value of 100. Candidates ' scores according to criteria are shown in Table 6.

Table 6. Candidates ' scores according to criteria.

	1.Candidate	**2.Candidate**	**3.Candidate**	**4.Candidate**
Reference	82,41	0,00	100,00	13,41
Experience	72,00	100,00	50,00	0,00
Performance in the job interview	0,00	80,55	52,78	100,00

After the scores of the candidates were calculated for each criterion, the general scores of the alternatives were calculated using the weights of the criteria. Candidates' scores are shown below Table 7.

Table 7. Candidates' overall scores.

Weights	0,08	0,50	0,42	
Alternatives	Reference	Experience	Performance in the job interview	Total Score
1.Candidate	82,41	72	0	41,12
2.Candidate	0	100	80,55	76,29
3.Candidate	100	50	52,78	52,81
4.Candidate	13,41	0	100	41,86

As seen in Table 7, the second candidate got the highest score with 76.29 points. Thus, second candidate is the most suitable from four civil engineer candidates who have applied to work as a construction manager of the construction company.

Results

In this study, MACBETH method, which is one of the Multiple Criteria Decision Making techniques, was applied in the construction manager selection problem and a solution was presented for decision makers. Also this study clearly demonstrated that selection of construction manager can be improved in several ways by implementing the decision making MACBETH method. MACBETH is a simple-minded method and does not instruct endless mathematical calculations as compared to other multi criteria decision-making methods. Although MACBETH method has widely applications to select the alternatives with qualitative measures.

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Comparative Life Cycle Carbon Footprint Analysis: A Case Study of Concrete-framed, Steel-framed and Timber-framed Tiny House

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Abstract

The selection of building materials not only requires material properties and initial costs but also carbon emissions over the life of the building. This study compares three commonly-used building materials, namely concrete, steel, and timber, by life cycle assessment (LCA) methodology based on their carbon footprint. A 25 m2 tiny house located in Ankara, Turkey, is designed as concrete-, steel-, and timber-framed structures. While the structural design of the systems showed variations, the architectural, mechanical, and electrical systems are considered the same. OneClick LCA plugin for Revit Architecture is used. The system boundary includes product stage, construction stage, and end of life stage; but excludes use stage due to rough assumptions for inventory and impact analyses in Turkey. Results revealed 462 kg CO2e for concrete, 447 kg CO2e for timber, and 420 kg CO2e for steel. The primary source of CO2e belongs to production and end of life phases. All three cases have approximately the same CO2 in the production stage, but the construction stage is higher in concrete case, while the end of life stage is higher in timber case. The results are expected to increase awareness of global warming potential of selected materials that lead to sustainable construction.

Keywords: *carbon footprint, concrete, life cycle assessment, steel, timber.*

Introduction

Since European (EU) Commission encourages the reduction in raw material sources and greenhouse gas emissions due to global warming issues, developing environmental profiles of building materials and systems with low impacts is required thereafter (Saghafi & Teshnizi, 2012; Ding, 2013). Life-Cycle Assessment (LCA) as a useful tool can help in decision making for the selection of sustainable materials by evaluating their environmental and economic impacts during their lifetime (Torabi & Ahmadi, 2020). The ISO 14040 standard describes the framework of LCA that includes raw material extraction and production, distribution, use, recycling and disposal with all transportation activities (Klopffer, 2006).

Environmental Product Declaration (EPD) is needed in LCA analyses to communicate about identity and life-cycle environmental impact of products that methodology of EPD is based primarily on ISO 14044/44 standard and operated under product category rules (PCR). There are some of generic LCA tools such as; GaBi, OpenLCA, SimaPro, EIO-LCA, OneClickLCA used for analyses both in academic and marketing purposes (Oladazimi et al., 2020).

There are common beliefs about construction materials which have more environmental impact than others. However, it depends on many factors such as; location, building type and function, all transportation distance and the methodology used for analyses. For this purpose, a compilation of studies on environmental impacts of concrete, steel and timber is given in Table 1. Some of them implies that replacing timber can reduce greenhouse gas emissions, while the others states that concrete and steel have significant environmental impacts. There is a lack of studies which compare these 3 building materials in the same location and structure.

In this study, three commonly used building materials; concrete, steel and timber are assessed in a one-storey tiny house built of concrete, steel and timber-framed structure in order to compare their life-cycle impacts by the help of quantitative LCA analyses. One Click LCA software which integrates with Revit Architecture is used to perform calculations of carbon footprint and other environmental impacts caused by these materials used in three case studies. The results of the study are expected to enhance knowledge of proper material selection by considering their impact on the environment.

Table 1. Compilation of studies on the environmental impacts of concrete, steel and timber.

Article Title	**Objective**	**Location**	**Material**	**Method**	**Results**
Ede et al. (2014)	Timber as a readily available material can replace concrete.	Duplex residential building in Nigeria.	Timber Concrete.	Athena Impact Estimator software	Timber is more environmentally friendly in terms of minimizing carbon emissions.
Buchanan et al. (2013)	Environmental effects of manufacturing building materials and their disposal.	Three-storeys building in Nelson.	Timber building, Steel building, Concrete building	Life cycle inventory based on ISO 14041, GaBi, AgriLink.	Timber has 8% lower global warming potential compared to steel or concrete.
Sandanayake et al. (2018)	Enhance knowledge of greenhouse emission profile and reduction capabilities at the construction stage.	Concrete building in Melbourne, Timber building in London.	Both timber and reinforced concrete buildings	Cradle to gate system boundary, Embodied GHG emission according to Australian national greenhouse gas	Timber usage reduce GHG emission compared to concrete.
Oladazimi et al. (2020)	Evaluates the pollution amount related to the construction of concrete or steel frame buildings.	Six-storeys concrete and seven-storeys steel buildings in Tehran.	Concrete frame building, Steel frame building.	Cradle to gate system boundary, GaBi, ReCiPe	Global warming emissions for concrete building was 38% higher than the steel building.

Material and Methods

A tiny house structure having 5 m to 5 m, 25 m^2 floor-plan with 3 meters height, located from north to south direction is designed for this study in Ankara, Turkey. Three case studies of this tiny house built of concrete (Case Study-I), steel (Case Study-II) and timber-framed structure (Case Study-III) are conducted respectively. All three case studies have the same architectural design, mechanical and electrical systems while having distinctive structural design specific to construction materials given in Figs. 1, 2, and 3. The structural skeleton of each case studies is designed as grid of beams and columns and their sizes specific to the structural system. 80x40 cm thick single footing for foundation, 12.5 cm width of brick wall with one door and one window opening are designed in each case study. Life-cycle assessment is used to determine the environmental impacts of the whole building for three cases. The general information about the assessed building is given below:

- Building type: one-dwelling building
- Construction year: 2019
- Service life of building: 50 years life-span
- Location: Ankara, Turkey
- Building area: 25-meter square gross floor area and 3 meters high
- Building function(s): Residential building with one room
- Extent of use: 1 occupant, yearly use.

Concrete structure designed according to Turkish standards no. 500 (TS 500). Live load and dead load of 2 kN/m2 is applied. A two-way slab of concrete with the height of 15cm is assumed for ceiling. For fulfilling the minimum requirements in the standards beams with height of 45 cm and width of 35 cm is designed for transferring the dead and live load to the footing 4 column with the side of 35 cm is designed. C25 concrete is used for all the sections and roughly the amount of steel for reinforcing the concrete is assumed approximately about the 1 ton of S 420 rebar (Fig. 1).

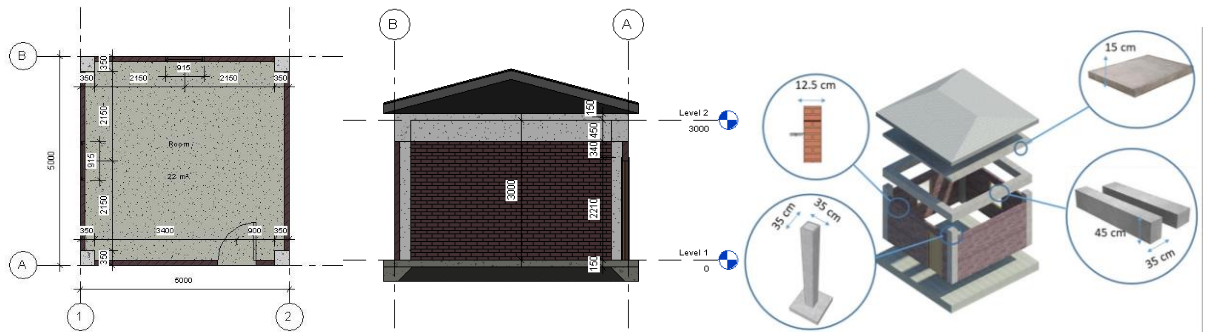

Figure 1: Case study- I: architectural plan (left), section (middle), structural system details of concrete-framed structure (right).

Steel structure is determined according to Turkish Steel Design Code (TS 648). The same loading principles are applied to the structure. 5 cm height reinforced concrete slab on a steel trapezoidal deck is designed for ceiling. In order to simplify the design and prevent use of cross beams in the structure for columns square shape steel boxes with side of 15 cm and thickness of 8 mm is used. Main beams in the surrounding is assumed as IPE 180 and secondary beams designed as IPE 120. For this case study same foundation and wall system is applied (Fig. 2).

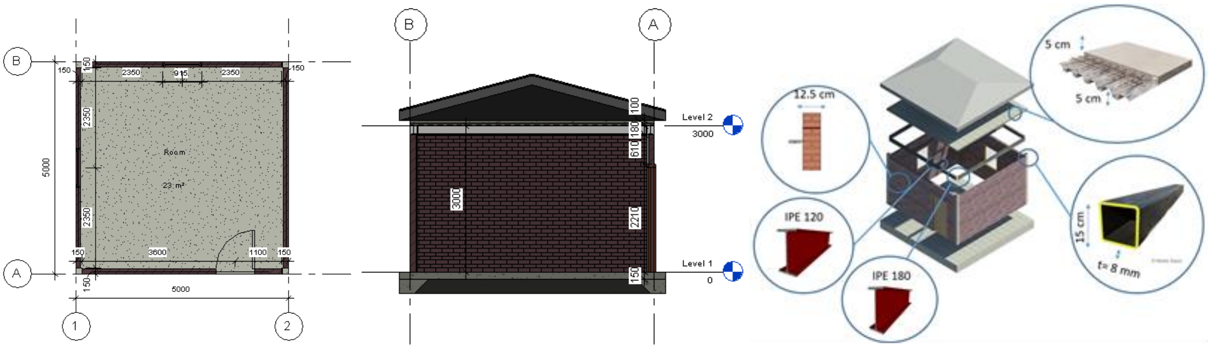

Figure 2: Case study- II: architectural plan (left), section (middle), structural system details of steel-framed structure (right).

For timber structure material class of C 40 with density of 500kg/cm3 is chosen. Structural elements designed according to Eurocode 5 (EN 1995-1-1:2004+A1). For girder timber elements with rectangular cross section with the side of 200 mm*400 mm and for purlin the same shape with the size of 125 mm*250 mm was decided. 4 square shape columns with the side of 250 mm x 250 mm is used to stand the live and dead load of the structure. Also, timber slab with the thickness of 15 cm is used for decking (Fig. 3).

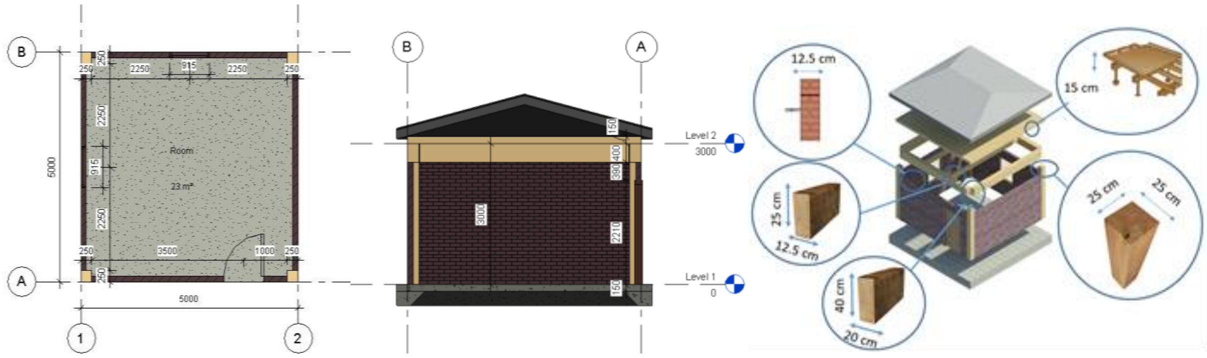

Figure 3: Case study- III: architectural plan (left), section (middle), structural system details of timber-framed structure (right).

LCA is performed on 3 case studies, namely concrete-framed, steel-framed and timber-framed whole building structure for the comparison of the environmental impact belonging to 3 commonly-used building materials. Essential procedures in identifying and assessing the impacts of structural concrete, steel and timber products include the definition of system boundaries, collection and processing of relevant life cycle inventory data. One Click LCA plugin for Revit Architecture is used to perform LCA process based on EN 15978 standard, which is in line with ISO14040/44 standard. Environmental product declarations (EPD) tools used in the analyses are based on EN 15804 standard, which is also compliant with ISO14040/44 standard. These standards are verified by third-party organizations to be used in One Click LCA which is in conformance with the provisions and requirements of international standards. EN 15978 supports CML –IA (2012) baseline methodology which is a database that contains characterization factors for LCA in European market and all assessed environmental impact categories. All of the datasets in the methodology follow EN 15804. Through the electable interface of Revit, the elements with their category used in the building, doors and windows are eliminated from the analysis due to overlapping the same materials such as, steel and timber used in these categories. External walls, roof and foundation are the same for each 3 types of building while structural columns and structural framing differs based on structural system of materials.

The life-cycle stages are defined by EN 15978 and OneClick LCA covers life cycle stages from cradle to grave with these 5 main stages shown in Figure 4. A1-A3 is the product stage of construction materials that include emissions generated from raw material extraction, their transportation and manufacturing process as well as the waste formed in the production process. A4 is the stage of transportation to the site from manufacturer in which exhaust emissions and environmental impacts caused by transportation are included. A5 stage includes the emissions and environmental impacts during site operations specific to the selected material itself. B1 to B7 covers the emissions caused by the maintenance and operation stage that is related with the energy used within the building as well as the energy produced externally by the systems in the building. C1 to C4 is deconstruction stage that involves the impacts of processing recyclable construction materials flow by waste recovery.

In this study, product stage (A1-A3), construction stage (A4-A5) and end of life stage (C1-C4) are included in the EN 15978 system boundary of the assessments. Operational energy and water stage (B5-B6) are excluded from the results due to the availability of impact categories and rough assumptions reached for inventory analysis in Turkey. D is an additional stage which can be included in the system boundary. However, D includes supplementary information out of building life-cycle that is cradle to cradle approach including the benefits and burdens of disposal after demolition.

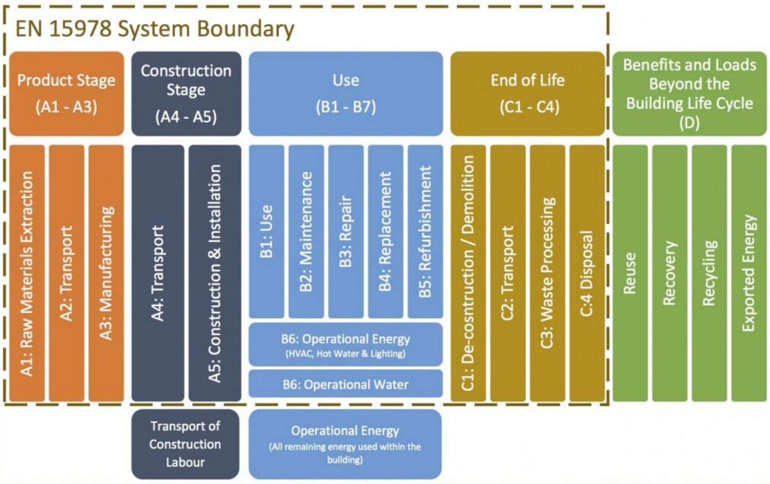

Figure 4: Life-cycle stages in EN 15978.

A4 and A5 stage, transportation and construction site operations differ in between 3 types of these buildings. The waste generated on site and the trips for the transport to the construction site are determined by calculating the amount of materials and waste in case studies (Table 2). The consumed and waste materials in each case studies (concrete, steel and timber structures) are given for each material respectively. Based on the structural design calculations, in total, 20200 kg concrete and 1080 kg structural steel are used in Case Study-I, concrete-framed structure. While 3210 kg concrete and 1404 kg structural steel are used in Case Study-II, steel-framed structure, 3648 kg timber is used in Case Study-III, timber-framed structure (Table 2). The transported distance for each material is determined as 60 km considering the locations of factories for one round trip from factory to site and reverse considering Ankara region in Turkey. The vehicles which are determined considering the amount of structural design used in transportations are mixer truck for ready mixed concrete, 3.5 to 5-ton delivery van and 1.2-ton delivery truck that are all specific to case study given in Table 2.

Table 2. The amount of consumed materials and wastes transported by given vehicles in the case study I, II and III.

Structure	Material Type	Consumed Quantity (kg)	Waste Quantity (kg)	Total Quantity (kg)	Vehicle Type
Case Study-I (Concrete-framed structure)	Concrete	**18878**	**1321**	**20200**	**Mixer truck**
	Steel	**1000**	**80**	**1080**	**1.2 ton van**
	Timber	**-**	**-**	**-**	**-**
Case Study-II (Steel-framed structure)	Concrete	**3000**	**210**	**3210**	**Mixer truck**
	Steel	**1300**	**104**	**1404**	**3.5-5 ton van**
	Timber	**-**	**-**	**-**	**-**
Case Study-III (Timber-framed structure)	Concrete	**-**	**-**	**-**	**-**
	Steel	**-**	**-**	**-**	**-**
	Timber	**3268**	**379**	**3648**	**3.5-5 ton van**

In this study, 6 impact categories, namely global warming potential (kgCO_2 eq), acidification potential (kgSO_2 eq), eutrophication potential (kgPO_{4-} eq), ozone depletion potential (kgCFC_{11} eq), formation of ozone of lower atmosphere (kgC_2H_4 eq) and primary energy (MJ) are assessed respectively. Each of the impact categories describes the effects of substances in the environment; however, global warming potential represents the impacts of greenhouse gases in the atmosphere which is commonly used and often called ‘carbon footprint’. The unit used (kgCO_2 eq) for global warming potential shows the amount of carbon dioxide equivalence of various greenhouse gases.

The difference in environmental impacts between these 3 types of structural system and their materials are compared in a new residential building, 25-square meter single-story tiny house located in Ankara, Turkey during 50-year service life. In this study, the determinant of the analyses is the environmental declarations of concrete, steel and timber materials in which provide quantified environmental information about the life-cycle of a product based on independently verified systematic data. The selected Environmental Product Declarations (EPDs) of concrete (a), steel (b) and timber (c) from the generic and EPD database of One Click LCA is given in Table 3. In these EPDs, country, density, date, related standard, EPD program, product category rules (PCR), technical specification and global warming potential of the products are given to be used in the analyses.

Table 3. EPDs of concrete, steel and timber products used in the LCA study.

Property	Concrete C35/45	Steel Generic	Timber Laminated
Country	**Germany, Poland, Sweden**	**Turkey**	**Norway**
Density	**2359 kg/m3**	**7850 kg/m3**	**470 kg/m3**
Date	**2013**	**2018**	**2015**
Environment Data Source	**Reinforced conc. Pref.**	**One Click LCA**	**Moelven Limtre**
Standard	**EN 15804**	**EN 15804**	**ISO14040**

EPD number	**N/A**	**-**	**NEPD115E**
EPD program	**ITB**	**One Click LCA**	**EPD Norge**
PCR	**PCR UN CPC 375**	**EN 15804**	**NPCR 015 Solid Wood**
Notes about PCR	**Only with EN 15804**	**-**	**Only with EN 15804**
Technical specification	**C35/45 (B35 M40)**	**80% recycled content**	**12% moisture content**
Global warming potential	**344.8 kg CO2e/m3**	**1.51 kg CO2e/kg**	**43.44 kg Co2e/m3**

Results and Discussion

The results of the Case Study-I, II and III (concrete-, steel-, timber-framed structures) are summarized as 6 impact categories in Table 4. The results of each category for all case studies show similarities with the other categories. That means the result of global warming potential which describes changes in local, regional, or global surface temperatures caused by an increased concentration of greenhouse gases in the atmosphere is enough to discuss the amount of environmental impacts. The results show that the highest environmental impact belongs to concrete-framed structure with 11.556 kgCO_2 eq, while timber-framed and steel-framed structures follow with 11.177 kg CO_2eq and 10.503 kgCO_2 eq, respectively. Results per denominator in Gross Internal Floor Area of 25.0 m^2 are determined as 462 kg CO_2e for concrete, 447 kg CO_2e for timber and 420 kg CO_2e for steel. The ranking between these materials according to their global warming potential per m^2 in kgCO_2 eq unit is also shown in Fig. 5 that concrete has the highest impact, timber follows concrete and steel has the lowest impact between them.

Table 4. The amount of environmental impacts of each case study.

Impact category	**Unit**	**Case Study-I [concrete]**	**Case Study-II [steel]**	**Case Study-III [timber]**
Global warming potential (greenhouse gases)	kgCO_2 eq	**11 556**	**10 503**	**11 177**
Acidification potential	kgSO_2 eq	**28,39**	**27,21**	**33,53**
Eutrophication potential	kgPO_4-eq	**5,68**	**5,5**	**6,6**
Ozone depletion potential	kgCFC_{11}eq	**0**	**0**	**0**
Formation of ozone of lower atmosphere	kgC_2H_4 eq	**23,93**	**23,31**	**23,54**
Primary energy	MJ	**189 349**	**188 959**	**191 292**

The distribution of impacts into life-cycle stages shows the density in between the stages seen in the charts in Fig. 5 and the quantified data of the environmental impacts in these stages is given in Table 5. The results show that the main source of CO_2 belongs to product stage (A1-A3) and end of life stage (C1-C4) follows it with considerable differences. All three cases have close CO_2 emissions in the production stage, but the portion of C1-C4, deconstruction or end-of-life stage is the highest in the timber case compared to other two cases. Except the product and deconstruction stage (A1-A3 and C1-C4), timber has the lowest environmental life-cycle impact while it has the highest emissions in external impacts at D stage that benefits from recycling timber's waste are the highest due to timber’s recyclable building material feature. However, the emissions belonging to these stages are related with the environmental declarations of products, country, location, building function, service-life of the structure and the standard used for LCA analyses.

The emissions of A4 and A5 stages are originated from the amount of construction materials and their installation process specific to each material in this study. The carbon footprint of the site transportation and installation of concrete is the highest due to the vehicle types used for the amount of materials and waste produced by processes. Since smaller vehicle is used for transportation to site and less waste is produced in steel- and timber-framed structures, they have slightly less carbon footprint of A4-A5 stages compared to concrete-framed structure. B1 to B5 stages represents the maintenance and material replacement of all three case studies for 50-year service life that is taken the same as 122 kg CO_2eq for all cases. However, the energy and water use (B6-B7) during the operation of buildings are neglected for this study. These two stages may have significantly effect on the results of the environmental impacts considering the location, electrical and mechanical systems and energy transmission losses of the building. The gross internal floor area of global warming potential of three cases is calculated by dividing the total emissions into building area measured by IPMS. IPMS stands for International Property Measurement Standards by RICS that establishes a consistent methodology for measuring buildings around the world. The comparison on the environmental impacts of gross floor area is more convenient since these numbers represent carbon emissions per meter square of each structures made of concrete (462 kg CO_2 eq), timber (447 kg CO_2 eq) and steel (420 kg CO_2 eq).

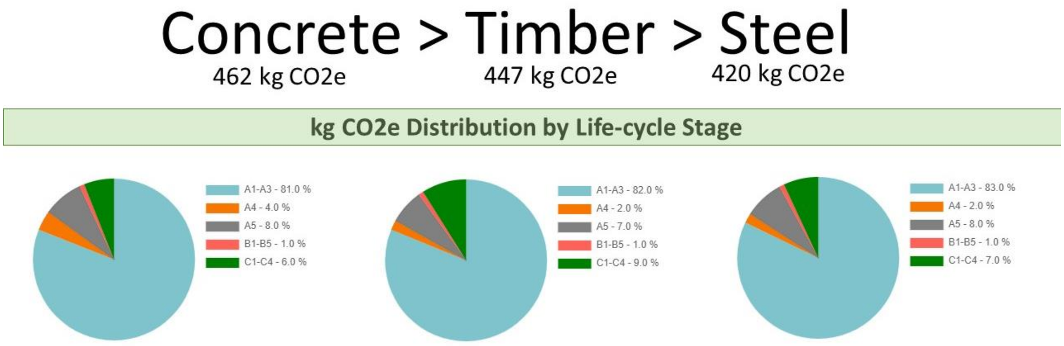

Figure 5: Global warming potential of concrete, timber and steel-framed building per m^2 with distribution by life-cycle stages in charts.

Table 5. The quantified distribution of global warming potential into the stages from A1-A5, B1-B7, C1-C4 and D in kg CO_2 eq unit.

	Global Warming Potential kg CO2 eq		
Stage	**Case Study-I [concrete]**	**Case Study-II [steel]**	**Case Study-III [timber]**
A1-A3 Construction Materials	**9325**	**9116**	**8671**
A4 Transportation to site	**462**	**185**	**221**
A5 Construction/installation process	**910**	**769**	**792**
B1-B5 Maintenance and material replacement	**122**	**122**	**122**
B6-B7 Use/Operational energy (not-included)	**0**	**0**	**0**
C1-C4 Deconstruction	**735**	**983**	**695**
D External impacts (not-included)	**-3283**	**-4801**	**-3076**

Total	**11556**	**11177**	**10503**
Gross Internal Floor Area (IPMS/RICS) 25 m2	**462**	**447**	**420**

According to European Commission, embodied carbon for residential structures is categorized into 6 group between A (for the best situation) and F (for the worst situation) specific to the building type and location based in order to monitor the energy content of building materials in the domestic market (Figure 6). Embodied carbon is the carbon footprint of a product that includes the emissions by production and transportation processes. The results show for these case studies that steel with the least embodied carbon (392 kg CO_2e/m^2) is placed in the B group, timber (420 kg CO_2e/m^2) and concrete (424 kg CO_2e/m^2) with similar embodied carbon are placed in the C group. That result shows about the way between 3 types of buildings (concrete, timber and steel) is built rather than how they are used. It is interesting that the embodied carbon of timber is rather high due to the energy content of a material which depends on the producer and the energy intensity of national level. It is more reliable approach to compare the energy consumption by product from their national statistics.

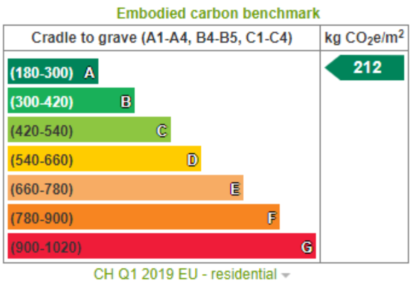

Figure 6: Embodied carbon benchmark (on the left), embodied carbon of concrete, steel and timber-framed structures.

Conclusion

The obtained results of the study show that the concrete-framed tiny house has the highest global warming potential compared to steel and timber-framed structures. Although timber has been identified with having the lowest carbon emission by most of the studies, timber-framed tiny house has the second highest environmental impact while steel-framed building has the lowest impact in this study. The results depend on different factors, including the building type and function, location, the standard used for LCA analyses, service life and environmental declaration of products (EPDs). The only distinctive factor used in the study is EPDs of concrete, steel and timber that have significant influence on the results. Besides, the difference between the amounts of materials used in these concrete, steel and timber-framed structures have an effect on the results of the carbon footprint emitted during their production, transportation and construction process stages, individually.

Since timber production, which includes harvesting, sawing, transporting and processing, consumes high amount of energy, timber ranks second in terms of carbon footprint. It should also be noticed that clear-cut harvesting of forest demonstrates that the vegetation of the site takes more than 200 years since the rate of decay of plants has exceeded their growth and a huge amount of carbons is contained in it (Think Progress, 2011). However, recycling of timber's waste derives the most profit due to its recyclable nature compared to other materials. On the other side, the reports about the emissions of steel production are non-controversial and compatible with EPA reporting (Report Environmental Violations) according to American construction industry, and the emissions of concrete industry are roughly obtained although; emissions from logging operations for timber are tough to acquire (WSA, 2019). The EPDs were selected from the nearby countries as a benchmark to be employed in the evaluations. Due to the lack of suitable EPDs for concrete and timber, only the EPD of steel (generic) was chosen from the country of construction site, Turkey. The product category rules (PCR) that set procedures for verification of EPDs varies in between the materials due to limited sources. Further studies are needed on the difference between PCR programs which provides harmonization to ensure consistency in quality and information types.

As the final outcome it can be concluded that many factors play roles in the environmental impacts of a material that is intended to be utilized in the architectural designs and the mere fact that a material like timber is natural does not mean that it is the best option. Hereby, further studies are encouraged on performing a comprehensive evaluation of the building materials (concrete, steel and timber) to investigate the carbon footprint variations in the design process of architectural projects.

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An Assessment of Building Energy Performances by Building Envelope

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Abstract

Façade, especially opening ratio of walls, is one of the most significant factors that affect the amount of energy usage of buildings. Deciding the right type of material regarding environmental parameters in the early design stage of a construction project helps reduce energy consumption during the lifetime of a building. This study aims to determine how different types of glasses impact both an office building's energy consumption and its Life Cycle Assessment (LCA) in terms of both carbon dioxide emission and energy performance. A reinforced concrete office building in Ankara/ Turkey with two façade systems (fully glazed and partially glazed) with three different glass types alternatives (i.e., flat, double-glass, and double E-low) is used as a case study. To what extent do glass types make a difference in LCA of an office building is examined. Building Information Modelling (BIM)- based LCA process is examined in this research. The LCA add-in tool Tally is used to present the differences in the LCA results. Finally, energy consumption outputs in Autodesk Insight and Global Warming Potential (GWP) of each glass type are evaluated. As a result, while flat glass has the lowest CO_2 *emission, it causes the highest energy usage during the operational phase of two façade options. Besides, double E-low glass required minimum energy while its environmental impact is high through buildings' life cycle.*

Keywords: *building information modelling, energy performance, glazing types, life cycle assessment*

Introduction

The construction sector that consumes a high amount of energy and natural resources has huge negative impacts on the environment (Petersdorff et al., 2006). According to the European Construction Sector Observatory (2018), the construction sector is responsible for almost 35% of carbon emissions and 42% of energy consumption worldwide. Moreover, increased CO_2 emissions in the atmosphere cause more energy demand in the built environment. Therefore, Life Cycle Assessment (LCA) should be considered in early project phases by designers who should take into account the future environmental impacts of buildings. Moreover, to achieve a sustainable holistic approach in the pre-design process, LCA can be integrated with Building

Information Modelling (BIM) (Röck et al., 2018). According to Forth et al. (2019), the integration of LCA and BIM technology simplifies the LCA calculation, contributing to the fully integrated sustainable design process. Besides, BIM integrated LCA enables the prevention of uncertainty and helps designers make informed decisions, especially during material selection for different types of buildings. In the view of building typologies, office buildings are responsible for large amounts of energy consumption. According to the Global Status Report (2017), the required heating-cooling energy and the used electricity in office buildings constitute 33% of the total energy consumption of Turkey. In office buildings, the facade system is the most important component affecting the amount of energy usage (Ihara et al., 2015). Therefore, it is necessary to evaluate different configurations for the facade of office buildings in order to improve overall energy performance. Accordingly, the aim of this paper is to determine how three different glass types (flat glass, double glass, and double Low-E glass) in different facade options impact both an office building's energy consumption and its Life Cycle Assessment (LCA) in terms of carbon dioxide emission and energy performance.

Literature Review

BIM and LCA are the key points for construction projects (Köseci, 2018). The reviewed literature shows that BIM integrated LCA analysis becomes available with the improvements in interoperability. According to Anton & Diaz (2014), BIM and LCA integration should be in the decision-making process of the projects by including environmental criteria. Integrating BIM with LCA can enable having more efficient and sustainable solutions for designers, engineers, managers, and specialists in the project development stage (Crippa et al., 2018). Besides, LCA calculations in BIM ease using LCA tools, accelerate the process and increase the comprehensibility of the results by using the graphical interface of BIM tools (Tsikos et al., 2017). However, as Crippa et al. (2018) state, in order to remove the lack of compatibility between modelling and analysis tools and lack of variety of materials stored in their databases, BIM-LCA tool integration should be improved for enhancing material databases and developing a user-friendly interface.

In the scope of LCA and façade design, Saleem et al. (2018) study on four different building facades, which are brick, granite, aluminum, and glass facades, to compare Life Cycle Assessment of each facade design alternatives. Then, an energy model is developed for investigating the energy consumption of the building, depending on the type of the facade. The environmental impacts of both a transparent composite facade and glass curtain wall system are researched by calculating Life Cycle Assessment (LCA). The results of energy consumptions and CO_2 emissions are compared to each other to assist designers in material selection from the perspective of life cycle (Kim, 2011).

Different glass types of a fully glazed commercial building are evaluated by their environmental life cycle to obtain knowledge about their environmental impacts (Kiani et al., 2005). According to the literature review, BIM-integrated LCA studies are mostly carried out in the scope of whole building components. LCA of different materials is evaluated from the perspective of façade design. On the other hand, the combination of flat, double, and double E-Low glass types has not considered for LCA of the facade components.

In this research, the combination of LCA and BIM is studied to determine and compare the environmental impacts of façade design alternatives according to the three selected glass types. CO_2 emissions and GWP of the proposed façade alternatives are evaluated in a BIM integrated

LCA tool. In addition to LCA calculation in the early design process, energy consumption amounts of all alternatives during their operational phases are estimated using BIM-integrated energy analysis tool Insight. Eventually, the results of CO_2 emissions and energy consumption are combined to obtain optimal facade design alternatives and glass types.

Scope and Methodology

The main objectives of this study are; (i) to analyze the environmental impact and energy performance of two design options with three different glass types, (ii) to present Life Cycle Assessment (LCA) of different configurations in terms of carbon dioxide emission and energy performance. The structural and mechanical systems of the buildings are excluded. The lifespan is considered as 60 years.

The general workflow of this study includes three major steps. Firstly, a typical office building with a two-façade configuration is designed in Autodesk Revit as a case model. Figure 1 presents a brief description of the building. Both design options have three alternatives in terms of glass types of their façade systems: flat glass, double glass, and double Low-E glass. From the point of material description of façade options, the aluminum mullion system is chosen for the fully glazed façade. For the wall with windows façade, wall layers include brick, Expanded Polystyrene (EPS) board, and paintings. The window frames are defined as aluminum.

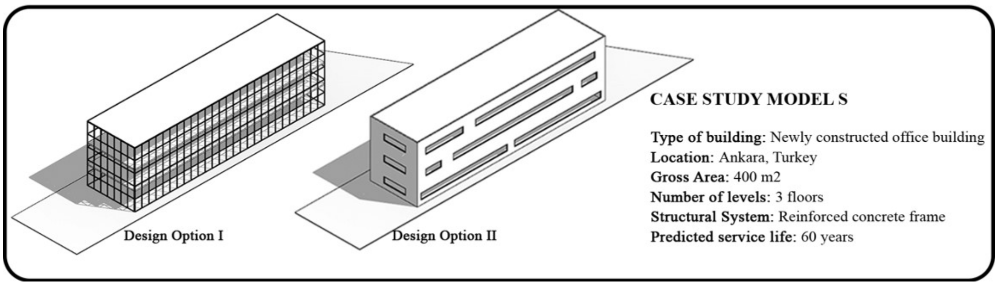


Figure 1: Main characteristic of the case study models.

Secondly, to support a BIM integrated approach, an LCA add-in tool for Revit, namely Tally, is used. After Global Warming Potential (GWP) of each glass type is evaluated, the Autodesk Insight program is used to calculate the total energy consumption of design alternatives with their parameters. Finally, according to the LCA results from Tally and energy consumption results from Insight, inferences, problems, and conspicuous points are described. The framework of the methodology can be seen in Figure 2.

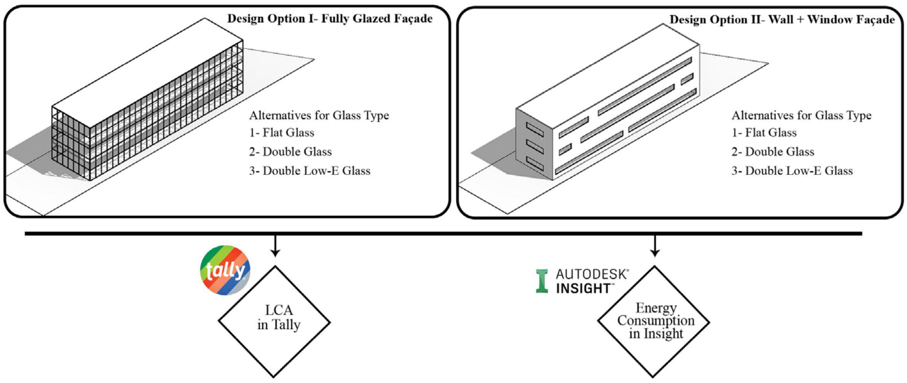


Figure 2: The framework of the methodology.

Results

The LCA analysis in Tally accounts for a full Cradle-to-Grave life cycle of the design process, including production, maintenance and replacement, and eventual end-of-life phases. The results of the environmental impact given by the analyses are discussed with reference to the Global Warming Potential (GWP) [kg CO_2 e]. Increased greenhouse gases (carbon dioxide and methane) lead to negative impacts on the ecosystem, humans, and material welfare.

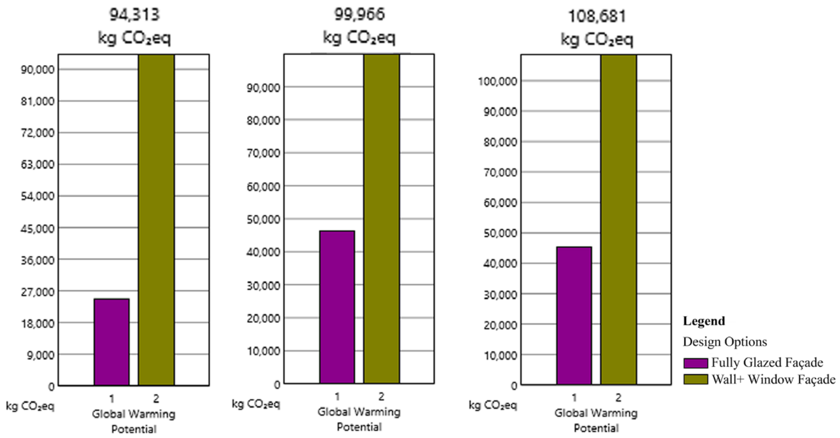
LCA in Tally

LCA calculation in the Tally add-in is carried out according to ISO 14040-14044, ISO 21930:2017, ISO 21931:2010, EN 15804:2012, and EN 15978:2011 standards. For the source of input data, GaBi 2018 databases are used to conduct LCA modeling. The data represents the USA and the year 2017 because, in regard to impact categories, Tally lies on a standard developed by US EPA (US Environmental Protection Agency) (Köseci, 2018).

Full cradle-to-grave LCA analysis in Tally does not include construction installation (energy and water consumed on-site) and operational energy (energy and natural gas consumed over the lifetime of the building), because the chosen site area, Ankara, is not mapped in Tally. The calculation is also based on one square meter as the functional unit. From the perspective of Life Cycle Stages defined by EN 15978, the included processes in Tally modelling are product (extraction, transport, manufacturing), construction (transport), use (maintenance, repair, replacement, refurbishment), end-of-life (transport, waste processing, disposal), and module D (reuse, recycling, energy recovery). The construction installation and operational energy are optional processes.

Tally provides a material library for users to assign materials using its environmental product database. Tally interface presents a well-defined material structure, easy-search filters and, very detailed features of materials (e.g., thermal properties, density, take-off method, service life). Finally, the transportation distance data for the materials are also inserted into the LCA calculation process manually due to the location decision.

As seen from Tally results in Figure 3, GWP of three different glass types (flat, double, and double low-E glass) in two design options show variations. Design option II represents the partially glazed facade while design option I is fully glazed. When the results are compared, the CO_2 emission of the wall and window facade is always higher than the curtain wall, which means that brick raises the GWP.



Flat glass Double glass Double Low-E glass

Figure 3: Comparative global warming potential (GWP) results according to three glass parameters in two façade options.

For the flat glass type in the partially-glazed façade option, the total impact of all life cycle stages is 94.313 tons CO_2e when this value is almost 25.000 tons CO_2e for flat glass type in fully glazed façade during its 60 years of service life. In other words, flat glass in the partially glazed façade has 1,3 tons of CO_2e emission per m^2 /year, whereas the flat glass in fully glazed façade emits 0,35 tons of CO_2e per m^2 /year.

For the double glass, the difference between the two design options is reduced. Double glass in design option II has 99.966 tons of CO_2e, while 46.000 tons of CO_2e is seen for design option I, both for the whole lifespan of the building. Accordingly, the partially glazed facade option causes 1,38 tons of CO_2e emission per m^2 per year, while the fully glazed facade option causes 0,63 tons of CO_2e emission per m^2 per year.

For the double E-low glass, GWP of fully E-low glass façade constitutes 42% of the CO_2 emission of wall + E-low glass window façade. CO_2 emission of the wall with an E-low glass window façade is 108.681 tons, while CO_2 emission of the fully glazed façade is almost 44.000 tons throughout their service life. In other words, E-low glass in wall and window facade emits 1,5 tons of CO_2e per m^2/year, and E-low glass in fully glazed façade emits 0,6 tons of CO_2e per m^2 per year.

Figure 4 shows that the CO_2 emission of production [A1-A3] module is significantly higher than the other life cycle stages. For the flat glass alternative, CO_2 emission of glazing production in the curtain wall façade is less than the CO_2 emission of masonry production in the partially glazed façade. Conversely, for the double and double E-low glass, glazing production for the curtain façade emits higher CO_2e than masonry production for wall with window façade.

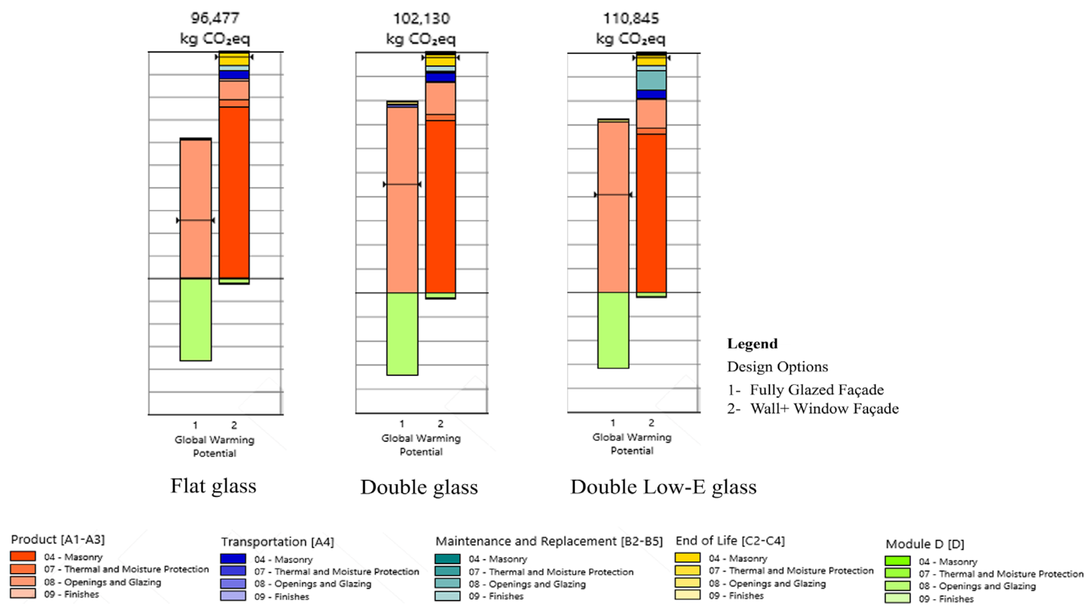


Figure 4: A comparative Global Warming Potential (GWP) results divided by life cycle stages according to three glass parameters in two façade options.

From the perspective of transportation [A4], the distance for each imported material to the site is inserted into the project manually according to the chosen location, Ulus- Ankara. Materials are chosen to be carried by a truck to the site area. Table 1 presents the transportation distances assigned for each component.

Table 1. Transportation distance for each material.

Material	**Truck (km)**
Aluminum curtain wall system, EPD	15
Argon Gas for IGU	15
Brick	250
Expanded Polystyrene (EPS) Board	30
Glazing, monolithic sheet, tempered	30
Hardware, aluminum	15
IGU spacer	15
Lightweight concrete, 2501-3000 psi	25
Low-E coating (for glazing)	30
Mortar type N	250
Paint, Brillux, Acrylic facade paint	40
Window frame, aluminum, powder coated, operable, insulated	15

Maintenance and Replacement [B2-B5] phase includes the replacement of materials according to their service life. The expected service life of used products is identified separately as shown in Table 2. This use stage contains the end of life intervention of the existing products, manufacturing from cradle to gate, and transportation to the site of replacement products.

Table 2. Data from maintenance and replacement [B2-B5] phase.

Product	**Expected Service Life (year)**
Masonry	60
Thermal and Moisture Insulation	60
Opening and Glazing	60
Finishes	15

CO_2 emission ratio of maintenance and replacement stage is depicted in Figure 4. According to the results, the use phase of the partially glazed façade increases CO_2 amount in the atmosphere due to finishing materials and their expected service life (15 years).

The green color in Figure 4 represents the reuse potentials of building materials. Accordingly, in view of GWP and reuse potentials, the lowest potential belongs to the fully glazed façade with flat glass. On the other hand, double Low-E glass and double glass have almost the same potential regarding Module D.

Energy Consumption in Insight

Total energy consumption of the office building is evaluated using Autodesk Insight tool. Building operating schedule and HVAC system are defined for the energy settings. The operating schedule is arranged as 12 hours in six days of a week, and a pipe fan coil system is assigned. In order to examine the effect of building envelope on the total energy consumption, only facade system components are included. The weather file of Ankara is used for energy consumption calculations.

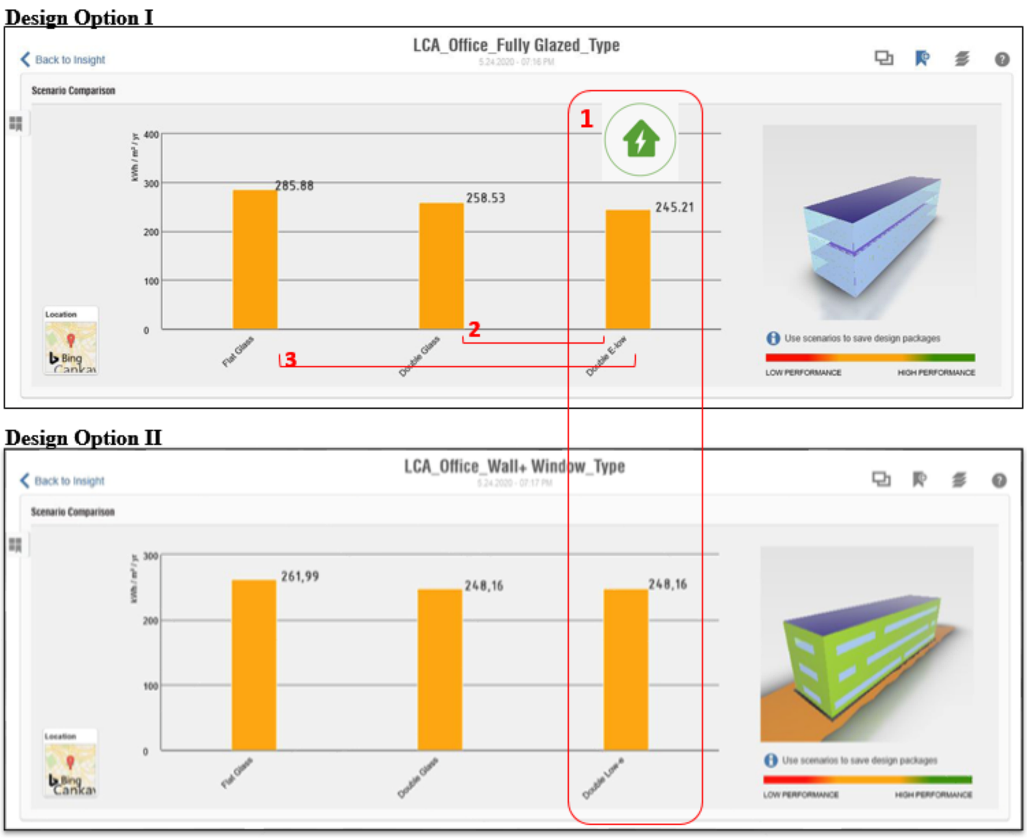


Figure 5: Total Energy Consumption of two design alternatives based on their envelopes.

Figure 5 presents the outputs of the Insight tool. Initially, it was thought that glass surfaces cause thermal loss in buildings, but the red frame (number 1) on the bar chart shows a similar amount of consumed energy in two design options. Line 2 shows that the difference between double glass and double e-low in option I is 13 kwh/m^2/yrs**.** When the difference is considered during the building's service life (60 years), the amount of used energy equals 86 houses worth of heating energy or 612 houses worth of electricity demand per year in Turkey. Lastly, Line number 3 represents that the difference between flat glass and double e-low in option I is 40 kwh/m^2/yrs**.** This amount is equal to the energy needed to heat 264 houses or electricity demand of 1883 houses per year in Turkey during the building's service life (60 years). It can be seen that Double Low E glass saves almost three times more energy per year.[1]

Conclusion

This research study is designed to address two research questions. The first question focuses on the environmental impact of two façade opening types (fully glazed and partially glazed) with different glazing types (flat glass, double glass, double Low-E glass) throughout their entire lifecycle. Tally plugin, which is one of the LCA tools for Revit, is utilized to investigate the Global Warming Potentials (GWP) of the investigated options. According to the LCA results of the two cases, GWP of two different façade designs, fully glazed façade, and wall-

[1] Footnote: The natural gas consumption of a residential unit per year in Turkey is accepted 1032 m^3 on average (Türkiye Doğalgaz Dağıtıcıları Birliği (GAZBİR), 2017)
The electricity consumption of a residential unit per year in Turkey is 1528 kWh (TEDAŞ, 2013)

window façade, differ greatly. The GWP risk of an office building with a wall-window façade is at least two times higher than a fully glazed façade.

The second research question of this study examines the total energy usage of the chosen office building using Autodesk Insight tool in the view of both façade design options and three different glass types. When the amount of energy consumption of the building is considered during its service life defined as 60 years, it is observed that the most energy efficient choice is the design option I (fully glazed façade) with double Low-E glass. On the other hand, the design option I with flat glass has the highest energy usage, among other glass type alternatives.

Consequently, a fully glazed façade with a flat glass alternative is more environment friendly with respect to CO2 emission and Global Warming Potential (GWP). On the other hand, double E-low glass has more potential with regards to reducing energy consumption. There are no definitive or widely accepted judgments about which criteria or impact category should be a priority. Therefore, from the sustainability perspective, it depends on the stakeholder's choice.

This study has some limitations. While using Tally, a specific location for Ankara is not mapped, since Tally's database only works with US standards. However, the location of the office building is accepted as Ankara, but Tally uses US EPA databases hence in the future, a sensitivity analysis will be performed to observe the effects of this decision. Likewise, transportation data is entered manually according to Ankara. Moreover, operational and construction installation energy related to the map was not included. Energy data, while calculating LCA in Tally plug-in, was excluded. Tally material library has limited alternatives. For instance, double Low- E glass type does not exist, there is only Low-E coating component. Because of this, double Low- E Glass type is created manually by using materials, which already exist in Tally's library.

As a future study, the cost estimation of the two cases will be investigated. In addition to the comparison of environmental impact and required energy data for two design cases, cost value should be inserted to this study to illustrate both the economical and environmental impacts.

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A Decision Support Mechanism For LEED Building Design & Construction: Transit Stations

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Abstract

Leadership in Energy and Environment Design (LEED) is one of the most known and widely preferred green building certificate that is provided by the United States Green Building Council (USGBC). Among the several certificate types of LEED, the most recent one is LEED Building Design and Construction: Transit Stations (LEED BD+C: TS), published in order to meet the requirements of transit stations with the valuable input obtained from the metro corporations in India and China. LEED BD+C: TS leads to a complicated decision process that requires multidisciplinary collaboration during decision making process, technical expertise and experience of the decision makers, and investment assessment. In this paper, a decision support mechanism is suggested for such decision-making process. This decision support mechanism utilizes Analytic Hierarchy Process Ranking method, aiming to provide an insight for the decision makers to choose the most efficient LEED credit alternatives in terms of LEED Certification achievement. The proposed decision support system will be tested on a metro station construction in Istanbul Turkey that the first Author has professional experience on, as a case study.

Keywords: *Green buildings, LEED BD+C, transit station, decision support systems, analytic hierarchy process*

Introduction

The construction industry impacts the environment, economy and society significantly by its construction stage and end-product life cycle. 2019 Global Status Report for Buildings and Construction Report of International Energy Agency (2019) states that the construction industry is responsible for 39% of the CO2 emissions around the world, making the industry one of the most extensive greenhouse gas emission contributors. 2019 sectoral data for CO2 emissions show that 17% of construction industry greenhouse gas emission caused by residential buildings, 11% is caused by non-residential buildings and 11% is caused by the manufacturing of construction materials and tools. The international awareness of global warming and its foreseen results on mankind enforced an attempt to hinder – and rewind, if possible – the effects of global warming by establishing an international initiative by the United Nations, called The Paris Agreement (UN Framework Convention on Climate Change, 2016). The Paris Agreement was signed by 196 parties in 2015, requesting each country to outline and communicate their post-2020 climate actions, known as their Nationally Determined Contributions (NDCs). In 2019, 136 of the 194 NDCs submitted to the United Nations included a reference to the building sector (UN Framework Convention on Climate Change, 2015). Overall, the submitted NDCs along with the existing policies of the contributing parties cover 50% of construction-related greenhouse gas emissions in 2018 (International Energy Agency, 2019).

The application of green building measures for new and existing buildings is an increasing trend around the world. This trend is supported by international and national green building organizations such as the United States Green Building Council (USGBC), Building Research Establishment (BRE) in the United Kingdom, and The German Sustainable Building Council (DNGB). Such organizations provide green building certifications for the projects that apply and fulfill the requirements. Most known green building certifications around the world are BREEAM by BRE, LEED by USGBC, and WELL Certification by IWBI. Even though the overall green construction activity is expected to exceed the certified green activities, these certifications are still preferred by project owners because using a certification system enables better performing buildings (67% of the respondents), provides marketing and competitive advantages (53%) and third-party verification in order to prevent greenwashing allegations (52%) (Dodge Data & Analytics, 2018).

According to the data obtained from Turkish Green Building Council (ÇEDBİK) (2020), 5 green building certification systems are utilized in Turkey since 2007: (1) Leadership in Energy and Environmental Design (LEED), (2) Building Research Establishment Environmental Assessment Method (BREEAM), (3) The German Sustainable Building Council (DNGB), (4) Excellence in Design for Greater Efficiencies (EDGE), (5) Turkish Green Building Council (ÇEDBİK). Currently, there are 484 buildings that acquired at least one green building certifications. As it is shown in Figure 1, LEED is the most dominant certification system in Turkey covering 84.2% of the certified buildings with 411 buildings in total (ÇEDBİK, 2020). According to the data obtained from USGBC, there are 897 building in total which is either certified or registered and 89% of these buildings are covered by BD+C type while 6.5% is covered by Interior Design + Construction and 4.5% is covered by Operations + Maintenance in Turkey (USGBC, 2020).

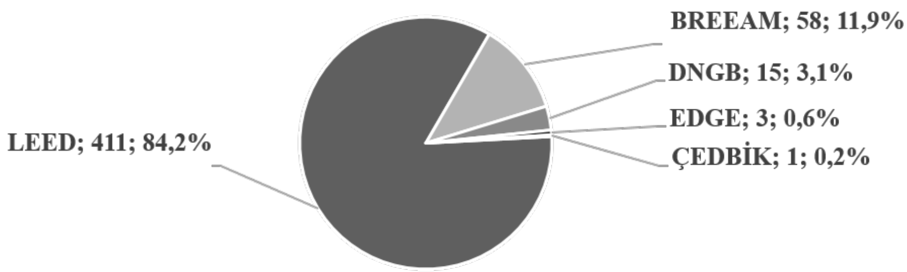

Figure 1: Green building certification systems distribution in Turkey (ÇEDBİK, 2020).

LEED certifications require multiple disciplines to work and decide together for the most appropriate and feasible credits to apply in the project in order to obtain a LEED certificate. There are 4 levels of LEED Certifications: (1) LEED Certified (40 - 49 points), (2) LEED Silver (50 - 59 points), (3) LEED Gold (60 - 79 points) and (4) LEED Platinum (80 + points). In terms of LEED certification management, the variables that affect the level of certification is the cost, simplicity, and the points of a credit. In this case, decision-makers are faced with the problem of balancing these factors because among the 40+ credits with a wide range of points assigned to each and concerning multiple disciplines in the organization, it is difficult to compare the cost, simplicity and point factors, and reach a conclusion. Literature review shows that several decision support systems are proposed and applied in different approaches for various LEED Handbooks, excluding LEED BD+C: Transit Stations since this handbook is fairly newer than its peers and still under development. Most of these studies utilized Analytic Hierarchy Process as a decision support system method and case studies to test the system (Arroyo et al., 2012; Choi et al., 2015; Erdogan et al., 2019; Işık, 2016). On the other hand, most of the studies conducted on this topic cover existing building certifications rather than new constructions (Abdallah et al., 2013; Cheng & Ma, 2014)

The purpose of this study is to propose a decision support mechanism for LEED BD+C: Transit Stations in order to ease the process of presenting alternatives for a final decision and test the proposed Analytic Hierarchy Process (AHP) design on a metro station in Istanbul, Turkey as a case study. LEED BD+C: Transit Stations is chosen because of its developmental nature in order to provide a scarce example among its peers if successful. The goal of this study is to obtain alternatives for: (1) the lowest cost, (2) collecting the highest LEED points, or (3) choosing the simplest credit requirements. The LEED BD+C: Transit Stations consist of 60 credits collected under 9 titles and not all but some of these credits will be selected as alternatives to be included in the study. Utilizing the Analytic Hierarchy Process (AHP) Ranking method through Super Decisions software appears as the most useful and sensitive decision support system for this study to reach the goal.

Methodology

In this study, Analytic Hierarchy Process (AHP) will be utilized as a decision support system. AHP is a structured technique for organizing and analyzing complex decisions, based on mathematics and psychology, developed by Thomas L. Saaty in the 1970s (Saaty, 1980). AHP is a tool to measure intangible factors through paired comparisons that use a judgment scale from 1 to 9 that leads to the priorities for the factors (Creative Decisions Foundation, 2020a). AHP consists of a hierarchical model structure with a goal, criteria (and sub-criteria, if exists), and alternatives that are needed for the pairwise comparison judgments that define the dominance of compared groups of elements in a level below in the context of the elements in the level above. This process allows ranking alternatives in order to provide a clearer vision for the decision-makers. The procedure for using the AHP can be summarized as: (1) Model the problem as a hierarchy containing the decision goal, the alternatives for reaching it, and the criteria for evaluating the alternatives, (2) establish priorities among the elements of the hierarchy by making a series of judgments based on pairwise comparisons of the elements, (3) synthesize these judgments to yield a set of overall priorities for the hierarchy, (4) check the consistency of the judgments and (5) come to a final decision based on the results of this process. The process diagram of the study is given in Figure 2. For the operation of AHP, Super Decisions (Creative Decisions Foundations, 2020b) software will be utilized. In the need for functions that Super Decisions do not offer, such as sorting and filtering and include additional data, data obtained from Super Decisions will be imported and modified in Microsoft Excel.

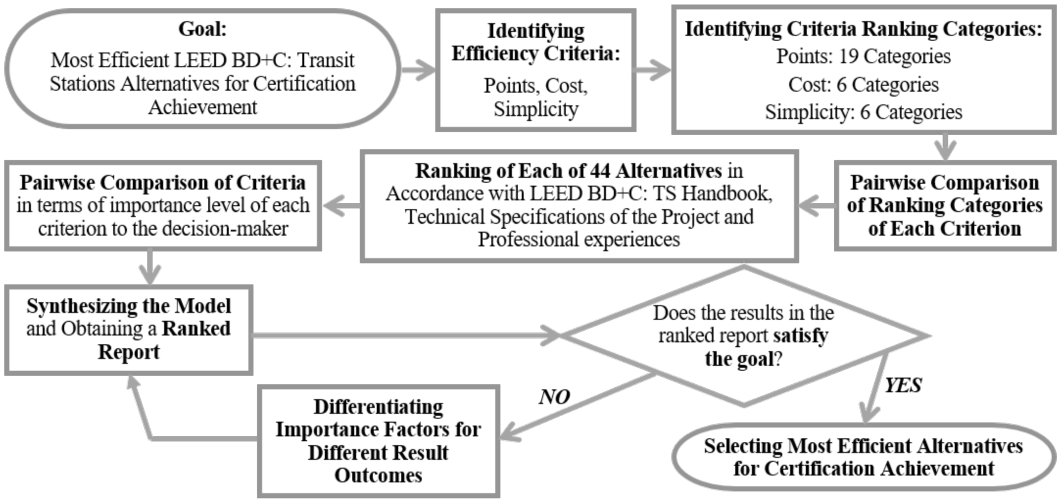

Figure 2: Process diagram of the study.

The selected LEED certification type for this study is BD+C: Transit Station, which has 60 credits under 9 categories: (1) Integrative Process (IP, 1 credit), (2) Location and Transportation (LT, 9 credits), (3) Sustainable Sites (SS, 7 credits), (4) Water Efficiency (WE, 7 credits), (5) Energy and Atmosphere (EA, 11 credits), (6) Materials and Resources (MR, 8 credits), (7) Indoor Environmental Quality (IEQ, 11 credits), (8) Innovation (IN, 2 credits) and (9) Regional Priority (RP, 4 credits). There are 114 points available under 60 credits if all the requirements in the handbook are met (USGBC, 2018; 2019). For the sake of this study, 1 of these categories (9) Regional Priority, and IN1 Innovation credit from (8) are discarded because of these are categorized as "bonus" credits. Also, the prerequisite credits are also discarded since achieving those credits is obligatory for collecting points under each respective category and prerequisite credits do not provide additional points for certification achievement. The remaining 8 categories provide 105 points to compare. The credits under these 8 categories will be called "alternatives" in the context of AHP. These alternatives will be prioritized by utilizing AHP Ratings. AHP Ratings enable rating each criterion for each alternative which is then used for calculating the priority value for each alternative. The priority values are affected by the criteria ratings and the weights of each criterion. The weights of criteria are calculated by a pairwise comparison matrix, in which each criterion is compared to the other criteria numerically. For this study, there are 3 criteria identified: (1) points, (2) cost, (3) simplicity. The hierarchy tree of the study is given in Figure 3.

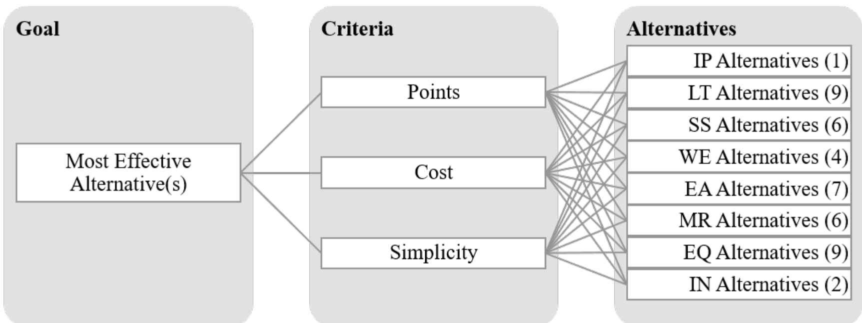

Figure 3: AHP hierarchy tree of the study, 1 goal, 3 criteria, 44 alternatives.

Each identified criterion has ranking values and Super Decisions calculate priority value for each rank according to the pairwise comparisons of the elements in the respective ranking set. The ranking categories and their respective priority values calculated in Super Decisions of each criterion are given in Table 1. The ranks of the Points criterion are given based on the maximum possible achievable point on the LEED BD+C: Transit Stations Project Checklist (USGBC, 2019), which is 19 points that EA2 alternative offers. For the comparison of the 20 ranking levels of the Points criterion, the “Direct Data Entry” function of Super Decisions was utilized and for each ranking level, except Rank 0, the numerical value of the level was assigned on the Direct Data Entry window. Since Super Decisions software does not allow “0” as a comparison value, a hypothetic “0,01” value was assigned for Rank 0. Cost and simplicity criteria rankings are identified on the basis of the first Author’s experiences on both rail systems and LEED certifications. For the Cost criterion categories, each category was pair-wisely compared on a comparison matrix and the importance factors of the categories were obtained by assigning the “higher price – to – lower price ratio” to the lower price (Figure 4). The ranks of the Simplicity criterion were also assigned on the Direct Data Entry window. Each category was assigned a number ranging from 1, the most unfavorable to 6, most preferable; (1) Non-Applicable, (2) Very Hard, (3) Hard, (4) Moderate, (5) Easy and (6) No Extra Work.

Table 1. Ranking categories and respective priority values of criteria (increasing order).

Criterion	**Ranking Ctgs.**	**Priority Values**	**Ranking Ctgs.**	**Priority Values**	**Criterion**	**Ranking Ctgs.**	**Priority Values**
Points	*0*	0,000526	*12*	0,631579	**Cost**	*≤€25.000*	0,039999
	1	0,052632	*13*	0,684211		*≤€20.000*	0,049996
	2	0,105263	*14*	0,736842		*≤€15.000*	0,066675
	3	0,157895	*15*	0,789474		*≤€10.000*	0,100000
	4	0,210526	*16*	0,842105		*≤€5.000*	0,200000
	5	0,263158	*17*	0,894737		*0*	1,000000
	6	0,315789	*18*	0,947368	**Simplicity**	*Non-Applicable*	0,166667
	7	0,368421	*19*	1,000000		*Very Hard*	0,333333
	8	0,421053				*Hard*	0,500000
	9	0,473684				*Moderate*	0,666667
	10	0,526316				*Easy*	0,833333
	11	0,578947				*No Extra Work*	1,000000

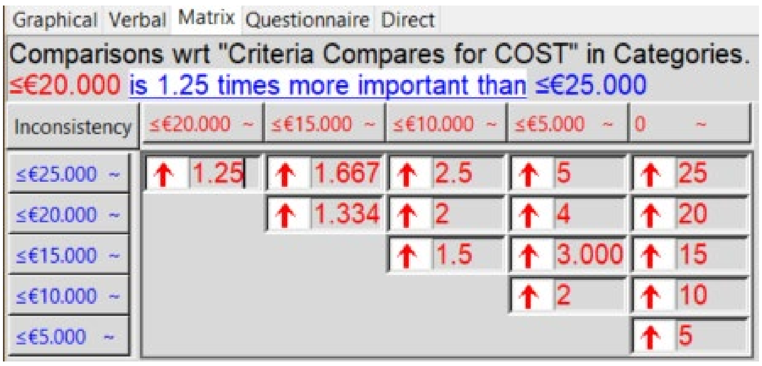

Figure 4: Pairwise comparison matrix of cost criteria categories.

Case Study

In order to test this AHP Ranking model, a metro station from a metro line in Istanbul that first Author has previously worked as a Design & BIM Architect is chosen. Since the data sharing permission process did not finalize, the first Author is not permitted to share project specific information at this stage. first Author has chosen the case study metro station by evaluating their level of knowledge and experience on the metro stations of the respective line and the chosen metro station is specially selected since it was the pilot metro station for construction activities to be analyzed and tested on, which enabled the selected metro station to achieve a higher physical completion percentage than the other stations.

The selected metro station is a cut-and-cover station that has a 3.350 sqm station footprint, 11.000 sqm gross floor area, and a 6.500 sqm construction site area. The station depth is 25 meters, with 2 exit buildings, including 4 escalators and 2 elevators reaching above ground and 16 escalators and 2 elevators reaching to the platform level. The structural elements of the metro station are curtain walls on the outer frame, 4 rectangular and 12 rounded rectangle columns. There is an 88 sqm skylight above the elevators that travel between concourse level and the platform level which enables all three floors of the metro station to make use of daylight. The selected metro station, in terms of LEED BD+C: Transit Stations, is studied and analyzed in accordance with LEED BD+C: Transit Stations Handbook and Technical Specifications of the metro line along with various interviews and ad hoc calculations with the employees of the project (Akarcalı, 2019).

For the AHP Ranking model, the study results from Akarcalı (2019) are utilized. Preliminary analysis showed that the existing design criteria of the metro station can only achieve 35 points out of 114 points, which is not enough to be eligible for a LEED Certification. Later on, a study on the irredeemable credits was conducted in order to investigate the possibility of increasing the total points collected and achieving a LEED Certification by applying appropriate measures to the existing design. This study showed that 8 of the irredeemable credits are suitable to include the station design: (1) EQ6 – Interior Lighting, (2) EQ1 – Enhanced Indoor Air Quality Strategies, (3) WE2 – Indoor Water Use Reduction, (4) WE4 – Water Metering, (5) SS3 – Rainwater Management, (6) IN3 – LEED Accredited professional, (7) EQ8 – Quality Views and (8) SS2 – Site Development – Protect or Restore Habitat. During model building, it was realized that another two irredeemable credit is also suitable to include to the design: (9) WE1 – Outdoor Water Use Reduction and (10) EQ4 – Indoor Air Quality Assessment.

In the light of these studies, an AHP Ranking model was applied to the selected metro station. The ranking diagram is given in Figure 5.

Table 2 presents the 10 LEED credits that are to be included in the design, along with their respective design measures, costs, and points provided along with the Cost and Simplicity criteria conversions for AHP Rankings. The price-range based categorization of Cost criterion was adjusted according to the approximate costs of the additional credits. The credits that can be achieved with existing design criteria were assigned with 0 since achieving them does not cause an additional cost. "No Extra Work" category is assigned to these credits under the Simplicity criterion. The Simplicity values of the credits given in Table 2 were assigned based upon the experience of the first Author. The rest of the credits are identified as Non-Achievable under the Simplicity criterion. The point and cost value of these credits are also assigned as 0.

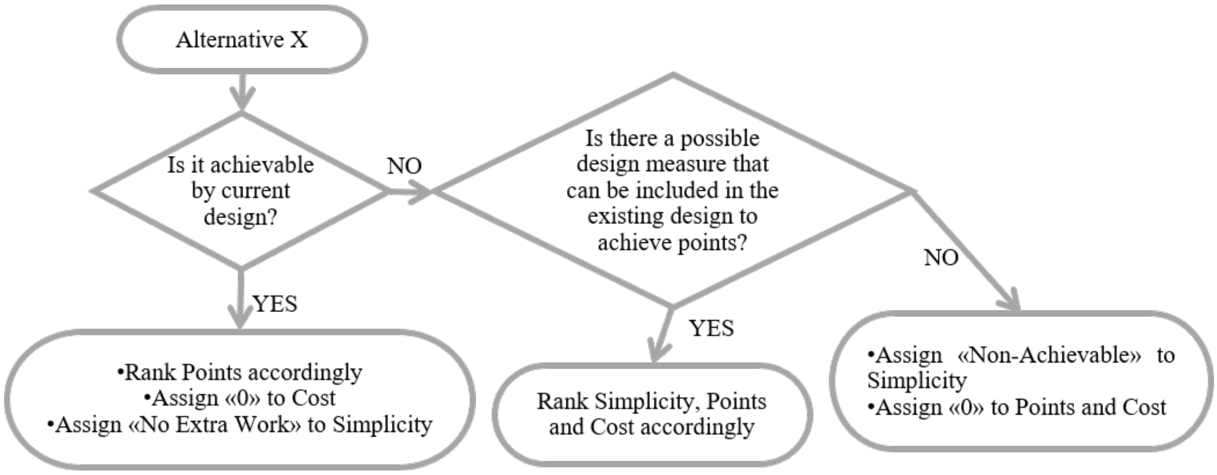

Figure 5: Ranking diagram of the alternatives.

Table 2. AHP rankings of additional LEED credits with respective design measures, cost and points (adapted from Akarcali, 2019).

LEED Credit	LEED Measures	Cost	AHP Cost Criterion	Points	AHP Simplicity Criterion
1. EQ1 - Enhanced IAQ Strategies	CO2 Monitors	€ 7.700,00	≤€10.000	1	Hard
2. EQ4 – Indoor Air Quality Assessment	Air Testing	€ 3.000,00	≤€5.000	2	Moderate
3. EQ6 - Interior Lighting	Dimmer Light Switch & Ballast	€ 950,00	≤€5.000	1	Easy
4. EQ8 - Quality Views	Public Art	€22.750,00	≤€25.000	1	Easy
5. IN3 - LEED Accredited Professional	LEED Accredited Professional	€18.000,00	≤€20.000	1	Hard
6. SS2 - Protect of Restore Habitat	Offsite Financial Support for Habitat Protection	€22.600,00	≤€25.000	1	Moderate
7. SS3 - Rainwater Management	Rainwater Collection Storage + Plumbing	€25.000,00	≤€25.000	2	Hard
8. WE1 – Outdoor Water Use Reduction	Reduced Irrigation	€11.600,00	≤€15.000	1	Hard
9. WE2 - Indoor Water Use Reduction	Fixtures and Fittings	€ 6.500,00	≤€10.000	5	Moderate
10. WE4 - Water Metering	Water Meters	€ 6.900,00	≤€10.000	1	Moderate

For the sake of the study, each criterion was assumed equally weighed and an exemplary priority matrix is obtained from Ratings for Super Decisions window. Later on, the obtained priority matrix was imported into Microsoft Excel and the "Actual Points", "Cost Rank", "Actual Cost" and "Actual Simplicity" columns were added for a more precise understanding of the matrix (Table 3). Lastly, the priority matrix was sorted descending in order to see the highest prioritized alternatives. Table 3 shows that there are only 18 credits that can be achieved with the existing design and these credits provide 35 points in total, which is not enough for achieving a LEED Certification.

Table 3. Modified priority matrix with equally weighed criteria.

Exemplary Criteria Weights (Balanced):		**0,333334**		**0,333333**			**0,333333**	
Credits	**Priorities**	**Point Value**	**Actual Points**	**Cost Value**	**Cost Rank**	**Actual Cost**	**Simplicity**	**Actual Simplicity**
EA2	0,035944	0,263150	5	1,000000	€ 0	€ 0	1,000000	No Extra Work
IN2	0,035944	0,263150	5	1,000000	€ 0	€ 0	1,000000	No Extra Work
LT3	0,034273	0,157891	3	1,000000	€ 0	€ 0	1,000000	No Extra Work
LT4	0,034273	0,157891	3	1,000000	€ 0	€ 0	1,000000	No Extra Work
WE3	0,033437	0,105260	2	1,000000	€ 0	€ 0	1,000000	No Extra Work
EQ9	0,033437	0,105260	2	1,000000	€ 0	€ 0	1,000000	No Extra Work
LT6	0,032601	0,052630	1	1,000000	€ 0	€ 0	1,000000	No Extra Work
SS1	0,032601	0,052630	1	1,000000	€ 0	€ 0	1,000000	No Extra Work
SS6	0,032601	0,052630	1	1,000000	€ 0	€ 0	1,000000	No Extra Work
EA3	0,032601	0,052630	1	1,000000	€ 0	€ 0	1,000000	No Extra Work
EA6	0,032601	0,052630	1	1,000000	€ 0	€ 0	1,000000	No Extra Work
EQ2	0,032601	0,052630	1	1,000000	€ 0	€ 0	1,000000	No Extra Work
EQ5	0,032601	0,052630	1	1,000000	€ 0	€ 0	1,000000	No Extra Work
EA1	0,029814	0,210520	4	1,000000	€ 0	€ 0	0,666667	Moderate
LT1	0,027307	0,052630	1	1,000000	€ 0	€ 0	0,666667	Moderate
MR2	0,027307	0,052630	1	1,000000	€ 0	€ 0	0,666667	Moderate
MR5	0,027307	0,052630	1	1,000000	€ 0	€ 0	0,666667	Moderate
IP	0,027307	0,052630	1	1,000000	€ 0	€ 0	0,666667	Moderate

In order to achieve a certification, at least 40 points are required. In this case, another exemplary priority matrix is obtained from Ratings for Super Decisions in which the Points criterion has the highest weight (Table 4). The results in Table 5 show that, by including WE2 – Indoor Water Use Reduction criteria to the design, the metro station becomes eligible to be LEED Certified, which only causes an additional € 6.500,00 for the construction cost of the metro station.

Results also show that it is also possible to achieve a LEED Silver Certification with the credits that require higher investment. In order to investigate this possibility, a third exemplary priority matrix with equally weighed Points and Simplicity criteria dominant over the Cost criterion was obtained (Table 5). The results in Table 5 show that this is possible if invested in WE2 – Indoor Water Use Reduction, EQ6 – Interior Lighting, EQ8 – Quality Views, EQ4 – Indoor Air Quality Assessment, WE4 – Water Metering, SS2 – Site Development, SS3 – Rainwater Management, EQ1 – Enhanced Indoor Air Quality Strategies and WE1 – Outdoor Water Use Reduction credits, which require a € 107.000,00 additional budget in total.

Table 4. Modified priority matrix where points criterion is the heaviest.

Exemplary Criteria Weights:		**0,818182**	**0,090909**		**0,090909**
Credits	**Priorities**	**Actual Points**	**Cost Range**	**Actual Cost**	**Actual Simplicity**
EA2	0,051695	5	€ 0	€ 0	No Extra Work
IN2	0,051695	5	€ 0	€ 0	No Extra Work
EA1	0,042145	4	€ 0	€ 0	Moderate
LT3	0,040484	3	€ 0	€ 0	No Extra Work
LT4	0,040484	3	€ 0	€ 0	No Extra Work
WE2	0,037099	5	≤€10.000	€6.500,00	Moderate
WE3	0,034879	2	€ 0	€ 0	No Extra Work
EQ9	0,034879	2	€ 0	€ 0	No Extra Work
LT6	0,029273	1	€ 0	€ 0	No Extra Work
SS1	0,029273	1	€ 0	€ 0	No Extra Work
SS6	0,029273	1	€ 0	€ 0	No Extra Work
EA3	0,029273	1	€ 0	€ 0	No Extra Work
EA6	0,029273	1	€ 0	€ 0	No Extra Work
EQ2	0,029273	1	€ 0	€ 0	No Extra Work
EQ5	0,029273	1	€ 0	€ 0	No Extra Work
LT1	0,025329	1	€ 0	€ 0	Moderate
MR2	0,025329	1	€ 0	€ 0	Moderate
MR5	0,025329	1	€ 0	€ 0	Moderate
IP	0,025329	1	€ 0	€ 0	Moderate

Conclusion

LEED is a valuable and one of the most known green building certificates, which is widely preferred worldwide. LEED Building Design and Construction: Transit Stations is a brand-new handbook of LEED, which aims to require more appropriate and applicable measures from the transit station constructions. Including 60 credits under 9 categories that provide 114 points in total, determining the most efficient way of obtaining a LEED Certification is a difficult task because of its multi-disciplinary nature and requirement of professional expertise to assess and quote necessary measures.

In an attempt to facilitate LEED credit assessment process, as a result of the literature review on the topic, the Analytic Hierarchy Process method utilized via Super Decisions software was found to be useful. For the AHP, the goal was set as finding the most efficient LEED credit alternatives for achieving a LEED Certification. In order to reach this goal, three criteria were set: (1) points, (2) cost, (3) simplicity. Later, each criterion was assigned convenient ranking categories, and 44 credits out of 60 credits that are appropriate for assessment were listed as alternatives in Ranking for Super Decisions.

In order to test the designed AHP model, a case study was conducted on a metro station in Istanbul, Turkey. All 44 alternatives were ranked accordingly to the LEED BD+C: Transit Stations Handbook and Technical Specifications of the metro station. Lastly, three exemplary priority matrices were obtained from Rating for Super Decisions, each consisting of different criteria weights. Results of the matrices show that: (1) in terms of the existing design criteria of the studied metro station, it is not possible to achieve a LEED Certification, (2) Points weight dominant matrix enables LEED Certified level with minimum cost, (3) Points and Simplicity weight dominant matrix enables LEED Silver level with a much higher investment requirement.

The case study shows that the designed AHP Ranking model facilitates decision making process for LEED Certification, but it should not be forgotten that the results obtained in this study are not universally valid. The general structure of the model along with Points and Simplicity criteria would be useful for most cases, but Cost criterion categories must be adjusted for each case by professionals. Additionally, it must be stated that, even though this case study was conducted by professionals from one discipline, it would provide better and more precise results if the rankings of the alternatives were conducted by professionals of the relevant disciplines of each LEED credit. The designed AHP Ranking model is convenient for the multidisciplinary decision-making process for LEED Certification, which is strongly suggested for decreasing the margin of error in assessment, assignment and application of measures, and keeping investment costs to a minimum.

Table 5. Modified priority matrix with equally weighed points and simplicity criteria dominant over cost criterion.

Exemplary Criteria Weights:		**0,473684**	**0,052632**		**0,473684**
Credits	**Priorities**	**Actual Points**	**Cost Range**	**Actual Cost**	**Actual Simplicity**
EA2	0,043070	5	€ 0	€ 0	No Extra Work
IN2	0,043070	5	€ 0	€ 0	No Extra Work
LT3	0,039771	3	€ 0	€ 0	No Extra Work
LT4	0,039771	3	€ 0	€ 0	No Extra Work
WE3	0,038122	2	€ 0	€ 0	No Extra Work
EQ9	0,038122	2	€ 0	€ 0	No Extra Work
LT6	0,036472	1	€ 0	€ 0	No Extra Work
SS1	0,036472	1	€ 0	€ 0	No Extra Work
SS6	0,036472	1	€ 0	€ 0	No Extra Work
EA3	0,036472	1	€ 0	€ 0	No Extra Work
EA6	0,036472	1	€ 0	€ 0	No Extra Work
EQ2	0,036472	1	€ 0	€ 0	No Extra Work
EQ5:	0,036472	1	€ 0	€ 0	No Extra Work
EA1	0,030974	4	€ 0	€ 0	Moderate
WE2	0,029489	5	≤€10.000	€ 6.500,00	Moderate
EQ6	0,028463	1	≤€5.000	€ 950,00	Easy
EQ8	0,027906	1	≤€25.000	€22.750,00	Easy
LT1	0,026025	1	€ 0	€ 0	Moderate
MR2	0,026025	1	€ 0	€ 0	Moderate
MR5	0,026025	1	€ 0	€ 0	Moderate
IP	0,026025	1	€ 0	€ 0	Moderate
EQ4	0,024889	2	≤€5.000	€ 3.000,00	Moderate
WE4	0,022891	1	≤€10.000	€ 6.900,00	Moderate
SS2	0,022682	1	≤€25.000	€22.600,00	Moderate
SS3	0,019108	2	≤€25.000	€25.000,00	Hard
EQ1	0,017668	1	≤€10.000	€ 7.700,00	Hard
WE1	0,017552	1	≤€15.000	€11.600,00	Hard

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A Case Study on Common Grounds of Building Information Modelling (BIM) and Lean Construction: Dudullu – Bostancı Metro Line

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Abstract

Several studies indicate that projects adapting BIM applications through their project life-cycle show parallel beneficial outcomes to Lean Construction. In this paper, a case study was conducted on Dudullu-Bostancı Metro Line, aiming to provide an example for the unintentional synergy between BIM and Lean Construction. In the case study, BIM functionalities and the Lean Principles enabled by these functionalities were analyzed to identify the BIM – Lean Construction interactions of the Project. Interviews were conducted with the experts of the Project, and the interview results were interpreted by the authors in the light of the first authors personal job experience in the Project. The results showed that 16 of the 18 BIM functionalities, 22 of the 24 Lean Principles and 27 of the 56 BIM – Lean Construction interactions were observed in the Project. The BIM – Lean Interaction Matrix were adapted in accordance with the identified interactions. The results showed that while it was proven that BIM and Lean Construction had a synergy inbetween, this synergy could be unintentional since the Project did not possess a lean management mentality.

Keywords: *Building information modelling, construction project management, lean construction.*

Introduction

Building Information Modeling (BIM) is a major technological and theoretical development for the architecture/engineering/construction (AEC) industry. Sacks et al. (2010) define BIM as a transformative information technology, as it is the integration of parametric AEC and Information Management which both took off concurrently in the late 1990s (Wierzbicki et al., 2011). Unlike the widely utilized Computer Aided Design (CAD) tools, BIM enables visualization of form, behaviour, function and various other information of building design and construction with its object-oriented properties. On the other hand, Lean Construction debuts itself as a new conceptual project and construction management approach in mid-1990s (Koskela et al., 2002). Essentially, Lean Construction is a translation, rather than a direct application, of Toyota Production System (TPS) principles, which is later labeled as Lean Production by Womack and Krafcik (Lean Enterprise Institute, 2013). Albeit it is a translation of principles, the focus of Lean Construction is same with its parent concept: (a) reduction of waste, (b) increase of value to the customer, and (c) continuous improvement (Sacks et al., 2010).

Even though the two aforementioned developments that effected the AEC industry emerged and were developed concurrently, both remained conceptually separate and independent while manifesting a synergy that is beyond circumstantial (Sacks et al., 2010). In this paper, a literature review on the synergy of Lean Construction and BIM is presented. Afterwards, a case study conducted on Dudullu – Bostancı Metro Line Construction Project was described. In the case study, a series of interviews were performed with the employees of the project, and the interviews aimed to extract their experience in BIM implementation including their previous experiences on similar projects that did not utilized BIM.

Literature Review: The Synergy Between BIM and Lean Construction

Recent studies show that BIM is an effective tool for addressing various principals of Lean Construction. Lean Construction principles can be achieved and/or enhanced through BIM technologies and methodologies, which provide significant waste reduction in terms of time and material while enabling high levels of collaboration, communication and data management. Sacks et al. (2010) argues that even the most basic BIM implementations may serve Lean Construction, if applied properly. A proper dedicated application of BIM in a construction project provide decreased target costs, reduced project duration and higher quality application. All of these outcomes leads to the conclusion of the unintentional Lean property of BIM, which is expected to make BIM an essential and inseparable component of Lean Construction (Gerber et al., 2010). The literature review on the topic showed that there are various synergies between BIM and Lean Construction, and some of them are explained in detail in the following paragraphs.

Clash detection function of BIM found to be highly efficient for waste elimination / reduction goal of Lean Construction (Aziz & Tezel, 2016; Dave et al., 2013; Gerber et al., 2010; Khanzode, 2010; Koskela et al., 2010; Sacks et al., 2010; Tauriainen et al., 2016). This feature enables interdisciplinary superposition of models, detecting and correcting clashes before the implementation phase, and these may prevent waste caused by defects, waiting, overproduction and excess processing. Köseoğlu et al. (2018) report that there were more than 600.000 clashes detected and solved before production at site in Istanbul Grand Airport (IGA) project. According to the study, encountering those clashes during execution would have cost an additional €2.5 billion and an extension of ten years on the contract. On the contrary, it was claimed that early detection and correction of the clashes provided 16.442.036 man/days of time saving and a £835.389.260 cost saving, which is near %10 of the total budget of the Phase 1 of the project.

BIM also allows reducing cycle times of a construction project by enabling rapid generation and evaluation of alternatives and solutions, clash detection, and quick performance analyses for engineering disciplines, time and cost estimation through the data which is stored in the models (Dave et al., 2013; Sacks et al., 2010, 2018). A case study was conducted at a 51.560 sqm health facility with a 286-bed capacity located in Tennessee by Hamdi and Leite (2012), reducing time cycles is found to be as a major contribution of BIM to Lean Construction.

“Gemba Walks” is an important term defined under Lean Production and Construction. Lean Construction Institute (2020) defines Gemba as “*where value is added or where the work takes place*” and Gemba Walks as *“a visual and purposeful walk at the source of the work to thoroughly see and understand work processes and the frontline work”*. This principle endorses the personal observation of the value-adding actions on site in order to understand the situation and/or problem (Liker, 2004). 3D BIM models enable the off-site employees to visit the construction site virtually and this capability provides time efficiency for detecting and solving problems (Erusta & Sertyesilisik, 2020; Sacks et al., 2010; Vestermo et al., 2016). 3D visualization also increases the client's comprehension of the design and construction processes of a building, while providing visual coordination for the team members which allow reducing the waste of time and effort of producing inconsistent interdisciplinary design (Akçay et al., 2020; Dave et al., 2013; Sacks et al., 2010; Vestermo et al., 2016).

Throughout the literature review, the most extensive study on this particular topic was performed by Sacks et al. (2010). In this paper, the authors defined relevant Lean Construction principles and BIM functionalities after a literature review on empirical evidence connection BIM and Lean Construction. They presented 24 Lean principles and 18 BIM functionalities that are to be systematically explored in terms of interrelation. In order to complete this exploration, the authors provide a matrix in which the 18 BIM functionalities are given in the rows and 24 Lean Construction principles are listed in the columns. Each cell in the matrix represented the relation of BIM functionalities and Lean Construction. This relation was evaluated by the experts and a total of 56 interactions are identified, enumerated and explained. Four of these interactions were found to be negative interactions, which diminish the goals of Lean Principles, while the rest was found to be enhancing them.

Methodology

In this study, a case study on the Dudullu – Bostancı Metro Line Construction Project (referred as DB Metro Line or the Project), located in Istanbul, Turkey, was conducted following the BIM – Lean Construction Interaction Matrix (referred as the Matrix) of Sacks et al. (2010). The evaluation of the Matrix was performed via a set of verbal undersigned interviews with the BIM experts and other engineers/architects of DB Metro Line. Interviewees were posed detailed questions related to the relation between the 56 BIM – Lean Construction Interactions presented in the matrix and were asked to evaluate those relations. Also, the primary author of this particular study had worked in DB Metro Line from January 2018 to September 2019 as a BIM & Design Architect in the Design Office. This author collated the outcomes of these interviews with her experience to evaluate the results.

Case Study

Dudullu – Bostancı Metro Line Construction Project is an on-going underground Mass Rapid Transit (MRT) construction, located in Istanbul, Turkey. The Project consists of thirteen stations, two underground car parks, 14 km of rail tunnels, a six-storey administration building, and a single-storey transformer/generator building. The Client of the project is Istanbul Metropolitan Municipality, the Consultant of the project is Arcadis – Tümaş Joint Venture and the Contractor is Şenbay – Kolin – Kalyon Dudullu – Bostancı Metro Construction Joint Venture.

In the case study, a total of nine interviews were conducted. The list of the interviewees were given in Table 1. The BIM Familiarity and the Lean Construction Knowledge Level of the interviewees were given on a three-point verbal Likert scale (1 – low, 2 – medium, 3 – high). The interviewees were asked 56 questions for each interaction. One "yes/no" question for each interaction defined in the Matrix. The questions were asked to identify whether the interactions could be observed in the Project. The answers from the interviewees were noted by the first author and she used her personal experience for interpretation of these answers. The existence of the interaction in the Project was defined based on the number of "yes/no" answers. If one of the answers was given by the majority of the respondents (i.e., five or more interviewees), it was acknowledged as integrated answer of that question. For example, for the 14th interaction, the interviewees were asked "Does automated task generation for planning help avoiding human errors such as omission of tasks or work stages in Dudullu – Bostancı Metro Line?". Since the majority of the answers were "no", this interaction was removed from the adapted Matrix. Apart from these yes – no scale questions, the reasons of their answers were also dicussed with the interviewees in a semi-structured way, prividing insights to the authors for the interpretation of the status of the BIM functionalities, Lean Principles and the interactions observed in the Project.

The interview results showed that there were 27 out of 56 BIM-Lean Construction interactions were observed in the investigated Metro Line. The observed interactions are given in Table 2. The numbers from 1 to 18 given in the columns of the Matrix are the index numbers representing the BIM functionalities and the letters from A to X given in the rows are the index letters representing the Lean Principles. The numbers in the intersecting cells represent 56 types of BIM – Lean Construction interaction. For example, the interaction of the second BIM functionality called "*rapid generation of design alternatives*", with the Lean principle called "*reduce variability (i.e., A)*" is representing the second type of interaction given in Sacks et al. (2010), which is explained as "*Building modeling imposes a rigor on designers in that flaws or incompletely detailed parts are easily observed or caught in clash checking or other automated checking. This improves design quality, preventing designers from 'making-do' (Koskela 2004a) and reducing rework in the field as a result of incomplete design*". Due to page limitations, the explanations of the types of interactions were not provided in this paper, and they can be found in Sacks et al. (2010).

Table 1. Interviewee list of the case study

	Occupation	**Organization**	**BIM Familiarity**	**Lean Construction Knowledge Level**
1	BIM Manager / Architect	Contractor	High	Medium
2	Chief of Structural Design / Civil Engineer, M.Sc.	Contractor	Medium	Medium
3	Chief of Site Works / Civil Engineer	Contractor	Medium	Low
4	Chief of MEP / Electrical Engineer	Contractor	Medium	Low
5.	Chief of Construction Works / Civil Engineer	Client	Medium	Low
6	Supervising Architect	Client	Medium	Low
7	Consulting Architect	Consultant	Low	Low
8	Consulting Architect	Consultant	Medium	Low
9	Consulting Architect	Consultant	Medium	Low

25 of the observed interactions were found to be positive, meaning that the BIM utilization contributes to Lean Construction assertively. The comparison of each BIM functionality in terms of the contribution to Lean Principles shows that *(10) Multi-user viewing of merged or separate multi-discipline models* is the most effective BIM functionality observed in DB Metro Line that enabled the most of the Lean Principles identified in the Project, with seven BIM – Lean Construction interactions given in Table 2. This functionality is followed by *(1) Aesthetic and functional evaluation,* which enables five Lean Principles to be observed in the Project. The rest of the functionalities present a maximum of three positive interactions with Lean Principles (Table 2).

Table 2. Lean principles and bim functionalities interaction matrix of the case study [adapted from Sacks et al. (2010)]

		Reduce Variability		Reduce Cycle Times		Reduce Batch Sizes	Increase Flexibility		Select an Appropriate Production Control Approach		Standardize	Institute Continuous Improvement	Use Visual Management		Design the Production System for Flow and Value				Ensure Comprehensive Requirements Capture	Focus on Concept Selection	Ensure Requirements Flowdown	Verify and Validate	Go and See for Yourself	Decide by Consensus Consider All Options	Cultivate and Extended Network of Partners
		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**P**	**Q**	**R**	**S**	**T**	**U**	**V**	**W**	**X**
Visualization of Form	**1**	2													3				4		11		6	4	
Rapid Generation of Design Alternatives	**2**												7	7		8									
Re-use of Model Data for Predictive Analyses	**3**																								
	4		10	12												8									
	5	2		12																					
Maintenance of Information and Design Model Integrity	**6**	11	11																		11				
	7	12	12																			12			
Automated Generation of Drawings and Documents	**8**	11															54	54							
Collaboration in Design and Construction	**9**			23						36															
	10	2, 13		24				33											43		56	46			
Rapid Generation and Evaluation of Multiple Construction Plan Alternatives	**11**				[29]										[41]										
	12				[29]										[41]					44		47			
	13				[29]								40	40		40						47		49	
Online/Electronic Object-Based Communication	**14**																					47	48		
	15	18																			45			49	
	16			27																					
	17																								
	18																					47	48		

The positive interactions suggest that the Project was successful at performing all of the BIM functionalities except for the third functionality which is the "*predictive analysis of performance"* and the 17th functionality which is the "*integration with supply-chain database"*. The seventeen BIM functionalities identified in the Project were found to be enabling 22 of the 24 Lean Construction principles given in the Matrix, except for "*reducing the change-over times"* and "*cultivating an extended network of partners"*. Even though the majority of the BIM functionalities and the Lean Principles given in the article were detected in the Project, less than half of the 56 interactions identified by Sacks et al. (2010) were observed. These findings showed that performing all BIM functionalities did not automatically ensure the delivery of all aforementioned Lean Construction principles.

The interviewees agreed that the Project could have shown more positive interactions if the BIM utilization were more advanced and less compromised because of the traditional construction project management methods that were used. Also, even though the BIM familiarities of the most of the interviewees are at the medium level, BIM knowledge of the interviewees is found to be low, except the Interviewee Nr.1, creating an obstacle for utilization of BIM at its possible maximum potential. The BIM application level and the BIM knowledge of the contract parties may explain the missing interactions on the Matrix.

On the other hand, the 29th and 41st interactions (represented with brackets in Table 2) represent the negative interactions that highlight the drawbacks of BIM utilization on Lean Construction. These interactions were observed at the 11th, 12th and the 13th BIM functionalities, which are related to the "*rapid design alternative generation and evaluation"*. Apart from the last two, the eleventh BIM functionality, *"Automated generation of construction tasks"* appears to be only negatively contributed to the Lean properties of DB Metro Line. In this context, it can be argued that establishing a wide inventory of detailed design alternatives may cause delaying the necessary selections while causing management complexity, leading to time and inventory wastes. On the other hand, the other two BIM functionalities had both the positive and negative contributions to the Lean Construction principles.

There are several reasons for not being able to achieve all Lean Construction principles through the extensive BIM functionalities of the Project. Firstly, the experts in DB Metro Line agreed that the observed BIM functionalities are not practiced at their full potential. For example, the fifth BIM functionality, "*the evaluation of conformance to program/client value*", was not utilized in all aspects of the project, thus only providing interaction with Lean Construction principles A, partially, and C, while missing the interactions with principles A, partially, B, R, S, T and U. On the other hand, utilization of BIM does not always mean abandoning traditional construction methods, which usually oppose Lean Construction principles. In the project, the project management was conducted by using traditional methods, rather than using BIM processes described in the standards, showing that BIM was not utilized at its full potential.

Conclusions

In order to investigate the relation of BIM with Lean Construction, a case study was conducted by using the BIM – Lean Interaction Matrix (The Matrix) developed by Sacks et al. (2010). Dudullu – Bostancı Metro Line Construction Project, located in Istanbul, was chosen as the case study project. A total of nine semi-structured interviews were conducted with the architects and engineers of the Project, questioning the existence of any BIM – Lean

Construction interactions. The interview responses were collected as yes/no answers which were collated with the job experience of the first Author for the interpreted Matrix (Table 2).

The results of the interviews show that 22 of the Lean Principles were achieved by the utilization of BIM and sixteen BIM functionalities were observed in the project. Even though the majority of the BIM functionalities were observed, it was found that utilization of BIM does not enable the practice of all Lean Principles since only 27 out of 56 interactions were identified in the Project.

The findings showed that BIM was not utilized in the DB Metro Line at its full potential. This low performance of BIM resulted in losing the chance of practicing more Lean Principles and less waste through BIM application. Not aiming to achieve Lean Principles as part of the project management strategy could also be one of the reasons since there were no drivers to improve BIM functionalities accordingly. The utilization of BIM does not always lead the managers of the project to abandon the traditional construction management methods, which acts as a barrier for BIM improvement. It is agreed that the traditional construction management methods utilized in the Project hindered the adoption of BIM at its full potential since these traditional methods oppose Lean Construction. This resulted in a lower number of Lean Principles observed in the interaction Matrix.

It can be argued that in order to observe more Lean Construction principles in the projects, the quality of BIM functionalities should be improved first. BIM utilization requires expertise and commitment, which is challenging for experts who are used to traditional management methods that pose as an obstacle for more contemporary and feasible construction management. On the other hand, apart from the BIM familiarity and knowledge, Lean Construction knowledge and the Lean potential of BIM should be endorsed and acknowledged. In order to achieve more Lean Principles through BIM utilization, the properties of BIM that can serve to Lean Construction should be deliberatively considered and applied to projects. Having said that, it can be argued that it is not possible to achieve the Lean Principles at most if Lean Construction is not a strategical project management aim of the project authorities. In brief, it is a start to utilize BIM for leaner construction projects but it is not possible to achieve a true lean project that operates with BIM without knowing and endorsing the lean properties of BIM, and moreover, setting Lean Construction as a management strategy.

However, even though it is known that the Project could not utilize BIM at its full potential because of lack of knowledge, opportunity, and commitment caused by traditional mentality, it was observed that the Project still showed Lean properties through the BIM functionalities without the aim of following Lean Construction principles. These results show that BIM could be an assertive partner of Lean Construction and it can be acknowledged that there is, indeed, an unintentional synergy between BIM and Lean Construction. There are several other metro lines in Istanbul, Turkey that utilize BIM and this study may be extended by the inclusion of these particular metro lines for a better understanding of the relationship between BIM and Lean Construction and to identify the flaws that prevent the interactions between.

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Causes of Delays and Cost Overruns in Public School Construction Projects

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Abstract

Public school construction projects are generally dated and they have limited budget. Achieving budget and duration targets in such projects is crucial for project success. Project delays and cost overruns are the factors that negatively affect educational strategies. There are many reasons for delay and cost overruns. In this study, causes and effects of delays and cost overruns in public school construction projects are analyzed. The frequency of the data is interpreted and main causes are determined. As a result, the main reason for delays and cost overruns is determined as change orders. Second reason is bureaucracy. It is seen that effective feasibility phase will greatly reduce project delays and cost overruns.

Keywords: *cost overruns, delays, public school construction projects, Turkish construction industry.*

Introduction

Two of the main indicators that measure the success of construction projects are the completion of the work on time and budget. However, various problems occurring during production prevent the project from being completed within the specified goals. It is observed that in public building constructions in Turkey, cost and time deviations due to many reasons may occur. It is very important to meet the performance targets because the budget of public building constructions is met from taxes and it will serve the people. Therefore, identification of problems causing time and cost overruns are especially important for public building constructions.

The production process of public building constructions differs from private buildings. Designs in public buildings are generally standardized and bureaucracy takes an important place in production. This triggers design-related change orders and delays in the program. This unique production model makes public building constructions an important research topic (Alinaitwe et al., 2013). Mostly deficiencies in planning and design phases causes change orders (Hsieh et al., 2004) and this effects project time and cost performance negatively. Poorly managed changes may have significant negative impacts on project time and cost performances.

In addition to the changes in the project, many reasons can have negative effects on cost and duration. Unexpected situations in the building area, bureaucracy, changes in the zoning cause various time and cost deviations. In this study, the main and root causes of cost and duration deviations in public school construction projects and the effects of these factors are investigated.

Literature Review

There are numerous studies in the literature on the reasons for time and cost overruns in construction projects. Several causes for time and cost overruns are identified in the literature.

One of the causes is the change orders. Oladapo (2007) investigated impact of change orders on construction projects. As a result, it was understood that the change orders had a great impact on time and cost overrun. Sunday (2010) examines the impact of variation on construction projects and the results show that the average increase in duration is 27.25% and the average increase in cost is 28.68%. Sweis (2013) implemented a survey to engineers in order to identified time and cost overrun factors. Author determined the most influential factors are design changes, and weather conditions. Aljohani et al. (2017) investigated the causes of cost overruns. For this purpose, authors reviewed the related literature. Authors claim that one of the most important reasons for the cost increases in construction projects is frequent design change during construction phase. Shrestha and Zeleke (2018) determined the effects of change orders in public building construction projects. The study shows that the change orders increased the project cost by 3.56% and increased project duration by 40% on average. Yap and Skitmore (2018) investigated design changes in Malaysian. The research reveals that building projects in Malaysia encounter time – cost overruns of 5–20% due to design changes. Shrestha et al. (2019) examined probability of change orders and their effects.

Enshassi et al. (2009) determined time and cost overrun factors derived from material-related situations. Lack of materials in markets and delays in materials delivery to the site are determined as the most important factors. Enshassi et al. (2014) also determined material-related factors as important causative factor. Rosenfeld (2014) identified root-causes of project cost overruns. The study has seen premature tender documents (design documents) as one of the major cost overrun factors. Mpofu et al. (2017) determined causative factors leading project delay. Results show that design-related factors affect construction schedule performance. Famiyeh et al. (2017) discussed major causes of cost and time overrun in construction projects. It is determined that material-related factors and financial factors are major issues cause overruns.

Material and Method

This study focuses on identifying main and root causes of delay and cost overruns in public school building constructions. For this purpose, 141 official duration or budget increase reports prepared by provincial directorate of national education for 85 public school building constructions between 2015 and 2018 were examined. Total increase requests, total project duration and budget data were collected from the reports. Basic statistical indicators of the data were interpreted. Thus, main and root causes of delay and cost overruns are determined.

Main Causes of Delays and Cost Overruns in Public School Construction Projects

Firstly, main causes of delay and cost overruns are determined. Results show that most of the factors that cause cost or time overrun are caused by change orders (Fig. 1). Approximately 50% of time and cost overruns arise from change orders. It is also understood that the majority of change orders consist of architectural design and heating systems.

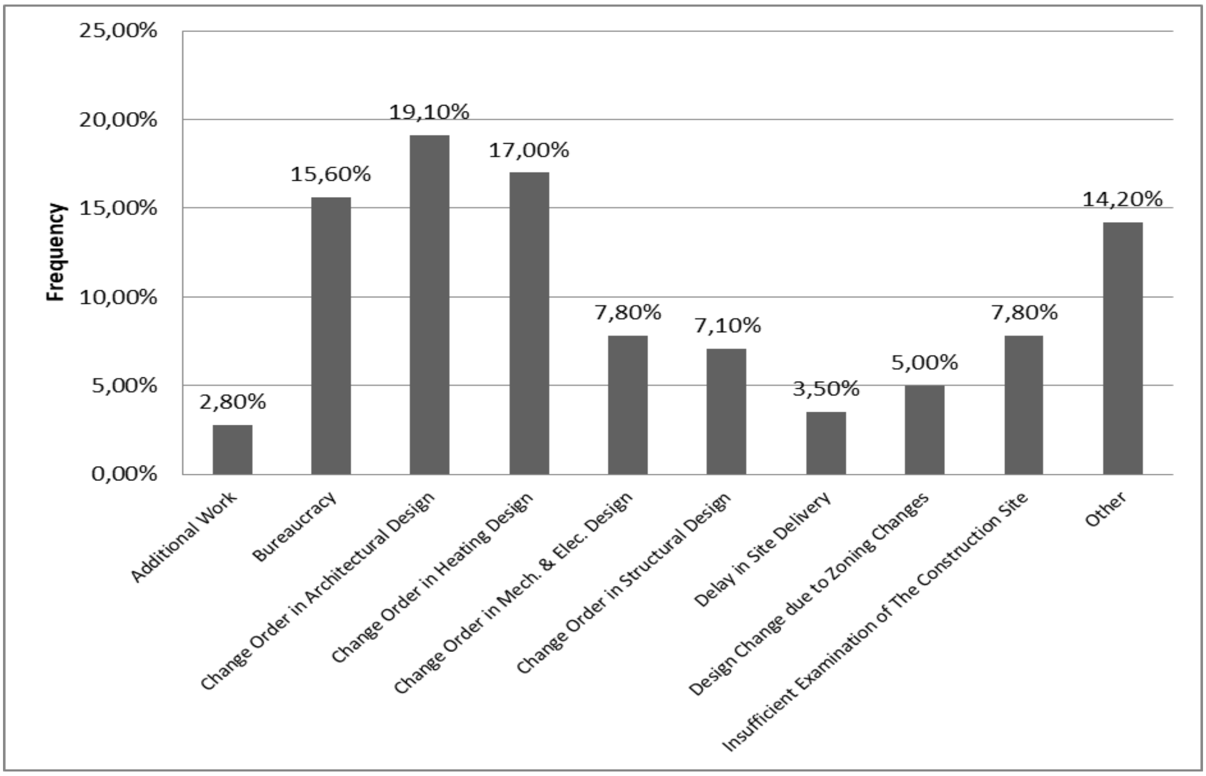

Figure 1: Main causes of time and cost overruns.

Other major factors are poor investigation of the construction site, delay in site delivery, bureaucracy and additional works.

Root-Causes and Effects of Delays and Cost Overruns in Public School Construction Projects

In order to prevent delay and cost overruns in construction projects, root-causes should be investigated. In this study, root-causes were also examined. As the most important factor in delay and cost overruns is change orders, firstly, the root-causes of this factor are studied. The root-causes of the change orders in the public building construction projects and their effects are as given in Table 1.

Table 1. Root-causes and effects of change orders.

Main Cause	Root-Cause	Frequency (%)	Cost Overrun (%)	Delay (%)
Change Order in Architectural Design	Change in Elevator Design or Size	40,70	1,09	8,55
	Change in Roof Design	7,40	3,50	21,50
	Change in Trim Works	14,80	4,75	18,00
	Complying with The Regulations	3,70	0,58	22,21
	Poor Observation of The Construction Site	3,70	2,67	45,33
	Layout Plan Revision	14,80	2,50	28,25
	Not Identified	14,80	-	-
Change Order in Structural Design	Structural System Revision	30,00	6,67	49,67
	Changing Concrete Quality	10,00	-	17,00
	Foundation Design Revision	40,00	8,75	19,25
	Not Identified	20,00	-	-
Change Order in Heating Design	Compliance with Existing Infrastructure	100,00	0,58	22,21
Design Change due to Zoning Changes	Zoning Changes	100	1,57	9,86
Change Order in Mechanical & Electrical Installations Design	Electric Cable Section Revision	27,30	0,33	2,00
	Increasing the Elevator Capacity	27,30	0,33	5,00
	Lighting System Revision	9,10	-	27,00
	Increasing Transformer Power	9,10	-	18,00
	Video Surveillance System Revision	9,10	3,00	8,00
	Not Identified	18,20	-	-

The major root-cause of change orders in the architectural designs is “Change in Elevator Design or Size” (40.70 % of change orders). But it does not seem to have a great effect on project cost and duration. The major architectural design factor causing the delay in the project is the poor observation of the construction site. It may cause a delay of 45% of the total project duration. This situation arises from the typical projects that are frequently used especially in the public. Other main factors causing delays in the project are; “Layout Plan Revision”, “Complying with the Regulations” and “Change in Roof Design”. Layout plan revisions arise from changes in zoning plans or insufficient observation of the building area. Insufficient observations during the design phase can cause serious delays in projects. In fact, each construction project has its own unique conditions and designs should be produced considering these conditions. Type projects cause serious delays in the project.

When it comes to cost overruns, it is observed that changes in fine works and changes in roof design are major factors increasing total budgets. These changes are mostly the request of the institution. These are factors that can be overcome by management's involvement in the design phase.

Another important reason for the delays in the projects is structural design change order. Revisions on the reinforced concrete structure have an impact on both time and cost. The most important root cause of reinforced concrete system revisions is the insufficient geotechnical examination. The incompatibility between the structural system and geotechnical soil reports causes changes in the production process, thereby increasing costs and duration of project substantially.

Another factor that is particularly effective on the duration of the project is the heating system and infrastructure mismatch. One of the handicaps originating from type projects is that it has a certain heating-cooling system. Heating systems of the type projects designed independently from the infrastructure of the region where the building will be constructed are often revised. Such revisions occur especially in regions have no natural gas infrastructure. As seen in the Table 1, not preparing the designs in accordance with the existing infrastructure causes a 22% increase in project duration.

Finally, the change orders in the installation designs were examined. It is seen that the revisions in the installation designs have no significant effect on the construction cost. But when it comes to delays, there is a considerable influence. Especially, in electrical design revisions, a delay in the range of 18% to 25% can be observed.

Other factors causing cost and duration deviations in public school construction projects are “Additional Work”, “Bureaucracy”, “Delay in Site Delivery” and “Poor Site Investigation”. The root causes of the factors are as given in Table 2.

In general, non-design factors have effect on project duration. These factors cause serious extensions in the project duration rather than cost overrun.

The first major root-cause discussed is “Additional Works”. It is seen that additional works that arise during the production process have serious effects on the project duration and cost. It is observed that demolition works and infrastructure works, which prevent the construction process from starting, have serious effects on the duration of the project. This factor causes an approximately 20% deviation in the project duration. On the other hand, the increase in quantities during the project causes cost increase rather than duration. Increases in quantities cause the cost overruns up to 9%.

The intensity of the internal bureaucracy in public construction works can cause significant time deviations in the projects. As seen in the table, awaiting and correspondence periods in the construction process may cause serious delay in project delivery. While this factor is related to the organization's own functioning, it is unfortunately difficult to avoid such delays. In order to prevent such delays, serious revisions should be made in internal approval and document processes.

Table 2. Root-causes and effects of non-design factors.

Main Cause	Root-Cause	Frequency (%)	Cost Overrun (%)	Delay (%)
Additional Works	Destruction	25,00	-	25,00
	Electricity Service	25,00	1,00	17,50
	Increase in Quantities	25,00	9,00	-
	Infrastructure Deficiency	25,00	2,00	-
Bureaucracy	Awaiting Confirmation	31,80	1,20	19,40
	Awaiting Notification Period	9,10	-	7,50
	Correspondence Period	22,70	-	13,60
	Electricity Service	4,50	1,00	17,50
	Evacuation Period	4,50	-	6,00
	Natural Gas Service	27,20	1,80	24,80
Delay in Site Delivery	Permit Process	60,00	-	10,33
	Unexpected Condition	40,00	2,67	45,33
Poor Construction Site Investigation	Incorrect Investigation	18,20	5,00	29,50
	Poor Infrastructure Detection	54,50	-	14,33
	Unexpected Condition during Excavation	9,00	-	17,00
	Not Identified	18,20	-	-

In public constructions, building production begins with site delivery. Unexpected conditions in the building area or the prolongation of the licensing processes may lead to delay in the delivery of the place and thus the extension of the project period. Unexpected conditions at the construction site result from poor observation of the construction site, as with design-related change orders. Old buildings or trees in the building area cause such delays. Another factor causing delay in site delivery is permit procedures. This factor is among the factors that cause time extensions in both public and private building projects. Bureaucracy, especially design approval processes in the public authority plays an important role in prolonging the permit procedures. In order to eliminate such delay problems, permit procedures need to be handled more realistically in the planning phase.

Ultimately discussed delay and cost overrun problem in this study is “Poor Site Investigation”. Failure to observe or analyze the construction site sufficiently can lead to unforeseen problems in the production process. This is largely due to the failure to observe the construction site or to identify the infrastructure in the region. Insufficient data about the region and the land causes unexpected problems during workplace delivery or excavation. Such problems cause approximately 20% deviations on the project duration.

Conclusions

In this study, the main and root causes of delays and cost overruns in public school building constructions were investigated. As a result of the report reviews, various reasons that cause deviations in cost and duration were determined.

As a result of the study, the main and root reasons that cause cost and time deviations were examined in two groups as design and non-design factors. In design factors, the reasons arising from change orders were investigated. At this point, the biggest problem that arises is the type project. The fact that type projects are not suitable for all regional infrastructures causes various changes. Especially the adaptation of the heating system and elevators to the current project causes both time and cost deviations. In addition, it is seen that reinforced concrete structure revisions caused by insufficiency of geotechnical soil reports cause serious time and cost deviations.

Non-design factors investigated in this study are “Additional Works”, “Bureaucracy”, “Delay in Site Delivery” and “Poor Site Investigation”. Although additional works may cause delays and cost overruns, bureaucracy, delay in site delivery and poor site investigation may cause serious delays in school building constructions.

In order to avoid such time and cost deviations, it is necessary to deal with type project implementation specifically for each region and examine the building area in detail.

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Performance Evaluation of Construction Projects by EVM Method, Using Primavera P6 – A Case Study in Istanbul, Turkey

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Abstract

Most of the construction projects are exposed to time and cost overruns due to various factors and this is a major problem. As a solution to this, the Earned Value Management (EVM) method is considered. EVM is a powerful and well-known method used in monitoring and controlling the project. EVM gives an early indication that either project is delayed or not and the project is either over budget or under budget at any particular day by tracking it. Thus, it helps to improve the management control system of a construction project, to detect and control the problems in potential risk areas and to suggest the importance and purpose of monitoring the construction work. This paper explains the main parameters of the EVM system involved in the calculation of time and cost for construction projects. In this study, the Primavera P6 software is used to deals with the project monitoring process of a seven-storey (G+6) faculty building whose construction is in progress at Istanbul, Turkey. A comparison between the planned progress of construction activities and actual progress is performed and the analysis results are interpreted. This case study justifies the benefits of using EVM for project cash flow analysis and forecasting.

Keywords: *construction cost management, construction planning, earned value management (EVM), Primavera p6, project management, project scheduling.*

Introduction

The construction industry is one of the most rapidly growing industries in the world. The construction sector is an important industry branch at both the global and national levels. Construction projects provide many investment opportunities across various related sectors. Therefore, the construction sector is an important economic indicator for developing countries like Turkey. The construction industry in Turkey plays a vital role in creating both economic growth and employment opportunities for the country.

In developing countries like turkey, most construction projects face time and cost overruns due to a large number of uncertainties in the construction industry (Vyas & Birajdar, 2016). It is the prime responsibility of the project manager to control the costs associated with the work packages. Project managers can avoid time and cost overruns by using an effective project monitoring and control technique.

Traditionally, the evaluation of the budgeted cost of construction projects is based only on two parameters: 1) Planned expenditure, 2) Actual expenditure. Although these parameters help the manager to compare the planned and actual spending, they do not contain information about the progress of the project. As it does not give any idea about the completed work, this information is not sufficient. Moreover, it is also not possible to relate the completed work with the amount of money spent on it (Waris et al., 2012).

The development of Earned Value Analysis Management helped overcome the shortcomings of traditional project management techniques and provided information to managers about the project progress (Karaman & Son, 2018). Except planned and actual expenditures, earned value management (EVM) introduces a third variable named earned value (EV). This parameter provides clear and concise information about the budgeted cost and schedule.

According to PMI, (2008) the earned value management (EVM) is recommended as the global standard for project performance measurement. The concept of implementation of the EVM into the cost control and even to overall performance measurement of construction projects have been presented by many authors (Burtonshaw-Gunn, 2009; CIOB, 2011; Fewings, 2013; Levy, 2012).

In this study, first earned value analysis is reviewed and the parameters constituting the analysis are explained. Within the scope of this study, the EVM analysis was applied to a real project data, and the results were interpreted with a case study. A G+6 building is selected for analysis as a case study. Later, the Primavera P6 is used to apply “earned value analysis” over some clusters of activities related to the construction project. The steps used to perform EVM analysis using Primavera P6 software are described and finally, results are evaluated regarding the performance of the activities.

Earned Value Management (EVM)

Earned value project management is a well-known management system that integrates cost, schedule and technical performance. It allows the calculation of cost and schedule variances and performance indices and forecasts of project cost and schedule duration. The earned value method provides early indications of project performance to highlight the need for eventual corrective action (Vandevoorde & Vanhoucke, 2006).

Earned value management as a good method for better project management. It is stated that this method can be used to estimate progress performance and project completion. It integrates scope, cost and schedule measures, and could give a good picture of current project status at the date of control Nagrecha (2002).

Earned value is a program management technique that uses “work in progress” to show what will happen to work in the future. EVA uses cost as the common measure of project cost and schedule performance. It allows the measurement of cost in currency, hours, worker-days, or any other similar quantity that can be used as a common measurement of the values related to project work. (Subramani et al., 2014).

Important Earned Value Management Terms

EVM monitors the project's progress against a baseline. It includes the following basic elements to evaluate projects technical performance. The basic terms related to earned value management are (PMI, 2011; Vyas & Birajdar, 2016) as follows,

Planned Value (PV): It is the amount of money budgeted to be spent at a particular point in time. Or in a simple way, the cost of the project according to the schedule of the project. PV is also known as budgeted cost of work scheduled (BCWS). Planned value is calculated before actually doing the work, which also serves as a baseline. Total planned value for the project is known as budget at completion (BAC).

Actual Cost (AC): It is the actual amount of money spent for the corresponding planned and earned value or the amount spent on the project to date. This actual cost must correspond to whatever was budgeted for the planned value and earned value (e.g. all labor, material, equipment and indirect costs). It is also known as the actual cost of work performed (ACWP).

Earned Value (EV): It is the amount of work in terms of cost that is actually accomplished at a particular point of time with respect to the planned value or the planned value of actually completed work. It is also known as budgeted cost of work performed (BCWP).

Cost Variance (CV): It is the difference between earned value and actual cost (EV-AC).

Schedule Variance (SV): It is the difference between earned value and planned value (EV-PV).

Cost Performance Index (CPI): It is the ratio between earned value and actual cost. If CPI greater than 1 then the project is under budget and CPI less than 1, then the project is under budget.

Schedule Performance Index (SPI): It is the ratio between earned value and planned value. It indicated how much ahead or behind schedule, the project is at a particular time.

Critical Ratio (CR): It is the product of the cost performance index and schedule performance index. It indicates the overall performance of the Project with respect to both cost and time.

Estimate at Completion (EAC): It's a prediction of the total project cost based upon the current trends in project performance.

Variance at Completion (VAC): It is the difference between the planned budgets at the beginning of the project to the estimate at completion. This value denotes how much more profit or loss the contractor will make on that project.

Time Estimate at Completion (EACt): It predicts the completion time of a project based on its current performance. EACt = (BAC / SPI) / (BAC / months).

Table 1. Earned value management formula and interpretation. (Bhosekar & Vyas, 2012).

Name	Formula	Interpretation
Cost variance (CV)	EV – AC	Negative is over budget, positive is under budget.
Schedule variance (SV)	EV – PV	Negative is behind schedule, positive is ahead of schedule.
Cost performance index (CPI)	EV / AC	Less than 1 poor performance is greater than 1 good performance.
Schedule performance index (SPI)	EV / PV	Less than 1 poor performance is greater than 1 good performance.
If SPI = 1, SV = 0 On proper schedule SPI < 1, SV < 0 Behind the schedule SPI > 1, SV > 0 Ahead of schedule		If CPI = 1, CV = 0 Project is on budget CPI < 1, CV < 0 Project is over budgeted CPI > 1, CV > 0 Project is under budgeted
Estimate at completion (EAC)	AC + ETC	As of now how much do we expect the total project to cost ₺ • Actual plus a new estimate for remaining work.
Estimate to complete (ETC)	EAC – AC	How much more will the project cost?
Variance at completion (VAC)	BAC – EAC	How much over budget will we be at the end of the project?

EVM implementations for large or complex construction projects helps in indicating and forecasting the cost performance (over budget or under budget) and schedule performance (behind schedule or ahead of schedule).

Application of the EVM in the construction site management practice does require a regular register of time and cost data (usually once a week) in order to get the two following values: AC which is the actual cost of work performed and PV which is budgeted cost of work performed. The third required value, namely EV is budgeted cost of work scheduled. It can be defined before the start of works, based on the time schedule of all works and the associated cost plan (Fig. 1).

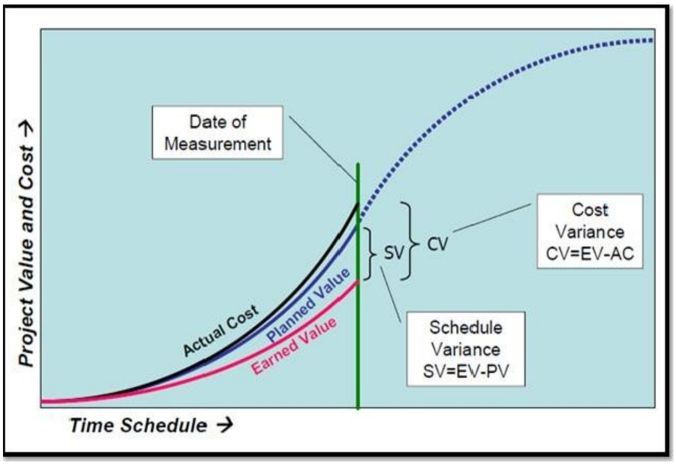


Figure 1: Three basic curves used in the EVM. A standard EVM graph.

Case Study

In this study, a seven-storey (G+6) a university faculty of dentistry construction project which is in progress in Istanbul selected as a case study. One of the authors worked as a planning engineer in the related project and the data were collected by him. The project duration is 28 months and the budget at completion (BAC) is ₺ 104,947,000,00. Construction, electrical and mechanical disciplines are included in the project planning. The number of activities of the project considered in the EVM analysis is 543 activities. Earned value analysis was done at 5 different points of time. Here the last EVA analysis of the project which was done at the end of the twentieth month is given. This analysis will indicate the efficiency at which the work was done and the rate at which it was completed. It also shows the additional profit or loss the contractor will make with respect to what was originally planned.

There are so many construction management software is available in the market. But nowadays, MSP and Primavera are the most popular software which is used for monitoring and control of construction projects. Primavera is an amazing software which can be used for small as well as a large project. In this software, we can control and monitor as many projects at the same time. In this study, the earned value analysis of a real construction project is done by using primavera p6 software. The following sections explain the software in brief. Also, give information about the steps involved in monitoring and control of our project.

Primavera is used for making project management smooth. It is helpful in civil engineering for creating strategies, controlling the delay of the project and determines the optimum use of resources. Primavera is used to completing the project within a specified time and cost. It is the application of skills, tools and techniques to project activities in order to carry out the demand of the owner. Primavera program is used to scheduling, controlling and estimating all types of projects (Saini et al., 2019).

Primavera P6 manages and controls activities associated to project management as well as resource management. Resources representing labor, materials, and equipment are used to track time and costs for the project. Projects’ activities are updated resulting in the adjustment of time-related bars. It needs the database of Oracle My SQL.

Steps involved in monitoring and control of our construction project are;

1) **Create a new project:** A project is a collection of activities and related information that forms a plan for creating a product or service. The project is made under the related department in Enterprise Project Structure with project ID and project name. Planned start and must finish dates can be given to the project. A calendar is assigned to the project which can be global, resource, or project calendar.
2) **Work breakdown structure (WBS):** WBS is a hierarchical structure of work that must be able to complete a project. Each project has its own WBS hierarchical structure. Each WBS element may include more detailed WBS levels, activities, or both in it as shown in Fig. 2.
3) **Determining activities:** Activities are the basic work elements of a project. They are the smallest part of a project. An activity has mainly the following characteristics such as activity ID, name, start and finish dates, activity calendar, activity type, activity codes, constraints, expenses, predecessor and successor relationships, resources, roles, etc., shown in Fig. 3.
4) **Relations between activities:** To constitute a network, the activities should be linked to each other, which is done by allocating relationship to the activities as shown in Fig. 4.
5) **Finding activity duration:** when planning the activity duration is entered in the original duration field.

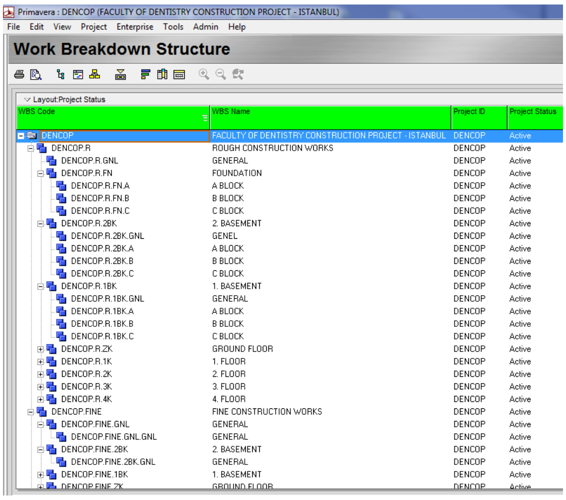


Figure 2: Work breakdown structure.

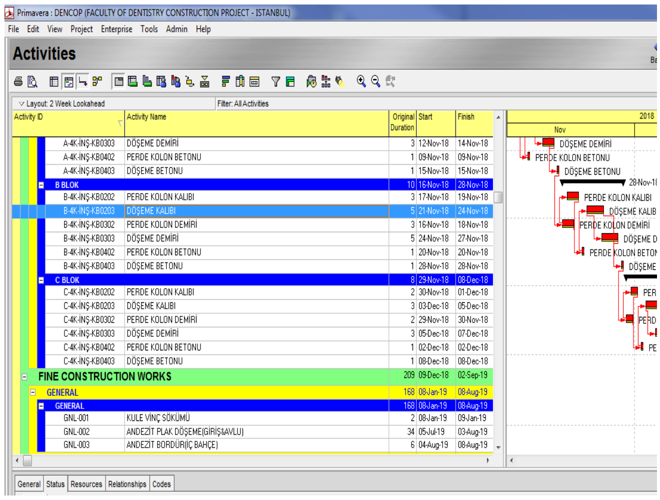


Figure 3: Determination of activity.

6) **Activity dates:** The following are the types of activity dates primavera; actual start, actual finish, planned start, and planned finish.
7) **Activity cost:** The activity cost is the addition of all the costs incurred to finish the activity.
8) **Resource assignment:** resources are the general name of the factors required for the completion of the activity. Labor, equipment and material are resource types. In Primavera software first, the resources are defined, then the required resources are assigned to each activity. As shown in Fig. 5.

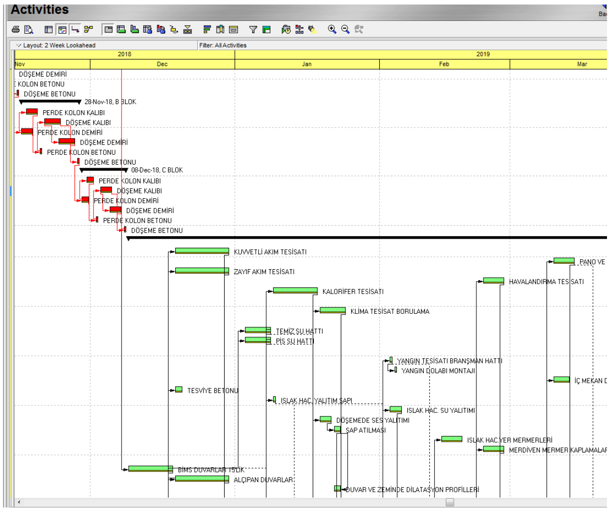


Figure 4: Relations between activities.

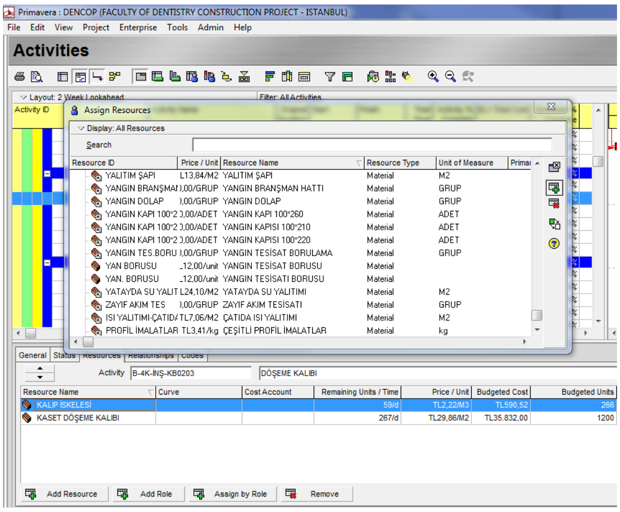
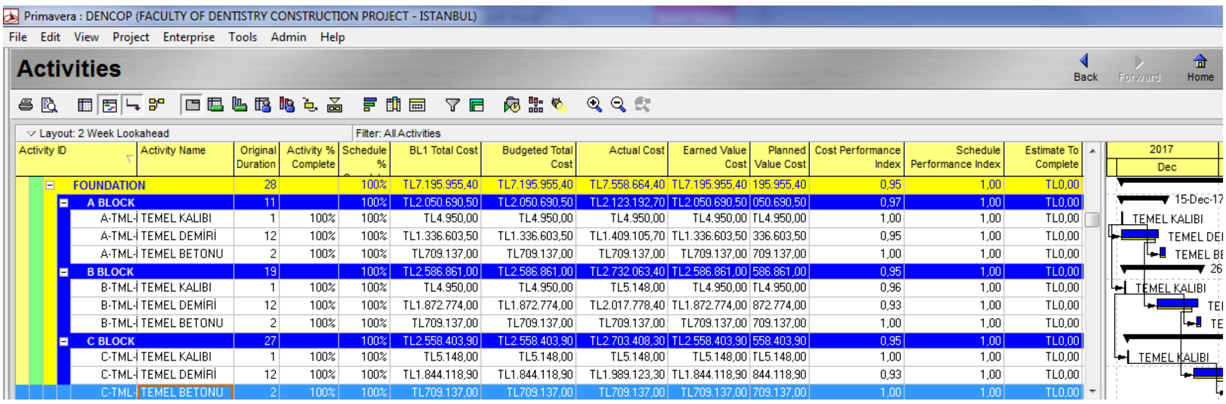


Figure 5: Resource assignment.

9) **Creating baselines:** Baseline is a standard benchmark based on the standard performance of the project is the measure. To create a baseline select project option in the activity toolbar and then select baseline after creating baseline assign baseline to the project.
10) **Update schedule:** After assigning a baseline again, the project is scheduled to update the project baseline for analysis.
11) **Tracking:** The tracking window is utilized for monitoring a project's progress by updating and periodic data entry of activities.

Results and Discussion

Earned value analysis is done on a university faculty of dentistry construction projects in Istanbul. The case study project was analyzed using Primavera P6, based on the Earned Value Analysis Method. CPI - Cost Performance Index, PD - Planned Duration, AD - Actual Duration, CV - Cost Variance, PV -Planned Value, AC - Actual Value, and EV - Earned Value variables were selected.



Activity ID	Activity Name	Original Duration	Activity % Complete	Schedule %	BL1 Total Cost	Budgeted Total Cost	Actual Cost	Earned Value Cost	Planned Value Cost	Cost Performance Index	Schedule Performance Index	Estimate To Complete
FOUNDATION		28		100%	TL7.195.955,40	TL7.195.955,40	TL7.558.664,40	TL7.195.955,40	195.955,40	0,95	1,00	TL0,00
A BLOCK		11		100%	TL2.050.690,50	TL2.050.690,50	TL2.123.192,70	TL2.050.690,50	050.690,50	0,97	1,00	TL0,00
A-TML-İ	TEMEL KALIBI	1	100%	100%	TL4.950,00	TL4.950,00	TL4.950,00	TL4.950,00	TL4.950,00	1,00	1,00	TL0,00
A-TML-İ	TEMEL DEMİRİ	12	100%	100%	TL1.336.603,50	TL1.336.603,50	TL1.409.105,70	TL1.336.603,50	336.603,50	0,95	1,00	TL0,00
A-TML-İ	TEMEL BETONU	2	100%	100%	TL709.137,00	TL709.137,00	TL709.137,00	TL709.137,00	709.137,00	1,00	1,00	TL0,00
B BLOCK		19		100%	TL2.586.861,00	TL2.586.861,00	TL2.732.063,40	TL2.586.861,00	586.861,00	0,95	1,00	TL0,00
B-TML-İ	TEMEL KALIBI	1	100%	100%	TL4.950,00	TL4.950,00	TL5.148,00	TL4.950,00	TL4.950,00	0,96	1,00	TL0,00
B-TML-İ	TEMEL DEMİRİ	12	100%	100%	TL1.872.774,00	TL1.872.774,00	TL2.017.778,40	TL1.872.774,00	872.774,00	0,93	1,00	TL0,00
B-TML-İ	TEMEL BETONU	2	100%	100%	TL709.137,00	TL709.137,00	TL709.137,00	TL709.137,00	709.137,00	1,00	1,00	TL0,00
C BLOCK		27		100%	TL2.558.403,90	TL2.558.403,90	TL2.703.408,30	TL2.558.403,90	558.403,90	0,95	1,00	TL0,00
C-TML-İ	TEMEL KALIBI	1	100%	100%	TL5.148,00	TL5.148,00	TL5.148,00	TL5.148,00	TL5.148,00	1,00	1,00	TL0,00
C-TML-İ	TEMEL DEMİRİ	12	100%	100%	TL1.844.118,90	TL1.844.118,90	TL1.989.123,30	TL1.844.118,90	844.118,90	0,93	1,00	TL0,00
C-TML-İ	TEMEL BETONU	2	100%	100%	TL709.137,00	TL709.137,00	TL709.137,00	TL709.137,00	709.137,00	1,00	1,00	TL0,00

Figure 6: Earned value analysis (EVA) for foundation works.

In this study, the main works of the case study project are examined and the EVM analysis was done. The cost variance of the foundation works was higher than any other main works. Thus the EVM analysis parameters for foundation work are given in table 2 and the results are interpreted.

Table 2. Results of EVA parameters for foundation works.

Original duration	28
Budgeted total cost	₺ 7195955,40
Earn value	₺ 7195955,40
Actual cost	₺ 7558664,40
Cost Variance	₺ -362709.00
Schedule performance index	1
Cost performance index	0,95

The project is on the schedule but it is over budgeted.

Conclusions

With the introduction of Earned Value Analysis to the monitoring of this project, the actual return of investment for the work done is found out. It also brings to light if the project is going as per what was originally planned. It shows how much ahead of schedule or behind schedule, the project is at a particular point of time. Consequently earned value analysis enables the contractor to monitor the progress of work in terms of cost and time in a much more effective.

This research on the earned value management in Primavera P6 software helps the management to find the problems in potential risk areas in early stages which can be controlled and gives detailed progress of variances in every single activity. After the analysis, the managers can make a decision about future works of the project which are to be achieved and control the budget of the project. Earned value in Primavera P6 software results in faster and true results when compared to manual calculations.

This study also demonstrated that EVM has considerable value and presents extraordinary properties that can benefit clients, consultants and industries.

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4D BIM Integrated Productivity Revision of Construction Projects

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Abstract

The compatibility of estimated schedules with real conditions is crucial for the planning and management of construction projects. Several research studies confirm that inaccurate schedules impose a considerable amount of cost and delay to the projects. One of the key reasons is the assumption of constant productivity of crews regardless of the projects' unique physical conditions. Therefore, there is a need of calculating project-based and preferably dynamic productivity values for construction activities. In recent years, 4D BIM has been increasingly utilized to improve construction productivity by providing a clearer view of the construction methods to managers. However, in general, the visual aspects of 4D BIM have been more in attention. In this work, a new concept is proposed by using 4D BIM and a visual programming language to revise the assumed productivity of the activities. The method exploits the elements' geometric information including their positions, adjacent elements, and quantities from a BIM model and assigns them to the elements as parameters to be used in the schedule. The concept is implemented on a case project to appraise the capability of being able to revise productivity values based on simulated job conditions. It is predicted that the revised productivity can improve the initial estimations' reliability and accuracy.

Keywords: *4D BIM, construction, dynamo, productivity, scheduling.*

Introduction & Literature Review

In recent years, rapid development in information technology has led the researchers to develop new approaches to modeling of projects such as Building Information Modeling (BIM) in the construction industry (Samuelson & Björk, 2014). BIM is a methodology that can digitize building components in a 3D environment by integrating corresponding data into them (Wang et al., 2014). A model generated by BIM is a core which gathers several disciplines of a project such as architecture, structure, etc. into the same platform to be designed and assessed simultaneously. This feature can reduce lots of inconveniences due to the clashes or mismatches among the several elements of that project. Moreover, BIM enables several analyses in construction works by integrating 3D models with the dimensions of time, cost, safety considerations, etc., which is called nD BIM (Rolfsen & Merschbrock, 2016; Smith, 2016). nD BIM is usually used for performing estimations, performance calculation, methodology evaluation, automatic quantity taking off, clash detection, and so on. For instance, 4D and 5D BIM stands for integration BIM with time and cost, respectively. 4D BIM is generally used for the simulation of construction sequences as well as clash detection among a project's elements. In order to perform a 4D simulation, a pre-generated activity-based schedule of the project is integrated into the corresponding BIM model. The schedule activities have to be mapped with the BIM elements, which is a manual process and takes a considerable amount of time. However, Altun and Akcamete (2019) proposed a method which constructs a 4D BIM by utilizing a two-phased method in which at the first phase, the system generates task IDs and assigns them to the activities in BIM environment and in the second phase, the method assigns same task IDs to the corresponding schedule plan list automatically. Finally, the generated task IDs are used for mapping between the model and schedule plan during 4D BIM generation in an automatic manner.

By developing BIM in recent years, more researchers have utilized 4D BIM for several purposes rather than visualization merely. Azhar (2017) investigated on how 3D/4D supporting tools can improve the construction of projects with considering safety issues, and showed that with 4D simulation, decision-makers can visually detect the work sequences leading to more effective safety plans. Kamat et al. (2011) demonstrated a method that visualizes not only operations and processes but also the construction data of products that means where and how a product is fabricated. They highlighted that in addition to locating a component physically in its' precise geometric location, it is also important to consider the progress of laborers, equipment, materials, and temporary structures in the visualized process.

Nowadays, productivity is one of the key factors determining the success of any business. Due to the limited time, budget, and natural resources, being as productive as possible is vital to stay competitive at any market including the construction sector that is considered as one of the biggest economic growth contributors in Europe (Nazarko & Chodakowska, 2015). Productivity values in construction tasks play an important role in determining activities duration. Productivity is a broad term that can be defined as production rate, performance, effectiveness, or units produced in a time interval and traditionally is whether the ratio of an input to the output (Dozzi & AbouRizk, 1993) or the output to one or more inputs (Huang et al., 2009) in a system. For instance, in a construction project, the productivity of laborers can be defined as manhour of a working laborer per tonnage of erected steel or vice versa as a ton erected per spent manhour. While, for the equipment and machinery, productivity can be represented by the "effectiveness" factor which is defined as the fraction of working time over the sum of working and non-working times (Dozzi & AbouRizk, 1993).

Jeong et al. (2016) proposed a BIM-based system that generates a simulation framework to predict productivity dynamics during planning. In another study, the advantages and disadvantages of 4D simulation-based schedules are appraised using construction professionals' viewpoints and highlighted the potential of using 4D BIM for generating better schedule plans (Rolfsen & Merschbrock, 2016). Despite several studies focusing on the simulation of construction projects through 4D BIM, none of them has considered the fact of activities productivity variation during a construction project. While, in real construction projects, the progress of activities can be affected by factors such as elements' proximity, changing site conditions, material availability, etc. These factors affect the productivity values of the activities dynamically. Therefore, assuming a constant productivity value to each activity cannot be a realistic manner to perform initial duration estimations. This study aims to propose a method to calculate the proximity of the project elements during the construction by benefiting from 4D BIM. The outcome of the method is planned to be revised productivity values which subsequently lead to more accurate schedules. A case project is chosen to implement the method and show its capabilities.

Methodology

In the present study, a new method is proposed to revise the productivity values of project activities by the use of element proximity calculation. The calculation is performed by a code package written in Python and a visual programming language tool called Dynamo. The flowchart of the process is presented in Figure 1.

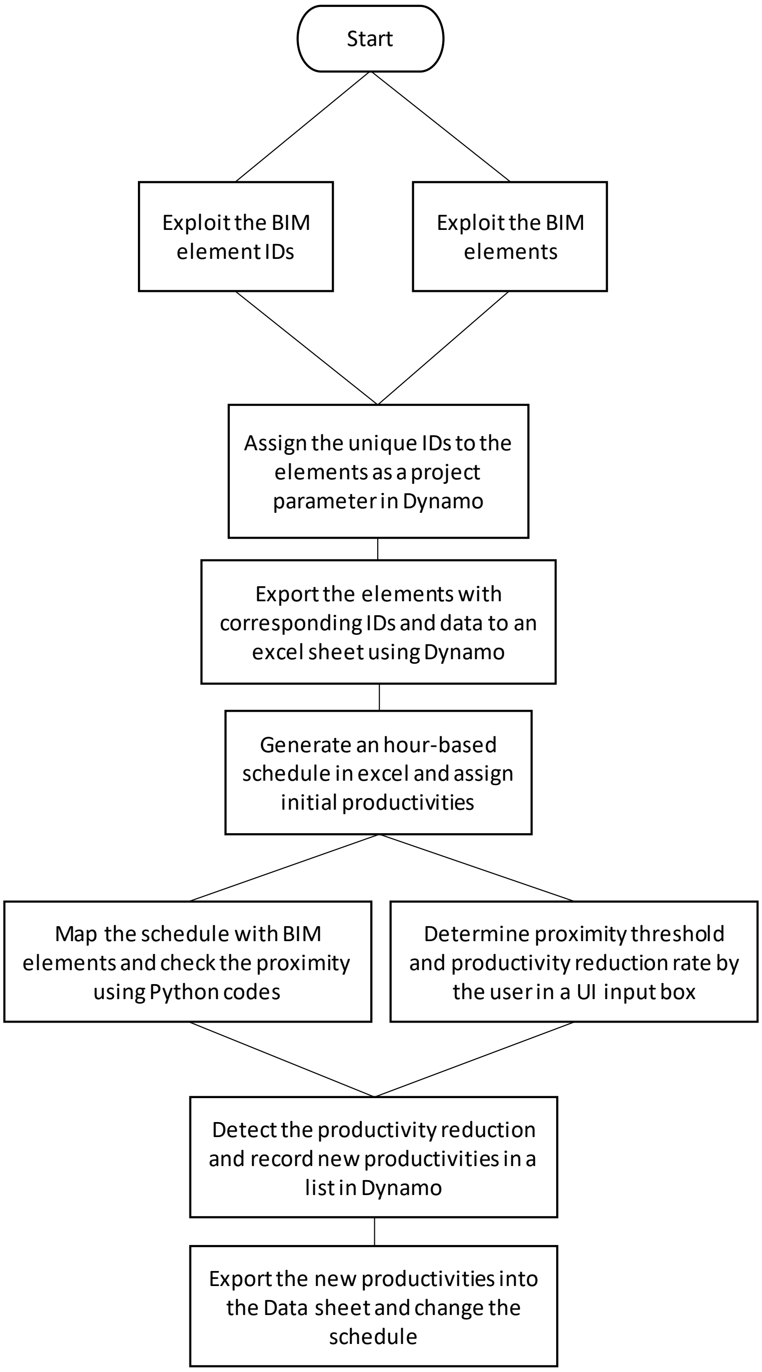

Figure 1: The flowchart of the proposed method.

In a BIM based model, each element can be identified by a unique ID. These IDs are used to map the elements with the schedule of activities and perform proximity calculations. In the first step, a BIM based model of the project should be generated (Figure 2). BIM not only facilitates the proximity analyses but also provides the needed data for the scheduling purpose. After generating the model, the unique IDs and other data of the elements are exploited using Dynamo. Dynamo is a tool that supports visual programming and Python coding languages which is used to perform proximity analyses and productivity revision during the presented study. The exploited IDs are assigned to each element in the model as a project parameter (Figure 3). Afterward, the exploited data and element IDs are exported to an excel sheet. This sheet is used to generate an hour-based work schedule based on the model elements, initial productivity values, and the elements' data such as quantity, material, weight, location, and so on (Figure 4).

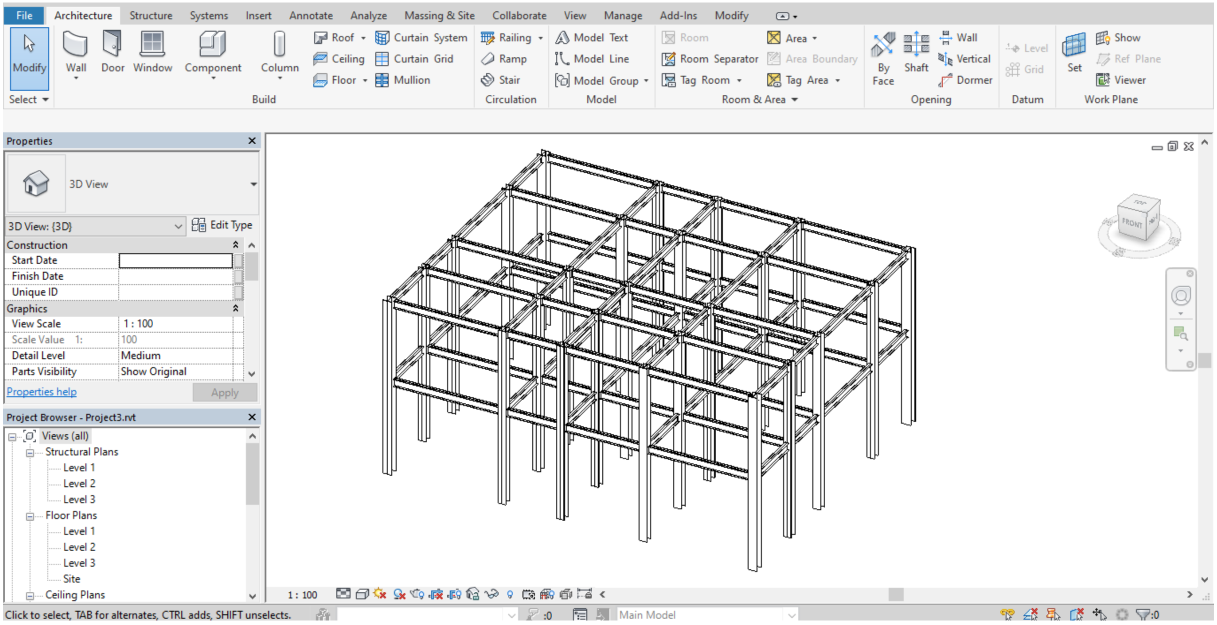

Figure 2: Generating BIM based model of the project.

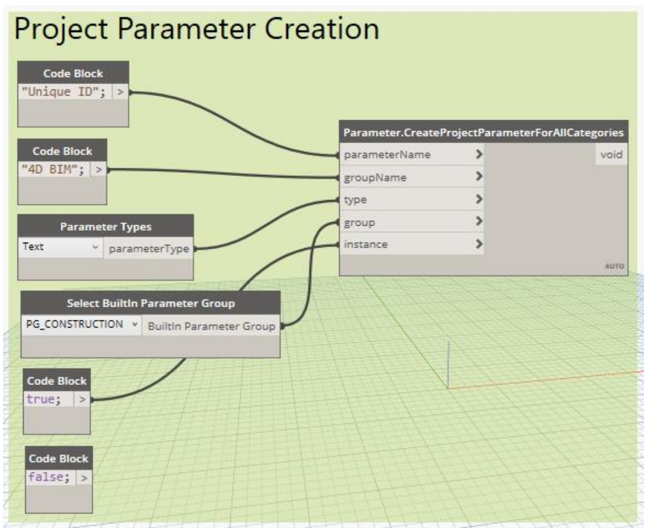

Figure 3: Creating a project parameter for unique IDs.

In the next step, the generated schedule is integrated into the BIM elements and also recorded in a list via a mapping detection manner which is coded in Dynamo (Figure 5). Afterward, for each schedule day and hour, an element proximity detection method is implemented among the elements. Before implementing the proximity detection, a threshold distance among the elements and productivity reduction rate for exceeding the threshold has to be determined by the user (Figure 6). Then the detection system for each working hour calculates the proximity among the under-execution elements.

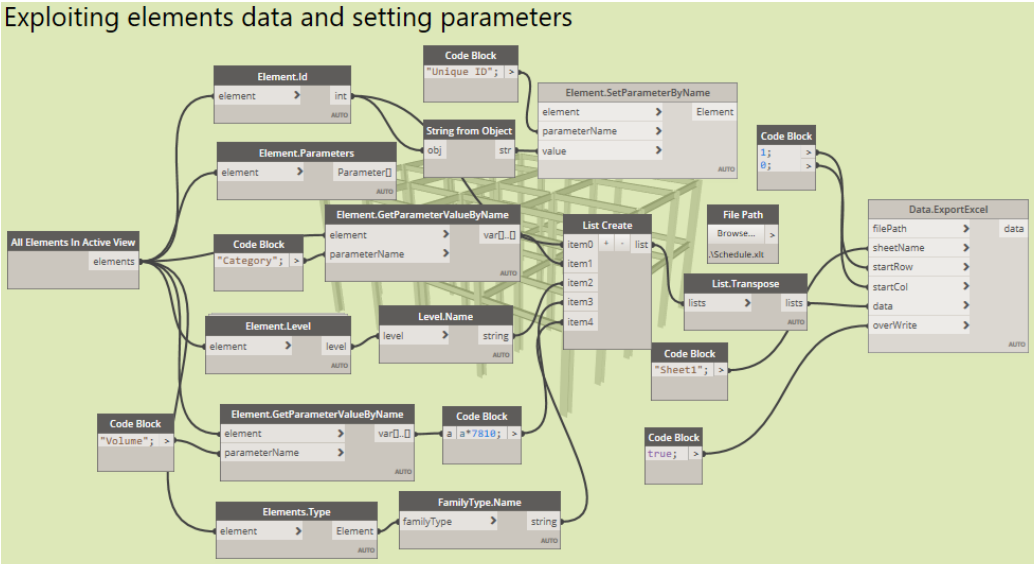

Figure 4: Exploiting elements' data from BIM based model.

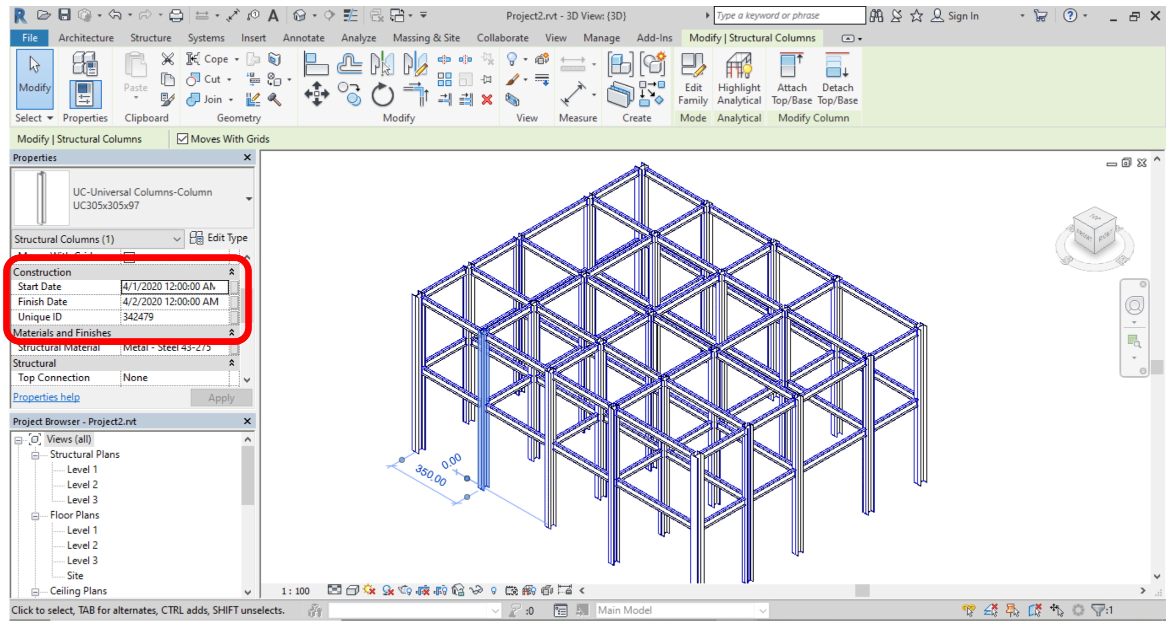

Figure 5: Integrating the schedule into the BIM as project parameters.

If the proximity excesses the defined threshold values, then the productivities of the corresponding concurrent elements are revised. The revised values are imported into the excel sheet and replaced with the initial productivities. Finally, the plan is rescheduled, and a more realistic new activity duration can be achieved.

Case Project

The proposed method was implemented in a case project to illustrate its capabilities. The case project is a two-story steel-structured project with approximate 360 square meters gross area. The activities used for proximity detection concerns columns and beams montage tasks merely. The initial schedule and productivity values for the montage works are presented in Table 1. The initial schedule of works consisted of 8 activities with a total of 87.1 spent manhours. The initial productivities were assigned based on the manager's insight and judgment. The proximity detection was run for this schedule with assumed columns and beams thresholds of 3 and 2 meters respectively (Figure 7). Furthermore, the productivity reduction was assumed to be %50 for breaching the thresholds.

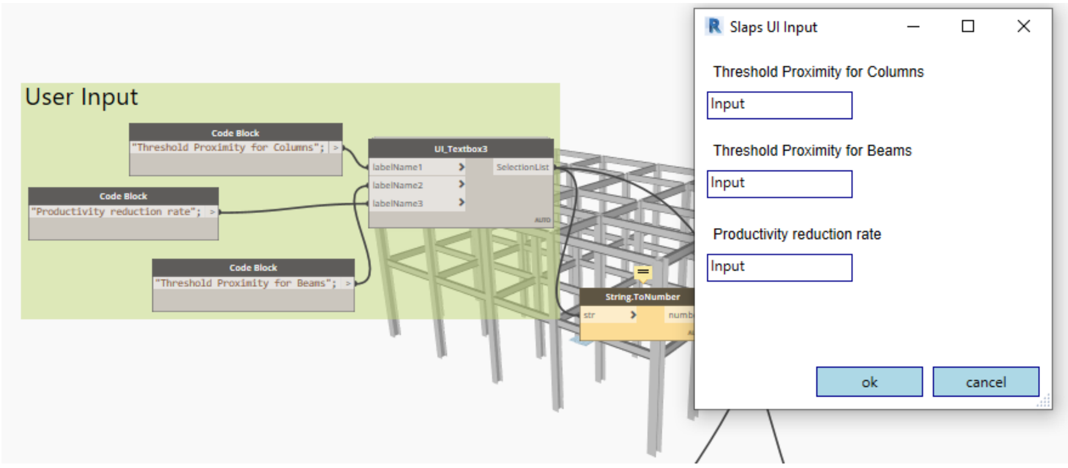

Figure 6: UI Input box for determining thresholds and production reduction rate.

Table 1. Initial schedule and productivity values.

Activity ID	Activity Name	Productivity (ton/manday)	Quantity (count)	Start	Finish	Total manhour (hour)
A1	Level 1 to 3 Columns	3 ton/m.d	8	4/1/2020	4/2/2020	16.02
A2	Level 1 to 3 Columns	3 ton/m.d	8	4/3/2020	4/4/2020	14.77
A3	Level 1 to 3 Columns	3 ton/m.d	8	4/5/2020	4/6/2020	15.40
A4	Level 1 to 3 Columns	3 ton/m.d	1	4/7/2020	4/8/2020	2.47
A5	Level 2 Beams	2 ton/m.d	25	4/7/2020	4/8/2020	12.29
A6	Level 2 Beams	2 ton/m.d	15	4/9/2020	4/10/2020	6.93
A7	Level 3 Beams	2 ton/m.d	16	4/9/2020	4/10/2020	7.91
A8	Level 3 Beams	2 ton/m.d	24	4/11/2020	4/12/2020	11.31

Total manhour (hour): **87.1 hours**

The results of the method implementation are presented in Table 2. They show the pair of elements breaching the threshold proximity in the concurrent activities and the distance between them. The system exported the breached cases and the revised productivities to the excel sheet to be used for revising the initial schedule. The productivity of the activities was replaced, and new work durations were generated. It should be noted that the plan was rescheduled according to the schedule network logic and assuming that all the activities are placed on the critical path. Finally, the rescheduled plan was obtained and is presented in Table 3. The rescheduled plan contained 9 activities with a total of 97.96 manhours to be spent which indicates approximately %12 variation in comparison with the initial estimation.

Table 2: Proximity detection results.

Activity ID	Activity Name	Element ID	Proximity (m)	Category	Revised Productivity (ton/m.d)
A2	Level 1 to 3 Columns	342228	2.88	Structural Columns	1.5
		342660			1.5
A3	Level 1 to 3 Columns	342535	2.39	Structural Columns	1.5
		341899			1.5
A5	Level 2 Beams	344134	0.12	Structural Beams	1
		343947			1
A8	Level 3 Beams	345900	0.12	Structural Beams	1
		345916			1
		345846	0.12		1
		345918			1

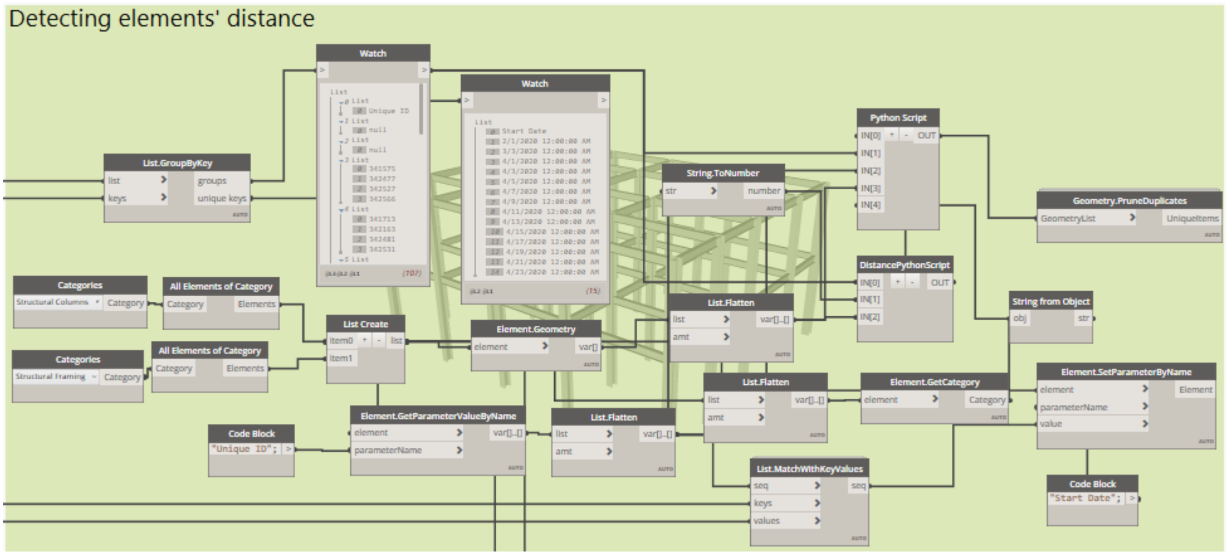

Figure 7: Proximity detection for the case project.

Table 3: Rescheduled plan after assigning revised productivities

Activity ID	Activity Name	Quantity (count)	Start	Finish	Total manhour (hour)
A1	Level 1 to 3 Columns	8	4/1/2020	4/2/2020	16.02
A2	Level 1 to 3 Columns	6	4/3/2020	4/4/2020	12.93
A3	Level 1 to 3 Columns	6	4/5/2020	4/6/2020	14.77
A4	Level 1 to 3 Columns	5	4/7/2020	4/8/2020	12.95
A5	Level 2 Beams	6	4/7/2020	4/8/2020	2.93
A6	Level 2 Beams	29	4/9/2020	4/10/2020	14.82
A7	Level 3 Beams	5	4/11/2020	4/12/2020	2.52
A8	Level 3 Beams	22	4/11/2020	4/12/2020	12.22
A9	Level 3 Beams	18	4/13/2020	4/14/2020	8.80

Total manhour (hour): **97.96 hours**

Summary & Conclusion

This paper presents a new method to revise the productivity values of the activities based on the proximity calculation among them by the use of 4D BIM and a visual programming language called Dynamo. In this method, the activities are mapped with an hour-based schedule of works and for each working hour, a proximity calculation system measures the concurrent elements' distance. It should be noted that the user is supposed to provide threshold distance values and productivity reduction rate for the project elements. Revised productivity values and subsequently a rescheduled plan are the outcomes of the proposed method. Thanks to the more realistic productivity values, more reliable initial estimations can be achieved. However, as a limitation, the method considers the position of the elements merely and does not cover the resource proximities and their effect on the project duration. Yet, unlike the traditional approaches assuming constant productivity for each activity amid a project duration, this method is able to generate variable productivity values due to the physical proximity among the elements. Moreover, it utilizes 4D BIM, a geometric model of the project using BIM and corresponding elements to accredit the analyses. It is expected that by deploying such methods the planners can benefit by practicing new technologies to increase the accuracy of the duration analyses and initial estimations.

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Investigation of the Effect of Risk Management on Cost Performance in Construction Projects

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Abstract

The one-off and unique production of construction projects increases and diversifies the risks within its structure. Among the risks frequently encountered in construction projects are political risks, financial risks, construction risks, design risks, legal risks, environmental risks, natural disasters, and operational risks. These risks, in large numbers and diversity, constitute an obstacle for the project to reach its basic objects such as quality, cost, and time and to complete it successfully. This situation makes the risk management inevitable for the construction projects that are desired to be completed successfully. In this study, a superstructure project was modeled in which simulation analysis was carried out for three different situations where risks are not considered, risks are taken into consideration, but risks are not responded, and risk responses are applied. The data obtained show that the risks encountered in construction projects cause significant deviations in the duration and cost targets of the project and these deviations can be minimized with effective risk management.

Keywords: *construction sector, Monte Carlo simulation, risk management.*

Introduction

In the business world, risk is an inevitable factor for all sectors, and risks that are not managed properly prevent the projects from succeeding. However, the unique, one-off and complex structure of construction projects and it's needed for a combination of different specialties make the construction industry more vulnerable to risks compared to the other sectors.

Risk management has many features that can provide many advantages for the construction sector, which is the locomotive of the economy, especially in developing countries. In the construction industry, depending on the project's size, complexity, techniques used, and the environment in which the project is carried out; there are different rates of risks in each project. By systematically evaluating these risks, it is possible to minimize financial losses, and disputes between the stakeholders (Birgönül & Dikmen, 1996).

In a research conducted; the advantages of risk management in construction projects are listed as follows:

- It provides a systematic and logical approach to decision making.
- It enables a detailed analysis of options in complex decision problems.
- It enables the decision-maker to face the risk and uncertainty realistically.
- It helps communication within the organization.
- It allows decision-makers to determine how much information is collected for a decision problem.
- Highlighting judgment and intuition in decision making (Kaya, 2010).

In this study, it is aimed to examine the effects of risk management practices on the cost performance of projects in construction projects. For this purpose, a superstructure project is modeled and simulation analysis is applied on the model for three different situations where risks are not taken into account, risks are taken into consideration, but risks are not responded and risks are included in the plan and mitigated. According to the results obtained, the impact of risk management on cost performance was examined.

Risk Management in Construction Sector

Risk is an inevitable factor for all sectors in the business world and causes the project to fail when it is not managed effectively. Arıkan (2005) stated that construction projects contain many uncertainties arising from the project, country, and market, making it difficult to implement risk management in construction projects. He also emphasized that in order to carry out the projects systematically, risk management systems that cover topics such as measuring project performance under varying scenarios and using past project experiences for new projects should be developed and used.

In construction projects, the target is generally determined as function, cost, time, and quality limits. For this reason, the most important risks encountered in constructions are exposure to these limits. The result of this situation is described as a failure (Baloi & Price, 2003).

The characteristics that make the construction sector a risk-prone sector are listed below (Caiado et al., 2016):

- Approaching every project that has started as a new project,
- The place where the project is designed and the place where it is executed are different and this situation causes uncertainties that can determine the final quality of the project,
- The construction phase takes place in contact with the external environment,
- Generally, exposure to situations that can cause harm to people, materials, equipment and work itself.

In addition to the above-mentioned features of the construction industry; the fact that globalization and technological developments have accelerated the competition in the construction sector both increase and diversify the risks related to the sector. Various classifications of these risks performed by different researchers are shown in Table 1.

Table 1. Various risk classifications of the construction sector.

Research Date	Researcher	Classifications of Risks
1985	Perry & Hayes	Physical Risks Environmental Risks Design Risks Logistics Risks Financial Risks Building Risks
1990	Al-Bahar & Crandall	Natural Disaster Risks Environmental Risks Design Risks Logistics Risks Financial Risks Building Risks
1996	Birgönül & Dikmen	Financial Risks Construction Related Risks Design Risks Political Risks Natural disasters
2015	Eker	***Internal Risks*** Owner's Risks Designer Risks Contractual Risks Subcontractor Risks ***External Risks*** Financial Risks Regulation Risks Policy Risks Environmental risks

As the common point of different definitions made in the literature; it is seen that risk management practices are an integral part of project management in achieving the basic targets of the projects regardless of the sector and risk management consists of determining, classifying, analyzing risks, and determining and implementing risk responses.

These risks, which are numerous and diverse, constitute an obstacle in achieving the basic objectives such as completing the project in the planned period, not exceeding the foreseen costs, and achieving the targeted quality. This situation makes it imperative to analyze the risks in detail in all projects aimed at success and to determine and apply the necessary methods to minimize the possible negative effects. The need to analyze the risks and demonstrate the necessary attitude towards the risks makes effective and successful risk management inevitable.

Methodology

The purpose of this study; is to investigate the effect of risk management practices on the cost performance of construction projects. For this purpose, a superstructure project was modeled in which three simulations are analyzed for three different situations where risks are not taken into consideration, risks are taken into account, but risks are not responded and risks are included in the plan and mitigated. For the study, a housing project with a reinforced concrete structural system, consisting of 4 basements, 1 ground floor, 11 normal floors, and 1 roof floor, with a total area of 19200 square meters is taken as an example.

Within the scope of the study, primarily; the project was planned through Primavera P6 software. Then, basic processes were determined through the project plan and risk analysis was applied on the determined processes. In the study, Monte Carlo Simulation technique was used to analyze the risks. Primavera Risk Analysis software was used as a tool for performing risk analysis and including risk responses in the plan. Finally, by comparing the data obtained for three different situations as a result of the analyzes, the effect of risk management practices on project cost performance was examined.

Monte Carlo method, one of the simulation techniques, is a system based on probability theory. It was created based on statistical and mathematical techniques. In this way, an experiment or a physical event that needs to be solved is animated and solved in computer environment by using random numbers many times. It facilitates the understanding of the behavior of highly complex systems where analytical results cannot be easily achieved (Yıldız, 2011; Kaplan, 2014).

Findings and Discussion

Within the scope of this study, a risk analysis of a residential construction was carried out and the effect of risk management on cost performance was investigated. In line with this purpose, the project taken as a case study is a residential project consisting of 4 basements, 1 ground, 11 normal floors, and 1 roof floor. The normal floor plan for the project, taken as an example, is shown in Fig. 1.

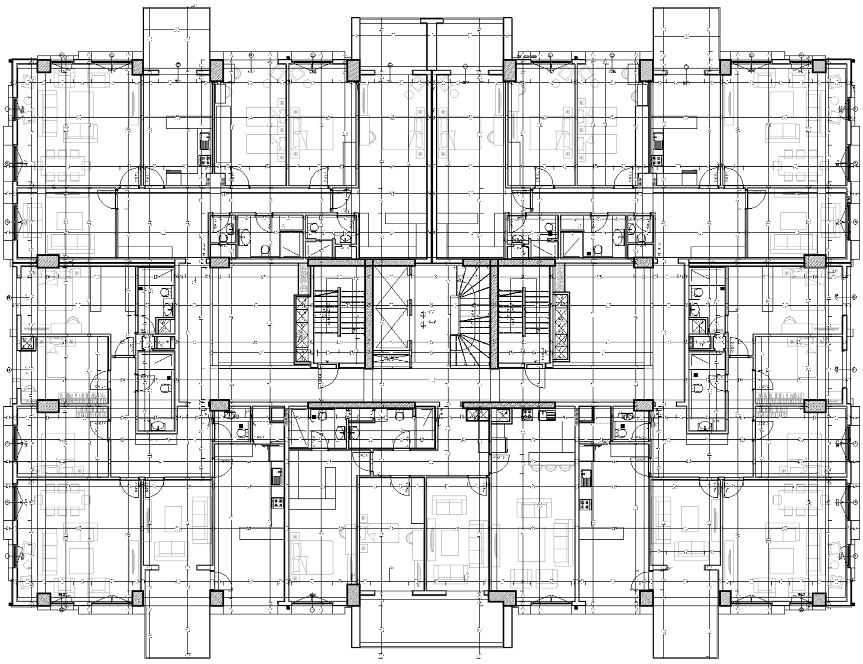

Figure 1: Normal floor plan of the project.

The project was planned with the help of Primavera P6 software and the basic processes of the project were determined as design, contract, site delivery, rough construction works, fine works, mechanical works, electrical works, and control/delivery process. The durations, costs, and planned start and finish dates of these processes are listed in Table 2.

Table 2. The durations, costs and planned start and finish dates of the processes.

Basic Processes of Project	Planned Start Date	Planned Finish Date	Duration (day)	Cost (TL)
Design Process	1.05.2018	11.06.2018	42	₺472,310.00
Contract Process	12.06.2018	22.06.2018	11	₺10,000.00
Site Preperation Process	23.06.2018	22.07.2018	30	₺90,000.00
Rough Construction Phase	23.07.2018	23.05.2019	305	₺7,928,991.00
Fine Construction Phase	20.10.2018	11.11.2019	388	₺11,151,293.00
Mechanical Work Phase	23.09.2018	8.09.2019	351	₺2,223,047.00
Electrical Work Phase	27.09.2018	12.10.2019	381	₺3,864,885.00
Project Control and Delivery Phase	12.11.2019	1.12.2019	20	₺270,000.00

Possible project risks for all processes of the housing construction project were determined within the framework of the literature review and the opinions of the project management team. The risk score for each risk was determined by evaluating the risk possibilities and the effects of the risk on schedule and cost. In evaluating the risk probability and the risk impact on the schedule and cost; very low (VL), low (L), medium (M), high (H), and very high (VH) levels were used as ratings. The probability and impact assessments of the identified risks are given in Table 3.

Table 3. Risk probability and impact assessments.

Risk No:	Risk definition	Probability	Schedule Effect	Cost Effect	Risk Score
R01	Incompatibility between design projects	M	L	L	6
R02	Changes of codes during the design process	H	M	M	12
R03	Not enough time for the design process, design flaw	L	VL	VL	2
R04	Changes requested by the employer	H	M	M	12
R05	Inadequate and incomplete contract documentation	M	H	M	12
R06	Not suitable contract type for the project	L	H	M	8
R07	Uncertainties in contract clauses	L	L	M	6
R08	Contractual provisions that regulate the risk distribution heavily to one or more of the parties	M	H	M	12
R09	Inadequate contractor-subcontractor selection	M	M	M	9
R10	Delay of site delivery	VL	M	VL	3
R11	Limited knowledge of the construction site area	VL	VL	L	2
R12	Failure to prepare the site plan well	M	VL	L	6
R13	Occupational accident resulting in fatal or serious injury	L	H	VH	10
R14	Delay in material supply	M	H	M	12
R15	Sudden increase in material prices	M	VL	H	12
R16	Earthquake, fire, flood, etc.	M	H	H	12
R17	faulty or low-quality construction execution	L	M	M	6
R18	Equipment malfunction	L	H	L	8
R19	Decrease in labor productivity	VL	M	M	3

R20	Financial difficulties (employer)	M	H	VH	15
R21	Financial troubles (subcontractors and contractors)	L	M	L	6
R22	War, coup, etc. political problems	VL	H	H	4
R23	Difficult weather conditions (extreme hot and cold weather conditions)	M	M	L	9
R24	Management and organizational problems	M	M	L	9
R25	Nationwide strike	VL	VH	M	5
R27	Failure to achieve the expected quality in the project	M	L	L	6
R28	Disagreement between parties regarding the extension of time	M	M	L	9
R29	Disagreement about the increase in costs between the parties	M	L	M	9
R30	Delay of final checks	L	L	L	4
R31	Prolongation of bureaucratic procedures	VL	VL	VL	1

The identified risks were assigned to the relevant processes in the project, the measures that could be taken for the assigned risks were identified, and quantitative analysis of the risks was carried out with the Monte Carlo simulation. In the light of the data obtained, the effects of risks on cost and schedule performances were examined for three different situations in which risks were not included in the plan, risks were included in the plan, but no measures were taken and action plans were taken against risks. Analysis results are given in detail below.

As a result of simulation analysis; in case the risks are not taken into account, the duration required for the completion of the project has been calculated as 611 days with a probability of 80% and the completion cost of the project has been calculated as 27,398,343 TL. It is predicted that the project will be completed in 791 days and the cost of completion will be 31,497,964 TL, with an 80% probability in case the risks are taken into consideration but no measures are taken against the risks. When measures are taken against risks, it is estimated that the project duration will decrease to 726 days with a probability of 80%, and the completion cost will be 29,433,848 TL. The comparison of the estimated project completion time and costs for the three situations identified is shown in Fig. 2 and Fig. 3.

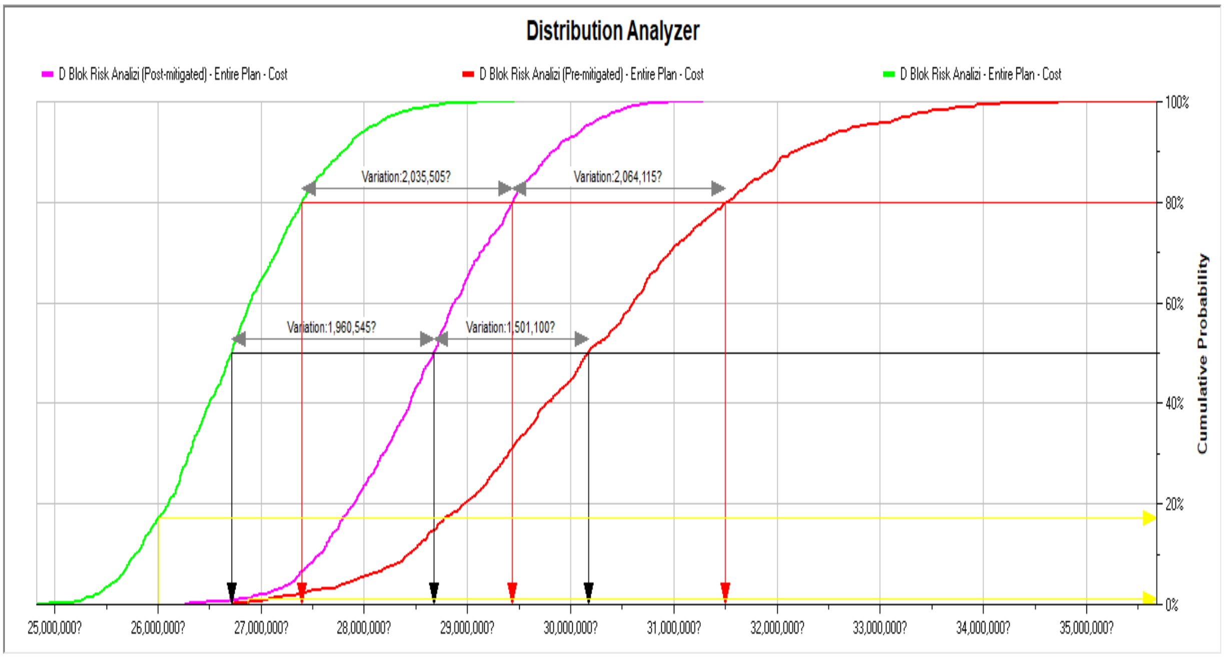

Figure 2: Cost comparisons for three identified situations.

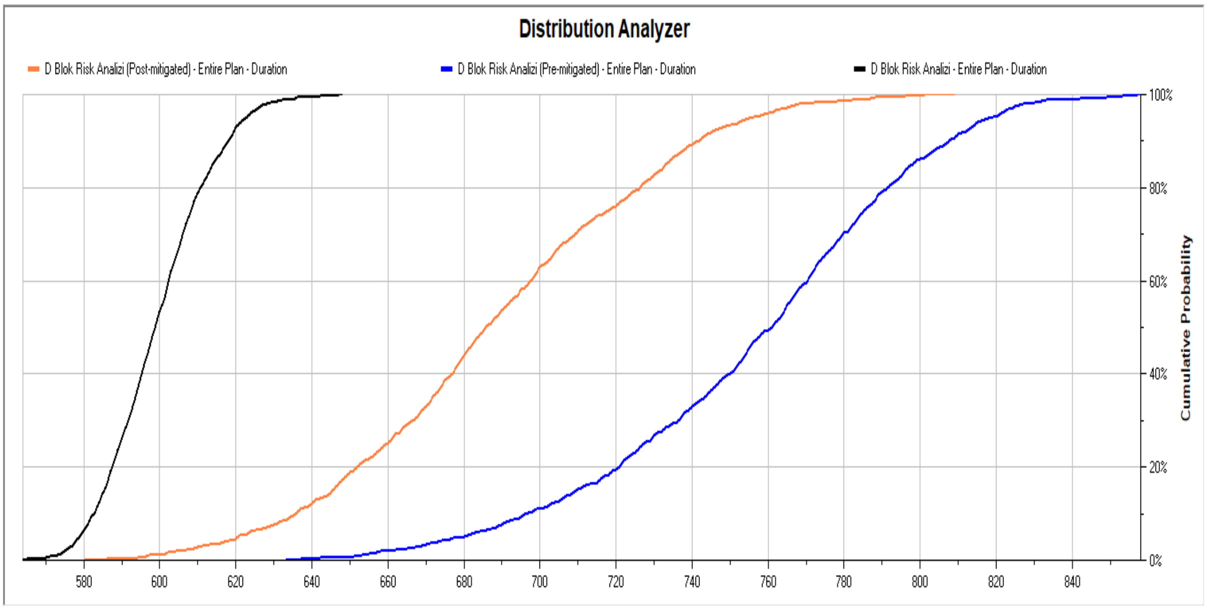

Figure 3: Duration comparisons for three determined situations.

Among the risks identified within the scope of the study, the three risks with the highest time sensitivity were contractual provisions that regulate the risk distribution heavily to one or more of the parties, the contractual changes in the design process, and inadequate and incomplete contract documentation. Among the risks that affect the cost the most; the first three risks were the financial difficulties experienced by the employer, occupational accident resulting in fatal or serious injury, and sudden increase in material prices. The diagrams of time and cost sensitivity are shown in Fig. 4 and Fig. 5.

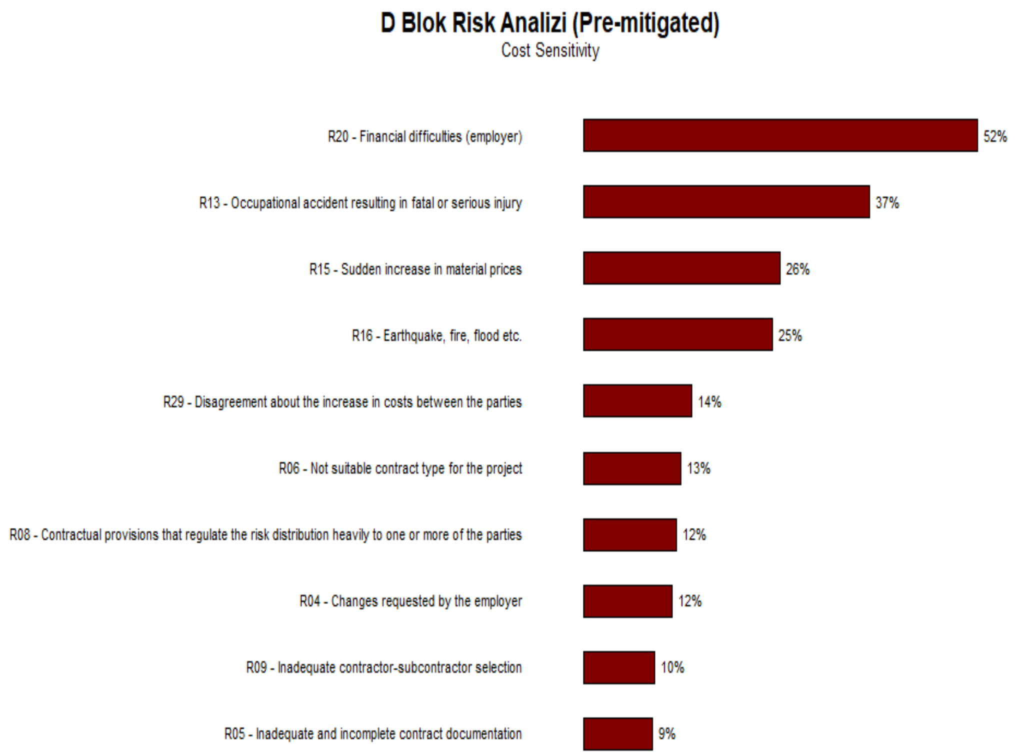

Figure 4: Cost sensitivity diagram.

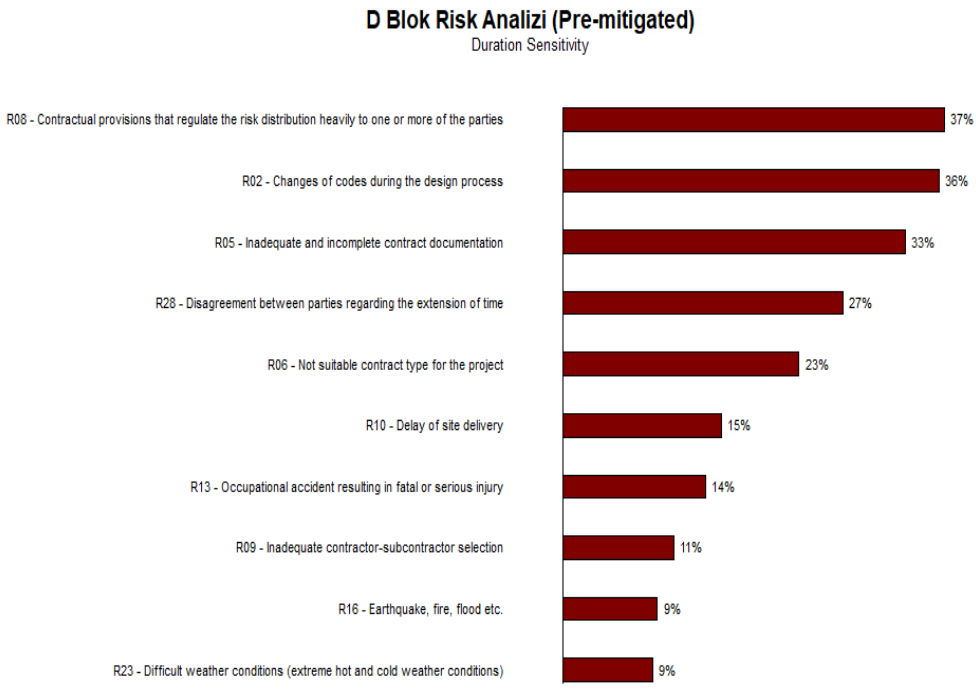

Figure 5: Time sensitivity diagram.

When the data obtained are analyzed, in case risks are included in the plan; according to the situation where the risks are not taken into account, it is seen that the project duration has increased by 30% and the completion cost by 15%. Besides, the results obtained; shows that the effect of the risk on schedule can be reduced by 8% and the effect on the cost by 7% with the measures taken against the risks.

In a similar study by Türker (2015), a superstructure project was modeled, and a simulation analysis was performed for three different situations in which risks were ignored, risks were taken into account and risk response plans were created and implemented. As a result of the analyzes made when the risks are taken into consideration, 34% increase in project duration and 12% increase in cost according to the situation where the risks are ignored; by applying risk responses, it is stated that the effects of risks on the schedule can be reduced by 42% and the effect on the cost by 45%.

When the study results are compared; it is seen that the impact of project risks on the cost and schedule performance of the project is quite close to each other. However, in case of taking measures against risks, there are serious differences in the effect of the measures taken on schedule and cost. It is thought that the difference between the results arises from differences in experience and management maturity between the project managers and planning teams.

Results

The purpose of this study was to investigate the effect of risk management practices on cost performance, which is one of the main objectives of construction projects. For this purpose, a risk analysis of a housing project taken as a case study was made and the effects of risks and measures that could be taken against the risks on the project duration and cost were determined. Obtained results show that the construction projects are largely affected by the risks due to their unique and complex structure. It can be seen that the time and cost overruns in projects can be reduced with the measures that can be taken against risks. However, the measures to be taken largely depend on the risk perception and experience of the project manager and planning team. It is also seen that the risk attitudes and management maturity of the project owners have a critical role in the risk management of construction projects.

It is thought that the numerical data obtained from this study will shed light on risk management for project owners and managers, especially in small-scale construction projects. It is also thought that the studies that can be carried out with different types and sizes of construction projects in the future may reveal the relationships between the main factors affecting risk management in construction projects and contribute to improving risk management practices in construction projects.

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An Investigation into the Green Marketing Implementation in the Turkish Construction Industry

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Abstract

Green marketing (GM) is an environment-oriented marketing philosophy providing strategies for customers' current and future needs. It is an efficient guide for the companies for the creation of continuous learning from customers and competitors and higher-up value for customers. The construction industry (CI) provides long-term customer investment product as a result of the long supply chain process. Adopting GM strategies in the CI can enable CI to become more sustainable and ensure customers satisfaction. This study aims to investigate GM implementation in the Turkish housing CI. The on-sale housing projects HPs in Turkey has been the focus of this study. A two-stage research has been carried out. The cities to be focused within the scope of this research have been determined by the qualitative secondary data analysis of the data gathered from the Turkish Statistical Institute. 325 Turkish construction companies operating in the focused cities have been determined based on the random sampling and their websites have been evaluated with respect to the GM mix tools implementation. The results emphasized not only the insufficiency of GM mix implementation but also inadequacy of traditional marketing mix application. This study is expected to contribute to the green marketing practices in the CI and guide academics, researchers and professionals in their future research.

Keywords: *construction industry, green marketing, marketing, Turkish housing industry.*

Introduction

In recent years, environmental sustainability has become an important driving force in marketing literature. Green marketing has been the subject of many studies (e.g. Dangelico & Vocalelli, 2017; Davari & Strutton, 2014) and has become an important research topic in the marketing literature. Green marketing strategy practices, from the managerial practices' perspective, have become the focus of professionals. This interest has been indicative for the commitment of different industries (e.g. Toyota and IBM) to sustainable development (Simão & Lisboa, 2017). Fast moving consumer goods, however, have become the main research topic of green marketing efforts from B2C marketing perspective (e.g. Dangelico & Vocalelli, 2017; Davari & Strutton, 2014). There is a lack of focusing on the service industry, which includes B2B and B2C green marketing practices.

The green performance of housing units from the B2C and B2B green marketing perspectives is significantly affected by the involvement of different green stakeholders and the inclusion of many green products / services. Due to the provision of a long-term customer investment product, it is believed that the housing project (HP) should meet the green needs and expectations of the target customers. Therefore, the implementation of GM mixed tools can play a significant role in marketing management of housing industry (HI).

This study aims to investigate how green marketing mix tools are being implemented in the Turkish HI. Qualitative secondary data analysis has been used as research method. Following the introduction, the paper is structured to describe the relationship between green marketing and construction industry (CI); the findings and discussion and lastly, to present concluding remarks.

Green Marketing and Construction Industry

Environmental sustainability and environmental concern led to the transformation of traditional marketing into sustainability-oriented green marketing. Therefore, green marketing has become one of the important strategic marketing approaches. Fundamentally, green marketing means minimizing natural environmental degradation (Tseng & Hung, 2013, Dangelico & Vocalelli, 2017) and emphasizes social welfare (Chabowski et al., 2011) and green financial performance (Kumar et al., 2012). Furthermore, green marketing enables companies to focus on creating value for customers by focusing on current and future needs (Kumar & Ghodeswar, 2015), continuous improvement of the production process and environmentally friendly business performance (Yadav & Pathak, 2013).

Green marketing focuses on all production stages with the consideration of environmental protection (Hasan & Ali, 2015); thus it has been transforming from the consumer-centric to the business-centric marketing (Polonsky, 2011). Marketing mix tools differ among industries depending on their activities, such as bringing products and / or services (Lee & Lam, 2012). 4Ps, the traditional marketing mix, are derived from the product, place, promotion and price whereas the extended marketing mix (7P) for the service industry adds people, physical evidence, and process to the traditional marketing mix (Tseng & Hung, 2013). While traditional marketing has evolved into the green marketing, there have been many attempts to transform the traditional and expanded marketing mix greener (Lee & Lam, 2012). Green marketing literature shows that most of the attempts to create green marketing mix tools were based on the transformation of existing traditional marketing mixes, which can be listed as green product, green price, green place and green promotion (Tseng & Hung, 2013).

The rising environmental concern of customers have brought the environmental awareness in all sectors (Osman et al. 2016). The strategical importance of green marketing approaches has started to take more attention of customers in their purchasing decision (Suki et al., 2016). Fundamentally, classification of CI as a product-oriented service industry reveals its differentiation from other industries (WTO, 2017). Furthermore, HI provides a long-term customer investment product as a result of a long supply chain process. Therefore, green features provided by the housing unit become the key influencer of consumers' green purchase intention (Boztepe, 2012). It is obvious that customer satisfaction is one of the key influencers in establishing the supply-demand balance in the HI. Any failure in meeting the customer expectations can be expected to accelerate the increase in the housing stock. Since customer green satisfaction is the focal point of GM (Solaiman et al., 2015), GM can play a significant role in the HI. Adoption of GM strategies can support increase in the sustainable performance of companies operating in the housing industry; creation of value for customers and balance the demand for supply in housing stocks.

Research Method

This study aims to investigate the existence of the GM mix implementation in Turkish HI. The on-sale HPs in Turkey have been the focus of this study. The secondary data analysis results conducted in the first stage provided determining the focus cities. Qualitative secondary data analysis is used as a research method to ensure the classification and evaluation of primary data, which provide answers to research questions in the next steps of the research (Dunn et al., 2015). Table 1 represents the research methods, which have been implemented in 4 sequential steps: focus determination, data extraction, categorization, and data synthesizing & analysis.

Table 1. Research methods.

<table>
<tr><td rowspan="6">First Stage</td><td colspan="3">Qualitative Secondary Data Analysis Overview</td></tr>
<tr><td>Phases</td><td colspan="2">Details</td></tr>
<tr><td>1. Focus Determination</td><td>1.1. Determination of the aim</td><td>1.2. Criteria Selection</td></tr>
<tr><td>2. Data Extraction</td><td colspan="2">Criteria Focused Qualitative Data Collection</td></tr>
<tr><td>3. Categorization</td><td>3.1 Criteria focused Data Classification</td><td>3.2 New Category Creation</td></tr>
<tr><td colspan="3">4. Data Analysing & Synthezing</td></tr>
<tr><td rowspan="5">Second Stage</td><td colspan="3">Random Sampling</td></tr>
<tr><td>Phases</td><td colspan="2">Details</td></tr>
<tr><td>1. Focus Determination</td><td colspan="2">Determination of the Focus Cities</td></tr>
<tr><td>2. Random Sampling</td><td colspan="2">Selection of Construction Companies Websites</td></tr>
<tr><td colspan="3">4. Data Analysing & Evaluation</td></tr>
</table>

The data are gathered from the Turkish Statistical Institute (TSI), and categorized into three main sub-research topics: (1a) population growth by city and (1b) provincial rate of net migration, (2a) sub-regional unemployment rate, (2b) sub-regional price level indices for consumption expenditure (2c) sub-regional price level indices for the main groups of consumption expenditures (rent, water, electricity, gas and other fuels), and (3) first sale housing rates by city. Figure 1 represents the categorization of data.

Random sampling has been used to examine green marketing mix implementation in the second stage of the research. The outcomes of the first stage provided focus cities where the construction companies were selected based on random sampling.

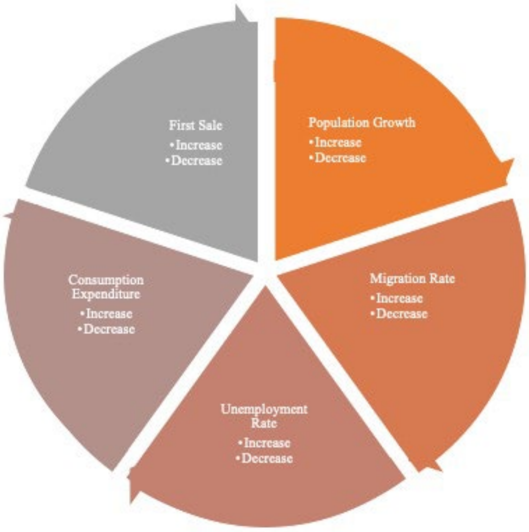

Figure 1: Categorization criteria of secondary data.

Data Extraction and Analysis

Data extraction has been simultaneously carried out at three different stages (see Table 2). At the first stage, population growth and net migration rate were determined as criteria, while price level indices for housing consumption expenditures in rent, price level indices for housing consumption expenditures in total and unemployment rate were the criteria in the second stage. The data were obtained based on the criterion of the first sales housing units at the third stage. Cities to be analyzed in the second part of the research have been determined based on the intersection of these categories.

Table 2. The phases of data extraction.

Phases	**Criteria**	**Basis**	**Categorization**
First Phase	Population Growth - Net Migration Rate (%)	Provincial Basis	1. Increase in Population - Increase in Net Migration Rate
			2. Increase in Population - Decrease in Net Migration Rate
			3. Decrease in Population - Increase in Net Migration Rate
			4. Decrease in Population - Decrease in Net Migration Rate
Second Phase	Unemployment Rate (%) - Consumption Expenditure in Total - Consumption Expenditure in Rent	Sub-region Basis	1. Above the Turkey's Average in Every Categories
			2. Above the Turkey's Average in Total and Rent Consumption Rate
			3. Above the Turkey's Average in Unemployment Rate
			4. The others
Third	First-Sale Housing	Provincial	1. Above the Turkey's Average
Phase		Basis	2. he others

First Stage of the Research

According to the TSI data, there are three different levelling for Nomenclature of Territorial Units for Statistics (NUTS), where level 3 represents 81 cities. Level 2 shows 26 different sub-regions, while Level 1 involves 12 regions (TSI, 2020). At the first stage, the data were extracted on a provincial basis and evaluated according to the population growth and net migration rate criteria.

Population of Turkey reached to 82.886.421 in 2019 (TSI, 2020). According to the TSI projections, the population is expected to reach to 100 million in 2040s and to approximately 107 million in 2080 (TSI, 2020). Based on the city-based assessment, Istanbul has been identified as the main contributor city to the total population at 18.66% in 2019, and its population is estimated to reach to 17 million in 2025, with a 18.81% contribution to the total population (TSI, 2020).

Net migration is one of the determinants of changes in population, which can be formulated as the difference between in migration and out migration (TSI, 2020) where positive net migration indicates an increase in provincial population. According to the annual data, both the population and net migration are expected to increase in some cities (e.g. Istanbul, Ankara, Izmir, and Antalya etc.) (TSI, 2020). However, it is estimated that the population increased in some cities where negative net migration occurred (e.g. Adana, Adıyaman, Manisa, Sivas etc.) (TSI, 2020). It is observed that the population is decreasing and that there is a negative net migration rate in cities such as Ağrı, Denizli, Karabük and Kocaeli (TSI, 2020).

Annual sub-region-based data have been evaluated to reveal the changes in the main consumption expenditure groups (TSI, 2020) (rent, water, electricity, gas and other fuels), the unemployment rate, and consumption expenditure price indices in total. According to the assessment (TSI, 2020) based on all criteria, TR10 (İstanbul), TR31 (İzmir) and TR51 (Ankara) were estimated to be above the average of Turkey. The assessment results showed that, unexpectedly, there were sub-regions that fall below the average of Turkey with respect to all criteria such as TR82 (Kastamonu, Çankırı, Sinop), TRA1 (Erzurum, Erzincan, Bayburt) and TRA2 (Ağrı, Kars, Iğdır, Ardahan).

The first sale in the housing industry refers to the sale of a newly built dwelling unit with the land ownership agreement between buyers and firms or the professionals building the dwelling (TSI, 2020). The evaluation of the first sales in the HI on a provincial basis has enabled determination of the cities where the annual increase rate results are above the general average (TSI, 2020). The results pointed out that between 2013 and 2019, Muş and Tokat were the cities where the annual growth rates in the first sale were above the general annual growth rate (TSI, 2020). In contrast, Eskişehir has been determined as the only city where annual growth rate fell under the general growth rate (TSI, 2020).

This study aims to evaluate the green marketing implementation in the Turkish HI in the second research phase of the study, where the focus was on the first sales HPs of Turkish construction companies. The results of the first stage of data analysis enabled the categorization of the cities to identify focus areas for subsequent research steps. Two categories became significant: the first category included cities where the population and the first sales in the HI increased while net migration was negative. In addition, the second category involved the cities that showed an increase in the first sale in the HI while the population has been decreasing and net migration is negative. Table 3 represents the city categorization results.

Table 3. Categorization of the cities.

Category		1	2	3	4
Cities		Muğla	Adana		Denizli
		Ankara	Adıyaman		Karabük
		Antalya	Afyon		Kırklareli
		Bursa	Karaman		Kocaeli
		İstanbul	Manisa		Mardin
		İzmir			Şanlıurfa
		Konya			
Cirteria	**Population**	Increase	Increase	Decrease	Decrease
	Net Migration Rate	Increase	Decrease	Increase	Increase
	First Sale	Increase	Increase	Increase	Increase
(red)		Above the Average of Turkey with respect to all criteria			
(orange)		Above the average of Turkey with respect to the consumption expenditure criterion			
(blue)		Above the average of Turkey with respect to the unemployment rate criterion			
(grey)		Under the average of Turkey with respect to all criteria			

Second Stage of the Research

325 Turkish construction companies have been chosen randomly from the companies operating in the cities listed in Table 3. Websites of the companies have been visited to examine the on-sale HPs to evaluate the offered green marketing mix and/or strategies. The research aimed to analyze the on-sale projects' traditional marketing mix (4Ps) (Simão & Lisboa, 2017; Dangelico & Vocalelli, 2017; Davari & Strutton, 2014; Shamsuddoha, 2005) It is targeted to enhance the research by investigating the existence of green marketing mix tools

implementation in the second stage. Table 4 denotes the conducted evaluation criteria for the on-sale building projects' websites.

Table 4. Green marketing mix tool-based evaluation (Adapted from Simão & Lisboa, 2017; Dangelico & Vocalelli, 2017; Davari & Strutton, 2014; Shamsuddoha, 2005).

Product	Place	Promotion	Price	People	Physical Evidence	Process
•Concept	•Location	•Website	•Price	•Designer	•Rewards	•Live progress
•Social conditions	•Closeness	•Contact details	•Payment Plan	Suppliers		
•Gallery		•Virtual Show				
•Numerical Information		•Call Center				
•Design options		•Project catalog				
•Sustainability		•Online support				
•Supplier brands		•Social media				
•Live progress		•Introductory film				
		•Rewards				
		•Designer				
		•Social responsibility				

Results and Discussion

From the product perspective, most of the construction projects offered for sale provided information about the concept and social conditions (93.23%) and supported the projects with a photo gallery (93.23%). Half of the evaluated construction projects provided numerical information (50.77%) consisting of the total number of residences, trade place and social/recreation facilities. Lack of supplier brand information (4.62%) and lack of options to follow the live progress of the construction project (4.31%) have been observed on the websites examined. Results showed that minority of the construction projects have provided sustainable information on material and/or progress (3.38%) and design option for end customers (3.08%).

From the promotional perspective, it appears that most of the construction projects have their own websites, independent from the construction company's website (96%), where construction projects represent contact information. Besides on the examined websites, it has been observed that 72.92% of construction projects offered project-oriented social media accounts on the websites. Introductory videos (27.69%) and virtual tour (11.38%) have been used as web-oriented promotional activities for construction projects. Lack of call center

(37,85%), lack of existence of online project catalog (34,77%), and lack of online support options (9,23%) have been observed. The results showed that almost none of the construction projects provide information on social responsibility activities (0,62%).

As a result of the evaluation of the project catalogs, it is seen that the current catalogs provided promotional tool to provide information about the construction projects such as social conditions (33.23%), project location (32.92%), proximity to the main center areas (32.31%), project layouts (32.31%), plans and quantity surveys (31.38%). Minority of project catalogs include design criteria (13.23%), designers' information (6.46%) and supplier brands (0.92%). There is almost no social responsibility and the contributions of construction projects mentioned in the catalogs (0.31%). In addition, there is no information about the payment schedule and prices (0%).

The results showed that the call center is one of the promotional tools provided by 37.85% of the construction projects. However, online support (9.23%) is one of the non-preferred promotional activities. Designer and supplier information (6.46%), rewards (3.38%), if any, and social responsibility (0.62%) are almost non-available as promotional tools.

It is seen that the payment plan (17.54%) and final price information (2.15%) are not preferred as a price tool. In terms of place, however, the location of construction projects (73.54%) and proximity to hub centers (40.31%) are the most preferred place tools on the construction project websites.

Conclusion and Recommendations

This research aimed to reveal the green marketing activities in the Turkish CI and to analyze the HP for sale in different cities. The research has been carried out in two stages. Qualitative secondary data analysis has been performed at the first stage. The data have been gathered from the TSI and analyzed in three phases based on the criteria determined. The second stage of the research aimed to analyze the green marketing mix implementation. Random sampling was used as a research method. 325 Turkish construction companies operating in the cities determined in the first stage of the research were randomly chosen and their websites have been visited. Evaluation results for HP in the Turkish CI reveals the inadequacy of traditional marketing practices. Furthermore, the results emphasized that green marketing initiatives seem to be insufficient in marketing practices.

The paper stresses the importance and development of green marketing in the CI. The results, however, show that both green and traditional marketing mix implementation results are not at the desired level. This study is intended to support the green marketing efforts in the CI as well as to enhance marketing practices in the CI for researchers. This study can provide a preliminary overview of the current traditional and green marketing practices in HP, and their importance in the CI.

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BIM Processes for Light Steel Construction

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Abstract

Cold-formed steel (CFS) structures are becoming more popular day-by-day due to priorities like standard production results, simplicity of design and construction phases, short production time, earthquake resistance. BIM concept which is defined as the next-generation solution to improve the productivity of stakeholders in the construction industry and facilitate the delivery process of buildings, is used in the design, planning, construction and management steps of cold-formed steel structures as in every field. The aim of this research is preparing reference information BIM Execution Plan (BEP) for cold-formed steel structures. The study is expected to be a guide for the next similar studies.

Keywords: *BIM, BIM execution plan, construction, light steel, LOD.*

Introduction

Steel structures are constructed with two types of load bearing systems. The first one is the construction of hot-rolled steel profiles and column beam steel frame of the building. The second one is the formation of wall/floor bearer, in which cold-formed steel profiles are brought side by side. The system consisting the second group is called Cold-formed steel (CFS) system (Akay, 2013).

These systems are similar to the wooden frames. 5/10 sectioned wooden is replaced by cold formed steel profiles. Steel designs are column designs consisting of machined C, U, Z profiles, their wall thickness ranges from 0.6 mm to 2.5 mm and its weight is maximum 0.075 kN / m. (STAHL, 2002).

Cold-formed steel profiles to the building industry; moved from the automotive, train and aircraft industries. CFS profiles were first used in the divider element systems used in the interior and roof systems (rafters etc.) due to their lightness. Later on, this material was used extensively in low-rise buildings and cladding systems in industrial buildings and recreation areas, especially in America. (Terim, 2006).

Although this is not yet so clear in Europe, in other developed countries there is an extremely rapid growth in the use of cold-formed framing systems for houses and other small construction. According to Pekoz's (1999) study, in the USA, about 500 homes were built in cold-formed steel in 1992. This number grown up to 15 000 in 1993 and 75 000 in 1994.

BIM (Building Information Modeling), which is one of the leading developments in the architecture, engineering and construction (AEC) industry in recent years. It combines traditional computer aided design with a digital project database where all the data defining the structure are kept. All the data generated during the design, construction and post-production process are managed.

BIM also provides 3D representation that includes all the data. It is a method that enables the management of project data in a digital environment by including different tools and processes in the design. While BIM minimizes time and cost loss due to the lack of simultaneous operation, it also enables environmentally friendly buildings thanks to various energy simulations to be integrated into its structure.

The purpose of this study is for the common project goals of a standard cold-formed steel project, it is necessary to identify BIM uses, figure their BIM uses during the construction phases and map the structural design processes of cold-formed steel. It is aimed to create samples that will assist in the preparation of BIM execution plans of cold-formed steel projects.

In the method section of this study, the production methods of CFS and the advantages / disadvantages of CFS usage are also included in order to understand the use of BIM in CFS systems. In addition, BIM Project Execution Planning Guide v2.2 that prepared by Pennsylvania State University Computer Integrated Construction Research Program is taken as reference for tables and BIM uses.

Cold-Formed Steel Production Method

Cold forming is a widely used method in the production method of cold-formed element sections used to produce construction elements. Cold-formed steel is a common term used for products produced by pressing or rolling the sheet of thin steel. Production of CFS begins with the production of crude steel made by combining iron ore or steel scrap with a small amount of carbon in the basic oxygen furnace or electric arc furnace, as in the production of other steel products (Yu, 2016). Molten steel is poured into molds reduced to thinner steel strips called "hot bands". The protective zinc coating is then added by galvanizing. The most recent product is "The roll". (Yu, 2016).

Sheet metal is supplied as a roll, it is drawn on roll form machines at the production site. Each piece produced on the roll form machine is designed with software such as AutoCAD and StruCad in the production technical office and transferred to the machine using the intermediary program. The connection points of each piece belonging to the carcass are determined at the design stage, and appropriate holes are left at the relevant points for the connection elements.

A variety of sections with different shapes and thicknesses can be produced this way. The depth of the section ranges between 51-305 mm. This provides consistent quality and design flexibility for designers. In addition to roll-forming, press-braking method is also being used for fabrication of CFS sections. (Yu & LaBoube, 2010).

Although some horizontal and vertical elements are used as U profiles in some manufacturer companies, "C" profiles with high strength are used in terms of providing economy in the material by using thinner material and more intervals to the load affecting the profile in the companies whose production system is developed.

Advantages of CFS listed below:

• Steel profiles are homogeneous and isotropic beside they have high rigidity and high ductility (Yildirim, 2010).

• Due to high bearing/weight ratio, CFS systems are affected from earthquake less than other systems (Terim, 2006).

• Corrosion resistance (zinc usage 245-275 gr / m2 for double surface) obtained by hot galvanizing method prevents the structure from being affected by environmental factors for many years (Yildirim, 2010).

• Light steel structures where screw joints are mostly preferred; In addition to the fact that the geometric characteristics of the material are independent and homogeneous from the profile length and the number of productions. They are the structures where the calculation values found as a result of the design are provided and applied by using methods that do not carry human factors at the connections. In this way, structures independent of application error can be obtained (Terim, 2006).

• Atmospheric conditions are not an obstacle to building construction. Construction can be done in any weather conditions where people can work and the structure is not affected by events such as rain, frost, heat (Uzgider & Arda, 1989).

• Steel is %100 recyclable material. Thus, even after the buildings are destroyed, they are used as raw materials, and the country's economy and the environment suffer less (Yildirim, 2010).

Disadvantages of CFS listed below:

• CFS partition walls are bearing walls. Thus building geometry has to be quadratic. It makes CFS systems more disadvantageous than conventional systems in terms of planning possibilities (Ekinci, 2006).

• In cold-formed steel systems, the stability of the structure is directly proportional to the stability of the corner joints, since the wall panels are bearers (Ekinci, 2006).

• The homogeneous and dense textured crystal structure of metals, which is formed from free or fixed electrons, is its general feature. These properties ensure that the pressure and tensile properties are equivalent and high. However, these internal properties of the steel material are due to the high thermal expansion; It is also the reason why they transmit heat, electricity and sound well. In terms of building comfort, sound and heat conduction is an important issue. Especially high thermal conductivity of steel material brings along condensation, moisture and water problems as well as energy loss. However, thermal expansions cause thermal stresses in the building elements. Fire and corrosion problems constitute the weaknesses of the steel structures, and these are the issues that need special attention and precaution (Ekinci, 2006).

• Although steel it is accepted as a nonflammable material, after the start of fire the material decreases to 20% of the strength in 10 minutes, and 10% after 20 minutes. As a result, sudden collapses are seen due to the flow of steel. However, this time can be extended with high

temperature resistant composite materials and it is possible to protect the bearer structure from temperature (Ekinci, 2006).
• Galvanized layers of profiles are more likely to be damaged in connection points than other systems. After construction, the damaged areas should be repainted with anti-rust paint (Terim, 2006).
• Since the electrical and mechanical installations pass through the walls and weaken certain points of the section, the designs of these works should be done in a very good and unchanging way (Öncü, 2010).

The most important element of BIM is "Information". The purpose of developing a BIM Execution Plan (BEP) is to facilitate the management of project information. The BIM Execution Plan can also be defined as the plan prepared to streamline how the "Information Modeling" part of a project is carried out. The BIM Implementation Plan is central to the BIM process and is an integral part of any new construction development project.

To integrate project to the BIM, developing a BIM execution plan should be first step for project team. The Execution plan outlines the vision throughout the project. Also it includes the implementation details (BCA, 2012).

By developing a BIM Execution Plan, the Employer and project members can:
• Clearly understand the strategic goals for implementing BIM on the project,
• Understand their roles and responsibilities for Model creation, maintenance and
• Collaborate at different stages of the project,
• Design a suitable process for them to participate in the implementation,
• Outline additional resources and services that may be needed and
• Provide a baseline plan to measure progress throughout the project.

The content of a BIM Execution Plan includes the following:
• Project information,
• BIM goal & uses,
• Each project member's roles, staffing and competency,
• BIM process and strategy
• BIM exchange protocol and submittal format,
• BIM data requirement,
• Collaboration procedures and method to handle shared Models,
• Quality control and
• Technology infrastructure & software.

BEP should be prepared specifically for each project. However, for the cold-formed systems, suggested parts that do not change from project to project and expected to be included in the BIM execution plan are considered within the scope of this study.

Application

How Cold-Formed Steel Systems Can Benefit from Building Information Modelling

BIM integrated cold formed steel project can benefit, but not limited, below items:

• CFS can be designed in numerous ways. BIM can help designers to find best option via visualize aesthetic and practical possibilities.
• BIM can help to produce shop drawings for CFS panel systems.
• BIM can prevent conflicts between the CFS framer and other trades (MEP contractor, architect etc.)
• Even if other stakeholders do not use BIM, CFS contactor can benefit from BIM.
• CFS layouts and schedule can be better optimized with BIM.
• BIM is a great marketing tool. Especially in meetings with prospective clients.
• Cladding materials provides strength to the structural system. BIM can help the coordination between architect and structural engineer.
• Fire protection is an important issue for CFS elements. BIM is perfect tool for fire protection design.
• CFS elements are %100 recyclable material. Energy analysis and sustainability evaluations can easily make with BIM.
• Dismantling works will be simpler with BIM for temporary CFS facilities (Buildsteel, 2017).

Project Goals

The goals of project depend on many items like budget, stakeholders, project team etc. The following table lists the project goals expected to not change from project to project in a CFS project using BIM. The BIM uses corresponding to these goals are matched with the BIM uses specified in the BIM Execution Planning Guide v2.2.

BIM integrated cold-formed steel structure project should include, but not limited, below goals and BIM uses:

Table 1. Project BIM goals and potential BIM uses.

Priority (1-3)	**Project Goal**	**Potential BIM Uses**
1 = Most Important		
	Producing MEP and architectural coordinated fabrication drawings.	3D Coordination, Digital Fabrication
	Reaching targeted sustainability goals via dismantling and recycling plans	Site Analysis, Sustainability Evaluation, Building Systems Analysis
	Getting shop drawings	Construction System
	Providing add value with 3D model	3D Control and Planning, Cost Estimation
	Planning prefabrication and construction phases	Programming, Phase Planning

BIM Uses Table

The table below shows which phase of the project the BIM uses planned to be used in the previous project goals table.

Table 2. BIM uses according to construction phases.

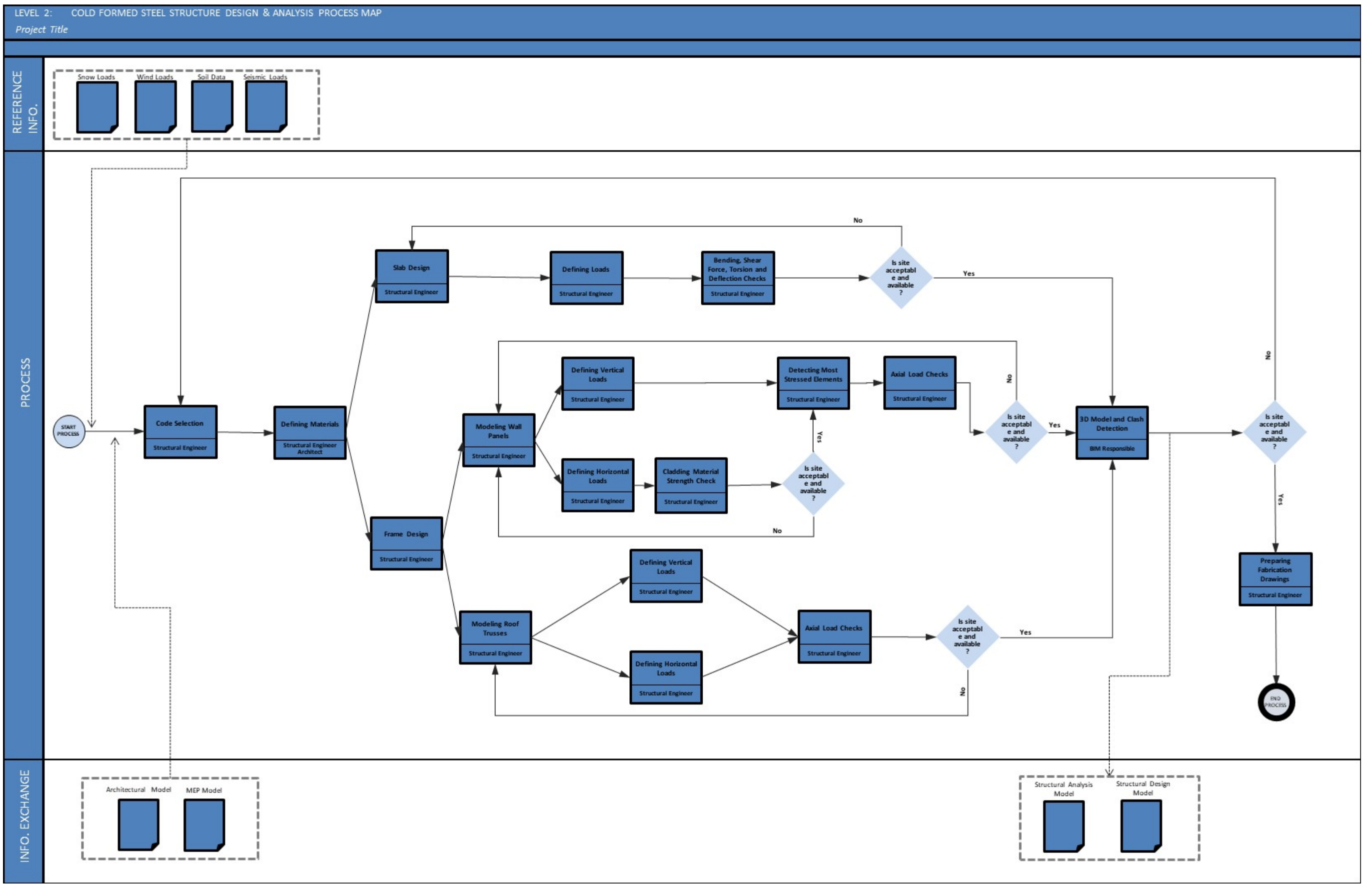
Operate	Construct	Design	Plan
	Cost Estimation	Cost Estimation	
	Design Control	Design Control	
Demolition / Dismantling Plan			
	Phase Planning		
		Virtual Mock-up	
Phase Planning	Phase Planning		
	Digital Fabrication	Digital Fabrication	
		Site Analysis	Site Analysis
		Sustainability Evaluation	
			Construction System

The BIM uses table should start with potential end-uses. Because if project team consider the end-uses at the planning, they easily define what information will be required for previous activity.

Cold-Formed Steel Design & Analysis Process Map

This map shows the BIM integreted Cold-Formed steel desgin and analysis work flow. BIM execution planning guide level 2 process maps taken as a reference (Messener, 2019).

Figure 1: Level 2 CFS design proces map.



Level of Development

Concept of Level of development (LOD) specifies how much content BIM model elements will be included in which stages, from design to construction, and at what level during the development of the project. The level of geometrical and informational content that the elements should contain is defined by LOD numbers. For example; LOD 200, LOD 300 etc. There are different companies and institutions that work by producing standards, tables and specifications about the level of knowledge that elements should contain, namely LOD definitions. Although they have defined the details of the models to be prepared under different titles according to their own standards, the main purpose is to eliminate confusion and produce more quality projects by explaining how the information in the BIM model will proceed.

Steel Framing Industry Association cold-form branch describes general LOD reflections on cold-formed steel systems in the below table.

Table 3. Level of development definitions and CFS examples.

LEVEL OF DEVELOPMENT	BASIC DEFINITION	COLD-FORMED STEEL (CFS) FRAMING EXAMPLES
LOD 100	Informational content related to an assembly. Assembly depth, thickness, size, and location are still flexible.	Approximate CFS framing dimensions. CFS cost per square foot.
LOD 200	Graphical content for generic assemblies with approximate quantity, size, shape, location, and orientation. May include non-graphical information.	Rough CFS quantities and member depth. Desired CFS member spacing.
LOD 300	Graphical content for specific assemblies. Precise quantity, size, shape, location, and orientation for the element can be measured from the model.	Specific CFS quantities, depth, spacing, locations, and geometries. LOD 300 is common for typical CFS framing coordination.
LOD 350	Includes LOD 300 with the parts needed to coordinate the element with other nearby or attached elements.	CFS framing assemblies modelled precisely at wall bottoms, tops, and sides. Includes bridging, strap, and other support information.
LOD 400	Requires sufficient detail and precision in order to fabricate the assembly or system component.	CFS fabrication, panelization, and installation information. CFS fabrication part numbers. All parts required to complete CFS installation. Includes CFS weld and connection information.
LOD 500	Field verifiable quantity, size, shape, location, and orientation of an assembly. LOD 500 can be considered the “as built” model. Not necessarily a higher level of element geometry.	LOD 500 is relatively rare for CFS assemblies, since CFS fabrication and installation development is provided by LOD 400. However, LOD 500 may be a contract requirement. It would provide an owner with vital CFS information for future reference.

Conclusions

In the study, the properties, production methods and advantage / disadvantage agents of Cold-formed steel (CFS) systems were generally researched. However, the reason why BIM should be used in a CFS project is explained with the items. As a result of this study, a map showing the project goals, the BIM uses corresponding to these goals, the level of detail (LOD) for

CFS elements and CFS design workflow, which were proposed for the preparation of a BIM implementation plan for a CFS project integrated into BIM, was created. Thus, it is aimed to present reference information for uses BIM in CFS projects and creates a new BIM execution plan.

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Return on Investment (ROI) in the Architecture, Engineering and Construction (AEC) Industry by using Building Information Modeling (BIM) Approach

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Abstract

Return on Investment (ROI) is a global issue in the Architecture, Engineering, and Construction (AEC) industry. The unsatisfactory management of costs not only causes difficulties in meeting the project budget targets but also affects urban/spatial design and planning in the future growth of cities. Many of the current efforts with Building Information Management (BIM) have focused on researching three-dimensional (3D) design-related staff and conflict analysis/management, which has so far been its main concern. In this study, it provides a summary of traditional budget/cost management methods as well as a comprehensive review of published literature on the latest efforts to manage risks by using new technologies such as info-based systems, reactive/proactive information technology, and the BIM approach. Findings in the research show that the BIM approach can not only be used to support the project development process as a systemic risk management tool but also as a basic data producer and platform to allow other BIM-based tools to do a better budget/cost management analysis.

Keywords: *architecture engineering construction (AEC) industry, building information modeling (BIM), cost management, return on investment (ROI)*

Introduction

Theoretically, the concept of "Building Information Model" was first introduced to literature by academicians in 1970 the 1970s (Latiffi et al., 2013). Three-dimensional modelling began to be developed, depending on the first computer-aided (CAD) studies in quite a few industries. While many industrial economists have developed integrated analysis tools and object-based parametric modelling that form the core concept of BIM, the construction industry has long been dependent on traditional 2D designs (Eastman et al., 2011; Gray et al., 2013). Modelling by using BIM in the construction sector was first used in the early 2000s to support the design of architects and engineers in some pilot projects (Penttila et al., 2007). As a result, researches in this area are mainly focused on clash detection, visualization, quantification, better data and cost management, preliminary design and planning (Eastman et al., 2011). In recent years, Professional expertise tools such as architectural design and engineering have also participated to basic functions have been carried out in this area such as structural analysis, energy analysis, work-planning, progression (track) follow-up and construction health & safety (Becerik-Gerber et al., 2012). In the past, the use of BIM has been focused on infrastructure and pre-planning, design, construction and integrated project delivery of buildings. However, in recent years, researchers have concentrated more on maintenance, modification, restoration, destruction, and end of life considerations (Akbarnezhad et al., 2012; Becerik-Gerber et al., 2012; Becerik-Gerber & Rice, 2010; Eastman et al., 2011; Lucas et al., 2013; Nicolle & Cruz, 2011; Sabol, 2008).

Eastman et al. (2011) defined Building Information Modeling (BIM) in his “BIM Handbook” as "a common digital representation of the physical and functional characteristics of a building that is a reliable basis for all decisions". Eastman et al. (2011) said that “A building model can now be defined by its content “which objects it describes?” or by its capabilities “what kind of information needs it can support?”. Among them, capabilities define what you can do with the model rather than how the database is constructed”. They furthered; “What a wall, flooring or roof is?” is determined by the relationship obtained by object classes according to their interaction forms with other objects. Essential attributes of objects are needed to create an interface with analyzes, cost estimates and other applications. One of the important steps in the evolution of the transition from CAD to parametric modeling is the need to share parameters of all objects. For example, if a wall is carried from one place to another, everything connected to it must be updated as well. Any change to an object may also affect other objects. For this reason, a BIM Manager analyzes these changes in order to improve their ability to analyze and selects the most efficient way to sort and update them. This capability is one of the most important technology available in BIM and parametric modeling (Eastman et al., 2011).

The interest in the use of Building Information Models (BIMs) in the construction sector has continued to increase over the recent years, as it provides tremendous advantages and resource savings during drawings, planning and building of construction (Bryde et al., 2013; Eastman et al., 2011; Gray et al., 2013; Leite et al., 2011; Nepal et al., 2008). However, the definition of BIM is not yet fully understood. Some people consider that BIM consists of virtual visualization, cost, and quantity estimates, and is a tool for conflict detection. However, the BIM itself is more about the idea of ICE and POP model which represents product, organization, and process (Kunz & Fischer, 2012).

The Return of Investment (ROI) with BIM

Transition to BIM results in inevitable costs. Determining cost items and more essentially cost values shows an advantageous state for monitoring incomes and expenditures. Besides, estimating possible opportunities helps making decisions on transition to BIM.

The main practical methodology is comparing similar type of construction projects, which executes under different disciplines. In this time the point is only one of those projects uses BIM technology. So that, in this case the costs and other variables can be tracked with investigating these projects. In the literature, there different types of economical methodologies to obtain BIM related opportunities and losses considering different projects.

Total Economic Impact is generally used by Stanford University's Center for Integrated Facility Engineering (CIFE) to display benefits of Virtual Design and Construction (VDC). CIFE method is derived from the return period of investment on BIM/VDC Systems (Kunz & Fischer, 2012). In this study, the return of investment is measured, calculated, within a case study including 10 projects to examine the opportunities of BIM usage by Holder Construction in USA.

Giel et al. (2010) compared two similar projects to clarify the effect of the return on investment. Either of which's applies BIM in the project. In the industry, Autodesk Revit is a prominent tool for calculating return of investment for first fiscal year, considering software cost, productivity fluctuations (Rundell, 2004). Jongeling (2008) proposed PENG model to quantify advantages of BIM usage. And conducted a case study that includes 5 different construction projects (European Union, 2011). Azhar (2011) concluded that ROI Analysis is a notable method among others to evaluate an investment. In this methodology, expected incomes and costs are compared to obtain feasibility of the investment (i.e. ROI = earnings / cost).

Moreover, annually, McGraw-Hill Construction publishes reports to reveal the return of BIM investments. However, uncertainty is the main drawback of these reports, because the outcomes and results are based on questionnaires and interviews from AEC industry. They reported in 2008 that users measuring return on investment usually focus on the following six main factors (Jones et al., 2008);

- Requests for information and field coordination problems are reduced,
- Three-dimensional visualization provides better communication,
- It increases efficiency and productivity of all the project staff,
- Gaining positive motivation to all the project staff,
- Project life cycle values of BIM Approach,
- Cost of Training of all the project staff.

Requests for Information: "Almost all of the construction documents cannot be fully fulfilled by agreement, drawings and specifications. There might be gaps, conflicts or ambiguities on them.". The purpose of the Request for Information (RFI) is a written amendment agreement (change order) between the Client and the Contractor. You can add, delete, or change the work in the contract documents while the construction contract is in the bid phase. In the case of contractual changes in the legal sense, business changes in the construction industry have become standardized (Giel & Issa, 2013).

Holder Construction consistently measured Return on Investment (ROI) by monitoring construction clashes that were discovered in Autodesk NavisWorks on ten BIM-used projects. Between 2005 and 2007, these ten different projects that their costs range between 14 M$ and 88 M$ were investigated (Azhar et al., 2011). In these projects, return on BIM investments are 96 times high. The reason why the difference is so high is that the scope of the BIM will change from one project to another. BIM savings are measured in some projects using the "real" construction phase data and the "direct" conflict prevention cost determination. However, in some other projects, BIM savings were measured using "planning" or "value analysis" cost avoidance steps. Even though, indirect, design, construction, administrative or other cost savings have not been included in the calculation. Therefore, the actual BIM ROI is most likely to be higher than the figures in the table below (Azhar, 2011).

Cannistraro wrote an article to reveal the savings achieved through collaboration via using BIM, which means fewer RFIs and less change orders. This is notable since anyone who has a few years of experience in construction industry can see that it is a great challenge for the construction industry to decrease costs of change orders and number of RFIs. Cannistraro analyzed a case study that revealed the economic impact of using BIM in his article in the Building Information Modeling Journal. According to Makaley, a project conducted by Boston-based mechanical construction firm J.C Cannistraro LLC achieved finance savings of 10%-20% of the project's total cost by using collaborative BIM. In this case, the firm used the number of change orders as the decisive factor to measure how 2D and 3D affect only the budgets of specific projects comparing only BIM (building models used for internal use) projects and collaborative-BIM projects. Significant cost savings can be achieved by reaching a project team that includes collaboration and the use of high quality of BIM. By using the collaborative BIM, it is ensured that a project team is able to detect errors' cost before construction, which means additional time savings and money-saving for the owner (Cannistraro, 2010).

Giel and colleagues at the University of Florida studied various projects through comparative studies. The next methodology was to obtain data from RFI, and change order records supported by bilateral interviews provided by the medium-sized general contractor (GC). The selected software platforms were Autodesk Revit Architecture, Structure and MEP. The selected projects were named as A and C (without BIM) and B and D (with BIM support) projects. The projects were comparable in terms of size, scope, contract value, delivery method and type of construction (Giel et al., 2010).

Return on investment calculations of projects A and C are based on analysis of direct and indirect costs that can be avoided by BIM. Subcontracting and change orders are two main direct cost items. Indirect costs stemming from schedule timeouts that can be avoided by BIM are based on four main cost categories. These are as follows; 1- Daily expenses of general conditions of the contractor. 2- Daily expenses for developer management based on contract size. 3- Daily expenses of the contract management according to the size of the contract. 4- Daily expenses of the employer's construction loan interest.

The calculated return of investment for the project A and for project C was used as a model element for project B and project D, which are supported by BIM. Project B's ROI based on only indirect costs, as Project B does not have any lapsed data related to direct costs avoided. When calculating the return on investment for a design system, it is necessary to consider not only the cost of the system but also changes in user productivity. When a new system is purchased, productivity starts to decline as users start to adapt with the new system. Then, as can be seen from Figure 1, the efficiency curve is climbing according to time and training (Rundell, 2004).

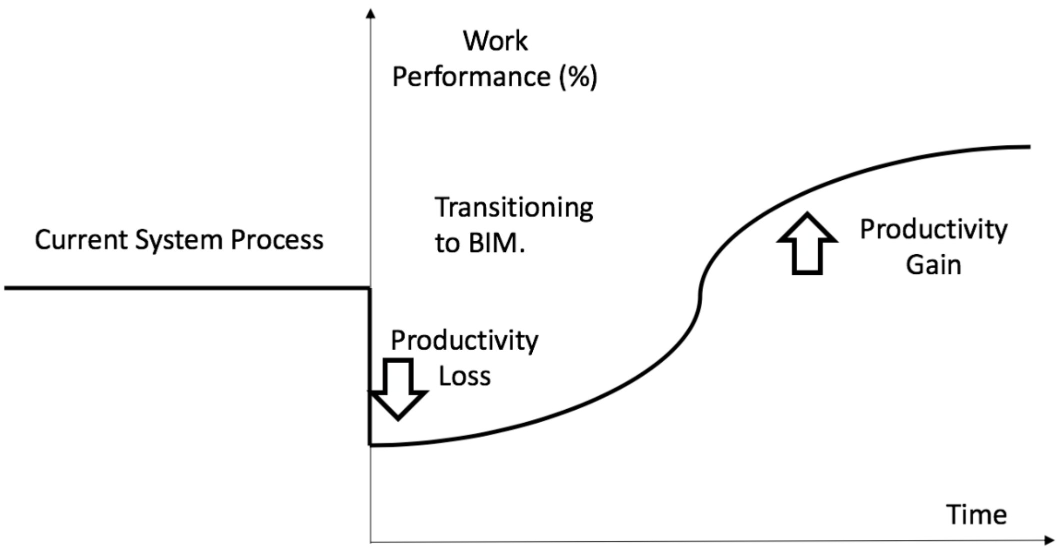

Figure 1: Design investment and productivity curve (Rundell, 2004).

According to Lee and Lee (2020), Return of investment for preventing reworks shall be calculated according to the following formula taking into account the prevented cost, BIM coordinator salary and BIM service costs (Lee & Lee, 2020).

$$BIM\ ROI = \frac{total\ economic\ impact}{BIM\ investment} = \frac{\sum_i^n EI_i}{sf + \sum_{s=1}^t (ms_s * w_s * d_s)} \quad (1)$$

BIM investment means total expenses on BIM technologies. In the divider sf refers to BIM service fee paid for BIM provider, ms_s monthly salary of BIM coordinator, w_s is total work duration in months of BIM coordinator. t is the total number of BIM coordinators. Total economic impact refers to total spending reductions after BIM methodologies are administered. Formula 2 declares total economic impacts. In the formula wv_i stands for effects weighting value, EI_{pr} stands for economic impact of preventing rework and wv_{pr} shows preventing reworks' weighting value.

$$EI_i = \frac{wv_i * EI_{pr}}{wv_{pr}} \quad (2)$$

As giving sample case studies, Autodesk has conducted a sensitivity analysis to measure the impact of each variable on the Return on Investment, by an online survey of its Revit users in December 2003. About 100 users participated in this survey (Rundell, 2004).

Conclusion

Despite the fact BIM shows an important impact on construction projects especially in terms of preventing extra construction costs, there is a still lack of confidence to transition to BIM in Turkey. Especially small size companies have hesitation on spending resources on BIM unless see a "BIM success story" in terms of preventing costs. There is a realistic ROI calculation are needed to fit in Turkey's economic and technological perspective. To handle ROI calculations a detailed survey is executed. Our next study includes a substantial statistical analysis to search positive and negative consequences in terms of financial benefits.

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Cost Comparison of Reinforced Concrete Structures Designed According to Turkish and European Earthquake Codes

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Abstract

Design codes provide methods to analyze and design structures according to different types of risks the structure may suffer, and they differ from each other in several aspects, such as load combinations and earthquake loads evaluation. In this study, the cost of the building designed according to both Turkish and European codes are compared, and cost-effectiveness is measured. The objective of the study is to identify which code provides a more economically feasible design. In consideration of seismic risk, Turkey is regarded to be one of the most hazardous places in the world. Since the case structure is located in Istanbul, in a zone with a high PGA (0,4g), the comparison of the designs will result in more distinctive outcomes about the cost-effectiveness of the codes. After the design of the structure is completed according to both codes, respectively, the bill of quantities for each is calculated, and costs are estimated for the structure. The cost estimation showed that the Turkish Earthquake Code is more economical than the European one. As the world goes into a deeper economic recession, the cost of the design plays a paramount role in being sustainable as well as resilient.

Keywords: *cost comparison, European Code 8 (EC89), structural design, Turkish Earthquake Code 18 (TDY18).*

Introduction

Structural design not only must consider the regulations provided by the design codes such as types of loads (dead, live, earthquake, wind, snow), fire protection for occupants, and provide a comfortable usage of the utilities; also, it must be economical, structurally efficient and build in short time duration. The success of the delivery of the project depends on the collaboration of structural engineers and project managers. Some of the responsibilities of the project managers are to deliver the project on the predefined time, quality, and within budget. These factors make project planning, scheduling, and structural design, one of the essential disciplines in the construction industry.

The design approach of the building defines the type of the bearing system and the material to be used in the structure. These two are considered the most important factors that affect the project budget.

The selection of a proper bearing system is also related to the location of the structure as the location affects the load types and magnitude. In general, each region has its own design code that considers different types of loads. Design codes provide methods to analyze and design structures according to different types of risks the structure may suffer, and they differ from each other in several aspects, such as load combinations and earthquake loads evaluation. The fact that the different codes consider a different type of load combination and different types of regulations, the budget of the structure can change drastically. Therefore, in this study, the cost of the building designed according to both Turkish and European codes are compared, and cost-effectiveness is measured. The objective of the study is to identify which code provides a more economically feasible design.

Regarding the seismic risks, Turkey is considered to be one of the most hazardous places in the world since it has active fault lines with a short distance from the surface (5-30km). Several chaotic earthquakes were causing not only life losses but also enormous damages that cause the structure to collapse fully. Therefore, Turkey updated the design and building codes several times until the final one the TBDY2018.

In this study, a 5-story building, including the basement floor, is modeled and designed according to both codes. Since the case structure is located in Istanbul, in a zone with a high PGA (0,4g), the comparison of the designs will result in more distinctive outcomes about the cost-effectiveness of the codes.

The next step is the calculation the bill of quantities for each code, respectively, after the costs of the structure are estimated. After the design method for both codes is compared, it was obvious that the Turkish code has more restrict measures, so the amount of reinforcement is expected to be higher, making the comparison more advantageous for the European design code.

This article is organized as following: Brief information about the history of the development of seismic codes is given. It follows with the comparison of the seismic codes in a manner of elements dimensioning, ductility approaches, seismic code assignment, and load combinations. In the last part, the example project is designed according to both codes, and the BOQ is used to compare the results; and conclusions are drawn.

History and Development of Seismic Codes

Earthquake engineering, which is the discipline that deals with seismic analysis, is quite young. It was developed in the 20th century (Fajfar, 2018). Around the world, countries lying on seismic zones were rapidly hit by destructive earthquakes. Through years as structural engineering, knowledge improves, developing new design methods and/or updating the seismic codes became a necessity.

The first-ever published seismic code for Turkey was in 1940 after the Erzincan earthquake, with a magnitude of 7.9 occurred. This was the most hazardous earthquake in the history of

Turkey, where around 33 000 people lost their lives, and around 117 000 buildings were damaged or collapsed. Table 1 presents the seismic events that occurred through the years in Turkey and the response taken from the government to develop seismic codes. The earthquake zone map was firstly developed in 1945. From 1940 when the code was first developed until 2018, it was revised and updated several times (Joint Research Centre: Eurocodes, nd).

Table 1. Event and seismic code development.

Year	Event	Code development
1939	Erzincan earthquake (M7.9)	-
1940	Committee formed to develop a seismic zonation map for Turkey	First seismic code published
1942	-	Earthquake zone map prepared, map promulgated in 1945
1943	Tosya earthquake (M7.2)	-
1944	Gerede earthquake (M7.2)	Seismic code revised
1947	-	Seismic code revised
1949	-	Seismic code revised
1953	-	Seismic code revised
1958	Ministry of Reconstruction and Resettlement established	-
1961	-	Seismic code revised
1963	-	Earthquake zone map revised
1966	Varto earthquake (M7.1)	-
1967	Adapazari earthquake (M7.1)	-
1968	-	Seismic code revised
1975	-	Seismic code revised, ductile detailing introduced
1992	Erzincan earthquake (M6.9)	-
1997	-	Seismic code revised, ductile detailing required
1999	Izmit earthquake (M7.4) Duzce earthquake (M7.2)	-
2007	-	Seismic code revised
2018	-	Seismic code revised

The first country that developed a seismic regulation for buildings was Italy in 1909. It was developed after the Messina earthquake in 1908. Although it was the first developed seismic code, it didn’t have a widespread effect worldwide. On the opposite of them, the Japanese had a greater impact on the code. They developed the seismic code in 1919, and later 1924 adopted it by using the seismic coefficient. In the United States, the development of the first regulation was triggered by the earthquake in Santa Barbara in 1925. The first mandatory seismic code was developed in 1943. Later the USA updated the code several times by using different approaches. The latest version was created in 2010, the ASCE 7-10. The table below presents a summary of the developed codes around the world.

The Eurocode started to develop in 1975, where the European Community took the initiative to create a program in the field of construction. The program was based on the Treaty of Rome (1957), and its objective was to develop technical regulations and eliminate the obstacles. The Eurocode was first developed in 1984 and published by the Commission. In 1992 the ENV Eurocodes were published. The codes contain different values for different regions of the EU. The codes were later updated through the years.

Table 2. The evolution of seismic codes.

Italy-1909	The first seismic regulations for buildings worldwide, with provisions for equivalent static analysis.
Japan-1924	The first code using the seismic coefficient was equal to 10%.
USA-1927	First edition of the Uniform Building Code (UBC).
USA-1933	First mandatory seismic codes in the United States.
USA-1956	San Francisco enacted a code with explicit dependence of the seismic loads on the building period.
USSR-1957	Implementation of the modal response spectrum method, which later became the main analysis procedure in Europe.
USA-1978	The start of modern codes with ATC 3-06 guidelines (probabilistic seismic maps, force reduction R-factors).
Yugoslavia-1981	Adoption of linear and nonlinear response history analysis for very important buildings and prototypes of prefabricated buildings in the seismic code.
USA-2010	Explicit probabilistic analysis permitted in ASCE 7-10

Comparison of TBDY 2018 and EC8

Some Basic Differences between TBDY2018 and EC8 in Reinforced Concrete Members Design

Table 3. Minimum allowed material strength.

Minimum allowed material strength		
	TBDY2018 – TS500	EC8 – EC2
Concrete	C25/30	C20/25
Rebar Steel	B420C	B and C class (400-600Mpa)

As seen in Table 2, TBDY2018 requires a stronger type of concrete, which increases the strength of the structure and also increases the cost. In the case of Rebar material, the strength has similar values. It is important to mention that both codes require ribbed rebars except for shear reinforcement.

Table 4. Minimum beam dimensions.

BEAMS		
	TBDY2018 – TS500	EC8 – EC2
Width	250mm	200mm
Height	l/10-l/12	Not defined

In Table 3, the minimum dimensions for beams are given. According to these regulations, TBDY2018 has stricter but less economical requirements.

Table 5. Minimum column dimensions.

Column		
	TBDY2018 – TS500	EC8 – EC2
Minimum dimension	300	250
Axial force limit (N_{dm})	$A_c > N_{dm}$ / 0,40 f_{ck}	$A_c > N_{dm}$ / 0,55 f_{ck}
Minimum rebar	6Φ14	Not defined

Table 6. Minimum shear wall dimensions.

Shear Walls		
	TBDY2018 – TS500	EC8 – EC2
Width	Max {0,15 ; h_s/20}	200mm
Area in one direction	$\Sigma A_g / \Sigma A_p \geq 0{,}002$	Not defined

Comparations of Seismic Load Assignment

The Ductility approach of EC8

EC8 has provided several rules for structural design considering its ductility class. The structural ductility can be defined as low (DCL), medium (DCM), and high (DCH). The ductility is reflected in the design by a force reduction factor called behavior factor (q).

DCL structures are not designed by considering their ductility, and the behavior factor is assumed as q=1,5, which means that the load will be less reduced, and its elements will remain larger. This is not the recommended choice, according to EC8. The only situation where it can be applied is when the PGA is less than 0,10 g.

Structures with medium and high ductility classes are considered almost the same in terms of material and performance. The difference is that the DCM is more preferred for moderate earthquakes, while the DCH gives better performance under seismic actions stronger than design seismic actions. The behavior factor is the factor that differs from the ductility classes. It is usually 50% larger in DCH than in DCM.

The Ductility approach of TBDY2018

In order to have a good seismic performance, TBDY2018 also gives huge importance to the ductility. Chapter 3.A. in TBDY2018 gives recommendations on how the principles of ductile and capacity design must be applied. Similar to EC8, TBDY2018 also divides the structures into three ductility classes: low, medium, and high ductility class. The earthquake load reduction factor, which depends on ductility, is applied differently for different structural periods. The factors are applied differently to the structures depending on the Hight and the irregularities of the structures.

When both of earthquake codes are summed up, in terms of ductility, they follow similar paths by strongly supporting and recommending the ductile design approach. The detail that makes them different is the behavior (reduction) factor. The higher value suggested by TBDY2018 makes the earthquake load effect lower, which leads to less demand. It will be clearly understood in the example project below.

Design acceleration response spectrum

The value of earthquake loads affecting the structure directly depends on the acceleration value of the ground motion affecting the structure. Every earthquake code gives the steps to plot the design response spectrum from where the acceleration is read. The design response acceleration spectrum gives the acceleration value corresponding to the period of the structure. One of the indicators of the acceleration is the seismic ground motion level of the earthquakes that were used to plot the design response spectrum.

The design spectrum, according to TBDY 2018, is defined by considering the characteristics of the zone where the structure is located, and the distance of the structure form active fault. The seismic ground motion level used for the design spectrum is DD-2. DD-2 earthquake ground motion level contains earthquakes with a probability of 10% to exceed the magnitude in 50 years, which corresponds to a repeat period of 475 years, and as a result, it is considered a very rare earthquake. This seismic ground motion level is also characterized as standard design seismic ground motion.

The same level earthquakes are used to create the design acceleration response spectrum, according to EC8.

The following tables give the fundamental values needed to plot the design acceleration response spectrum according to both codes.

Table 7. Eurocode 8.

		EC8	Explanation	Reference
Floor number		6		Project
Building height		23,2m		Project
Importance factor		I	Residential	Table 4.3 (EC8)
Ductility class		DCH		
Behavior factor q_p		4,5		Table 5.1 (EC8)
Response spectrum type		1	High seismicity	Figure 3.2 (EC8)
Ground type		B	Gravel	Table 3.1 (EC8)
Soil Factor (S)		1,2		Table 3.2 (EC8)
Design ground acceleration		0,38 g		
Periods	T_B	0,15	Type 1 Ground type B	Table 3.2 (EC8)
	T_C	0,5		
	T_D	2,0		
Damping factor		5%		Chapter 3 (EC8)
RC design method			Ultimate limit state	EC2
Seismic design method			Response spectrum analysis	EC8
Structural analysis software			ETABS	

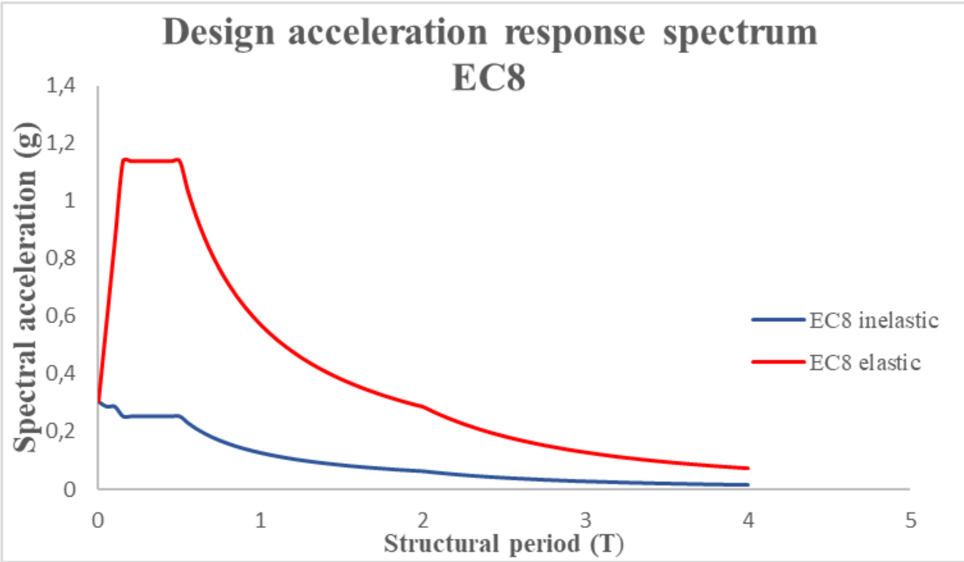

Figure 1: Design acceleration response spectrum EC8.

As stated by EC8 for high ductility class, the behavior factor varies from 4 to 6, while according to TBDY2018, these values are much higher, and it varies from 6 to 8. The reason for this difference may be correlated to the seismic regions where the codes are developed. When the seismicity of countries is compared, Turkey is founded in a zone with much higher seismicity than almost all European countries.

Table 8. TBDY2018.

	EC8	Explanation	Reference
Floor number	6		Project
Building height	23,2		Project
Ductility class	DCH		
SDS	0,831		
Earthquake design level	1a		Table 3.2 TBDY2018
Structure height level (BYS)	5		Table 3.3 TBDY2018
Importance factor (I)	1.0	Residence	Table 3.1 TBDY2018
Behavior factor (R)	6		Table 4.1 TBDY 2018
Strength excess factor (D)	2.5		Table 4.1 TBDY 2018
PGA	0.38g		
Damping factor	5%		Chapter 3 (EC8)
RC design method		Ultimate limit state	TS500
Seismic design method		Response spectrum analysis	TBDY2018
Structural analysis software		ETABS	

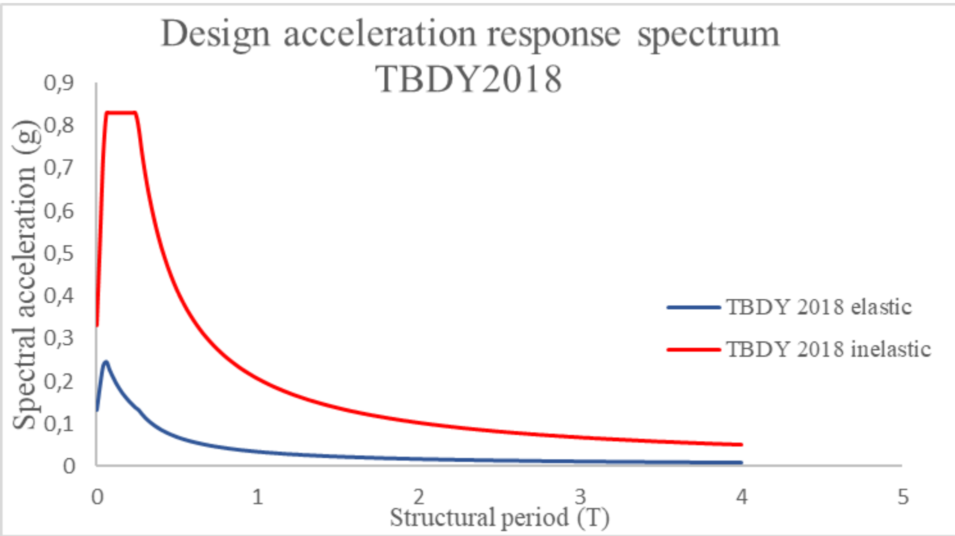

Figure 2: Design acceleration response spectrum TBDY2018.

Load Combinations

Since the responsibility of the structural engineers is to design a serviceable and safe structure, the magnitude of load types and the combinations of loads that act on the structure must be considered. Table 8 present the load combinations for both codes EC2 and TS500. The structure is later designed by the most unfavorable load combinations. Sometimes it is essential to make an envelope in order to shorten the design process.

Comparing the load combinations shows that the EC2 has lower factors of magnitudes of the loading cases, which results in smaller reactions and, therefore fewer reinforcement requirements for the structure.

Table 9. Ultimate limit state load combinations.

	EC2	TS500
1	1,35 G	1,4 G
2	1,35 G + 1,5 Q	1,4 G + 1,6 Q
3	G + Q + E	G + Q + E
4	G + E	0,9G + E
5	G + 1,5 Q + 0,9 W	G + 1,3 Q + 1,3 W
6	G + 1,5 W	0,9 G + 1,3 W
7	1,35 G + 1,5 Q + 1,3 H	1,4 G + 1,6 Q + 1,6 H
8	G + 1,3 H	0,9 G + 1,6 H
9	G + Q + E + H	G + Q + E + H
10	1,35 G + 1,5 T	G + 1,2Q +1,2 T

Example Project

Two structures with the same properties are constructed in two different places, one in Istanbul, Turkey, and the other in Ulcinj Montenegro**.** Structural systems were designed according to the codes of the countries, respectively. The codes used to design the structures are TDBY2018 (seismic code) and TS500 (RC structures), while in Europe, EC8 (seismic code) and EC2 (RC structures).

Table 10. Structure properties.

Building Type	Reinforced Concrete
Design Usage	Residential
Story Height	3,2 m
Total Height	23,2
Building Dimensions	22 m x 16 m
Concrete	C30/35
Steel Class	420C
PGA	0,38g
Beam sample	EC8 200/400mm
	TBDY2018 250/400mm
Column sample	EC8 200x800mm
	TBDY2018 300x800mm
Shear wall width	EC8 20mm
	TBDY2018 25mm
Slab thickness	EC8 15mm
	TBDY2018 15mm

The table above gives some brief information about the structure, such as structure type, dimensions, materials used, dimensions of structural elements, seismic auction properties.

The software used to model the structure and perform the analysis was ETABS. The ultimate state method was used for structural analysis. Non-elastic response spectra were defined according to both seismic code and were assigned to the system in order to obtain the earthquake load.

The formwork plan and the 3D model of the structure where given in figures bellow.

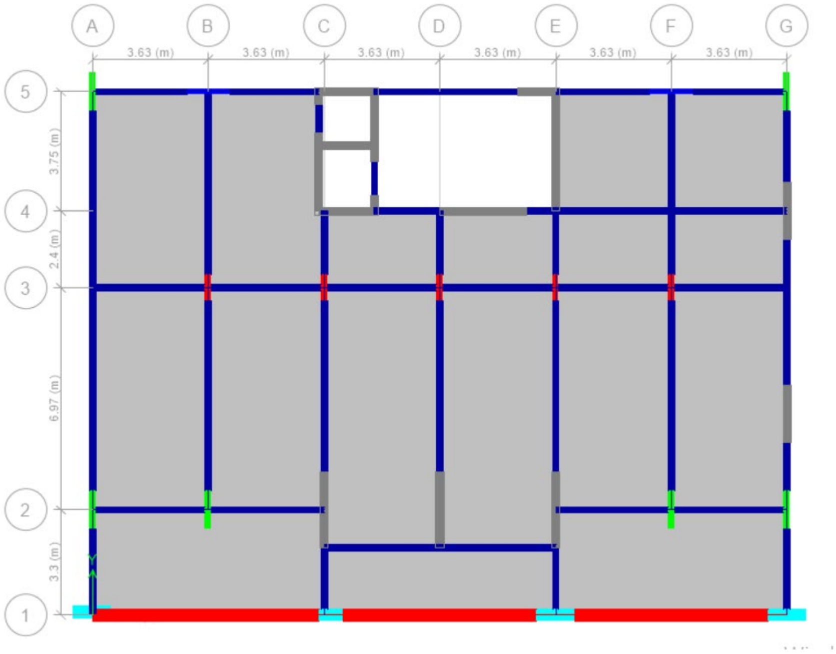

Figure 3: Plan view.

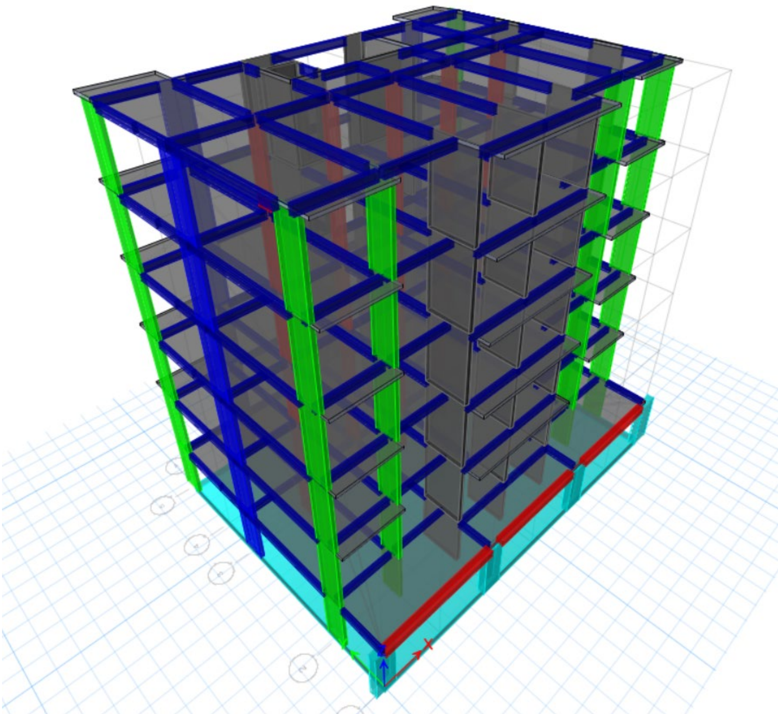

Figure 4: 3D model.

Results

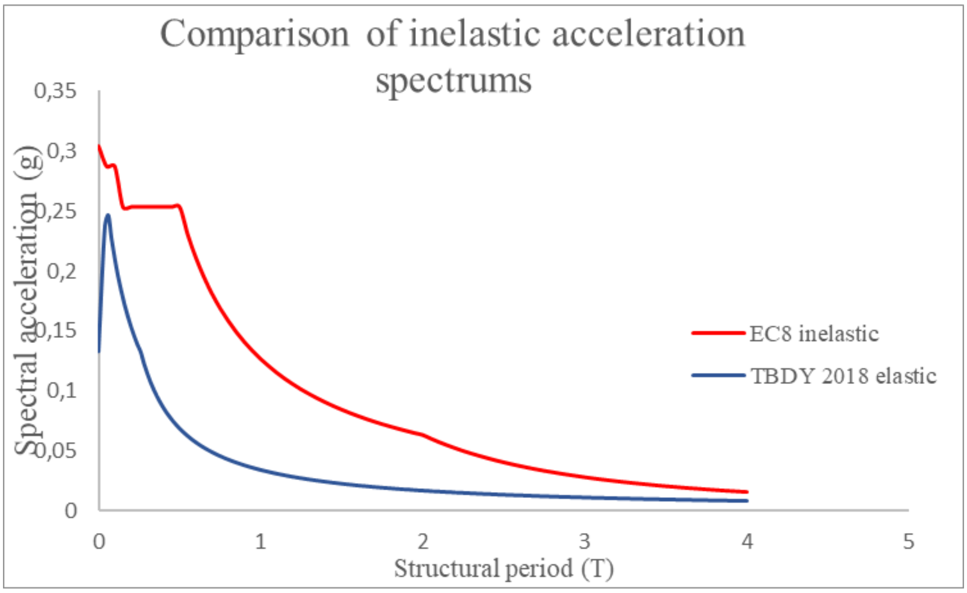

Figure 5: Comparison of inelastic acceleration spectrum.

From the graphics above, it is observed that the design spectrums plotted according to TBDY2018 and EC8 are significantly different from each other. Although the PGA used to determine both graphics is 0,38g, the acceleration values achieved from the design spectra are much lower than PGA. The main reason that makes the inelastic spectra different is the behavior factor value, which higher in TBDY2018 (R=6) than according to EC8 (q=4.5). Even though the fundamental periods are similar to each other, the seismic load applied to the structure will be different.

The exact same structural system, respecting the rules in the manner of dimensions, materials, and seismic conditions according to EC8 and TBDY2018, was analyzed. In order to be able to compare the results, they were taken from the software, and the effect of different design response spectrum was observed.

Analysis Solutions

When the analysis was performed, every single element of the structure was designed and controlled. Ultimate attention was shown to important details such as minimum and maximum reinforcement ratio; dimensions of beams and columns, depth of foundation, slabs and shear walls.

In the end, the bill of quantities of both designs was summed up and compared. In Table 10 and Table 11 the concrete and rebar quantity values for both codes were given in the manner of structural elements.

Table 11. Concrete BOQ.

	EC8 (ton)	TBDY2018 (ton)
Column	195.99	286.16
Slabs	1139.354	1139.354
Beam	175.637	216.059
Shear Walls	431.62	431.62
Total (t)	1942.604	2073.193
Total (m^3)	810	863.75

Table 12. Reinforcement steel BOQ.

	EC8 (ton)	TBDY2018 (ton)
Rebar	86,278	95.012

Considering the values estimated in tables above, it is seen that in the manner of concrete according to the EC2 and EC8 design, 810 m^3 are required, and according to TBDY2018 and TS500 design, about 864 m^3 are required. European design requires a 6.67% less amount of concrete compared to Turkish design. Regarding the rebar amount, it is calculated that the Turkish code requires a 10% higher amount of rebar steels than European code.

Table 13. Construction materials prices in Europe and Turkey.

	Europe	Turkey
Concrete C30 (m^3)	75 €	30 €
Rebar Steel (t)	660 €	460 €

Table 14. Construction cost.

	Europe	Turkey
Concrete C30	60750 €	25910 €
Rebar Steel	56945 €	43705 €
Total Cost	117694 €	69615 €

Conclusions

As the seismic load has a great impact on the structure, it has a great role in structural design.

The objective of this study was to compare the cost of the building designed by Turkish and European regulations and to classify which code provides a more economically feasible design.

The major findings of the study are:

- Regarding the rebar comparison: This is affected by the dimensions of the structural elements provided by the RC members regulation.
- Considering the RC members' concrete quantities, the Turkish code requires a 6.67% higher amount of concrete.
- Considering the rebar BOQ, the Turkish code requires a 10% higher amount of rebar steel.
- After the BOQ's are summed up and compared, EC was assumed as a more economical solution.
- The material prices are taken from competent authorities in both countries were used to estimate the cost of the building. Even though the European code has less amount of concrete (m^3) and rebar steel (ton), the price for building the object is significantly higher in Europe. Therefore, the price for the same buildings bearing system in Europe is estimated to be 117694 € and 69615€ in Turkey, making Turkey 41% cheaper.

Results of example project have shown that structures with exactly the same properties under seismic loads with the same magnitude, constructed in different areas, demand different quantities of materials due to different regulations in places where they are constructed. As a result, the cost of the structure changes. Also, an important factor affecting the price of the buildings is the prices of the material in that area.

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An Overview of Risk Management in Construction Projects: Literature Review

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Abstract

This article presents an overview of risk management and quantification in construction projects. A general review and detailed content analysis of selected articles from reliable and relevant academic journals published over the last decade were conducted. First general view of the risk management field is presented, by introducing the basic concepts and principles. Secondly this article tries to focus on historical development of the field. Finally this article addresses the lack of a systematic review and content analysis of published articles related to risk quantification, and it provides researchers with data on the risk quantification.

Keywords: *literature review, risk cost, risk management, risk quantification.*

Introduction

The concept of risk and risk assessment has a history of more than 2400 years. The Athenians offered their capacity of assessing risk before making decisions. However, risk assessment and risk management as a scientific field is young, not more than 3-4 decades. (Aven, 2015). Majority of the researchers approached to risk management in construction projects using a reductionist approach that produces poor results and limits the quality of project management. Generally, risk is handled through the application of contingencies (money) or floats (time) that are not determined based on a comprehensive analysis of the risks that can affect a particular project, Then, in most of the cases projects end with costs overrun and late (Serpell et al, 2014).

The risk factor in construction business is very high. Construction objects are unique and built only once. Construction objects life cycle is full of various risks. Risks come from many sources: temporary project team that is collected from different companies, construction site, etc. Moreover, the size and complexity of construction objects are increasing which adds to the risks. This is in addition to the political, economic, social conditions where the object is to be undertaken. Object risk can be defined as an uncertain event or condition that, if it occurs, has a positive or negative effect on at least one project objective, such as time, cost, quality (Zavadskas et al., 2010). The risks cause cost and time overruns in construction projects.

This article presents an overview of risk management and quantification in construction projects. First general view of the risk management field is presented, by introducing the basic concepts and principles. The research objectives are threefold. The first objective is to analyse the existing literature concerning the concept of risk, risk management and methods used in managing risks. Secondly this article tries to focus on historical development of the field. Finally this article addresses the lack of a systematic review and content analysis of published articles related to risk quantification, and it provides researchers with data on the risk quantification.

Research Methodology

This study is based on a comprehensive literature review of recently published (2010-2020) relevant articles. The literature is consisting of mainly on peer- reviewed articles published in academic journals specialised in construction management, project management and risk analysis. The following databases were utilised for researching relevant articles: Emerald, Web of Science and Science Direct. In addition to this, the published literature on the Google Scholar search engine was scrutinized in order to support reviewing the literature. As a result of the search, more than 200 articles have been found. However, only 56 articles were found to be more relevant. Ultimately, these articles were scrutinized and reached to the fundamental information.

Literature Review

Basic Concepts and Principles of Risk Management

Risk management is a systematic approach to dealing with risk. A risk management system should: establish an appropriate context; set goals and objectives; identify and analyse risks; influence risk decision making; and monitor and review risk responses (Edwards & Bowen, 1998). Risk management is about defining sources of uncertainty (risk identification), estimating the consequences of uncertain events/conditions (risk analysis), generating response strategies in the light of expected outcomes and, finally, based on the feedback received on actual outcomes and risks emerged, carrying out identification, analysis and response generation steps repetitively throughout the life cycle of a project to ensure that the project objectives are met (Cakmak & Tezel, 2019) (Dikmen et al., 2008). Risk analysis/assessment is the process that focuses on evaluating and seeking the likelihood in which potential risks in the risk identification stage may occur (Cooper et al., 2005) and it is implemented by two approaches: qualitative risk analysis and quantitative risk analysis. In qualitative risk analysis process, the main focuses are rating and prioritizing individual project risks for further analysis or action by assessing their probability of occurrence and severity of consequence/impact as well as other characteristics. On the other hand, quantitative risk analysis process focuses on numerically analysing the combined effect of identified individual project risks and other sources of uncertainty on overall project objectives (Project Management Institute, 2013).

Historical Development of Risk Management in Construction Industry

There have been diverse studies on risk management in construction industry. Some of them focused on literature reviews about risk and/or risk related topics. For example, Taroun et al. (2011), Majetka et al. (2014), Renuka et al (2014), Taroun (2014), Cagliano et al. (2015), Dealmeida et al. (2016), Renault et al. (2016), Tesfaye et al. (2016), Chen et al. (2017), Friday et al. (2018), Xia et al. (2018), Siraj et al. (2019), Omer et al. (2019) conducted comprehensive literature reviews. In addition, Zou et al. (2010), Zhao et al. (2013), Jia et al. (2013) and Abdulrahman et al. (2019) presented risk management maturity model for construction. Abdelgawad et al. (2011), Purnus et al (2012), Nasirzadeh et al. (2014), Zadeh et al. (2014), Nasirzadeh et al. (2016), Muriana et al. (2017), Thaheem et al. (2018), and Moselhi (2020) shared various versions of risk quantification. Lazzerini et al. (2011), Yuan et al. (2011) and Zhang et al. (2014) investigated risk impact factors and risk response strategies. Dikmen et al. (2008), Motjahedi et al. (2010), Jin et al. (2011), Nieto-Moreto et al. (2011), Fang et al. (2012), Lu et al. (2013), El-Sayegh et al. (2015), Taillandier et al. (2015), Datta et al. (2017), and Islam et al. (2017) presented risk assessment and/or allocation systems using artificial neural network, multi-attribute group decision making technique, fuzzy, decision support system, fuzzy multiple criteria decision making, multi-agent models. And Marcelino-Sádaba et al. (2014) and Hwang et al. (2014) studied specifically on risk management in small construction firms. Marle and Vidal (2011), Serpell et al. (2014), Qazi et al. (2016), Malekitabar et al. (2018) and Willumsen et al. (2019) focused on general risk management issues. Zavadskas et al. (2010) and Mousavi et al (2011) focused on general risk assessment modelling. Yan et al. (2016) and Xie et al. (2017) focused on more specific categories of risks in international construction projects. And lastly Zhong et al. (2016) studied construction risk knowledge management BIM and Adedokun et al. (2013) studied qualitative risk analysis.

Table 1. Classification of articles conducted on risk related topics.

Classification	Author
Risk management in construction: a literature review	Taroun et al. (2011), Majetka et al. (2014), Renuka et al. (2014), Taroun (2014), Cagliano et al. (2015), Dealmeida et al. (2016), Renault et al. (2016), Tesfaye et al. (2016), Chen et al. (2017), Friday et al. (2018), Xia et al. (2018), Siraj et al. (2019), Omer et al. (2019).
Risk management maturity assessment model for construction	Zou et al. (2010), Zhao et al. (2013), Jia et al. (2013) and Abdulrahman et al. (2019).
Risk impact factors / risk response strategies	Lazzerini et al. (2011), Yuan et al. (2011) and Zhang et al. (2014).
General risk assessment modelling.	Zavadskas et al. (2010) and Mousavi et al (2011).
Risk management in small construction firms.	Marcelino-Sádaba et al. (2014) and Hwang et al. (2014).
Qualitative risk analysis	Adedokun et al. (2013)
Risk assessment and/or allocation systems using artificial neural network, multi-attribute group decision making technique, fuzzy, decision support system, fuzzy	Dikmen et al. (2008), Motjahedi et al. (2010), Jin et al. (2011), Nieto-Moreto et al. (2011), Fang et al. (2012), Lu et al. (2013), El-Sayegh et al. (2015), Taillandier et al. (2015),

multiple criteria decision making, multi-agent models.	Datta et al. (2017), and Islam et al. (2017).
Risk management	Marle and Vidal (2011), Serpell et al. (2014), Qazi et al. (2016), Malekitabar et al. (2018) and Willumsen et al. (2019).
Risks in international construction projects	Yan et al. (2016) and Xie et al. (2017)
Construction risk knowledge management BIM	Zhong et al. (2016)
Risk quantification	Abdelgawad et al. (2011), Purnus et al (2012), Nasirzadeh et al. (2014), Zadeh et al. (2014), Nasirzadeh et al. (2016), Muriana et al. (2017), Thaheem et al. (2018), and Moselhi (2020).

Conclusions

This study is based on a comprehensive literature review of recently published (2010-2020) relevant articles over last decade on risk management in construction projects. As various researches have been conducted for many decades, construction risk management preserves the popularity as a research issue and is a developing and ongoing process. By means of this study, it can be stated that researchers have shown a remarkable contribution towards risk identification and assessment and considerable progress has been made. But it is unfortunate that, there is still a wide gap between theory and practice.

From the results, it can be specified that risk quantification, risk response, risk monitoring and control were not taken into consideration by the researchers. And keywords of the disregarded issues are less addressed than the other ones.

It can be stated from this study that, between 2010-2020 among the examined published articles, only few attempts (Moselhi et al., 2020; Thaheem et al., 2018; Muriana et al., 2017; Nasirzadeh et al., 2016; Nasirzadeh et al., 2014; Zadeh et al., 2014; Purnus et al., 2012; Abdelgawad et al., 2011) have been made related to risk quantification of the construction projects. The majority of the mentioned researchers approached to risk quantification with a fuzzy based risk allocation model.

To conclude, the construction industry has a risky nature, and the present methodologies, theories and tools are deficient in capturing the accurate picture of risk quantification.

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Investigation of Productivity in the Construction Industry

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Abstract

The construction industry has great importance for the economy, especially in developing countries. While having such great importance at macro level, there are many uncertainties for the industry to overcome. This study aims to identify the multi-causal factors affecting the productivity of technical personnel in the construction industry through factor analysis. For this purpose, a detailed questionnaire survey was taken among 400 professionals in the construction industry. The top nine factors affecting technical personnel's productivity are listed in the study and 47% of these factors affecting technical personnel's' productivity is expressed by management factors. By gathering the perceptions of the professionals in the construction industry, the results of this research will be a guide for maximizing the technical personnel's productivity for developing countries like Turkey.

Keywords: *Multi-Casual Factors, Management Factors, Technical Personnel, Questionnaire Survey*

Introduction

The construction industry has a significant role for developing the economy, it has mutual and causal relationships between the industry and gross domestic product (GDP) (Cox et al. 1998, cited in Enshassi et al., 2007), especially in Turkey. Contingencies that exist in the construction industry make this sector risky in terms of project management, because the outer parameters effect the project management as much as the inner parameters. Construction is a labor-intensive industry and efficiency of a construction project mostly depends on the productivity of the employees. Therefore, productivity of the labor in the construction industry has become one of the most researched topics (Jergeas and McTague, 2002; Jarkas and Bitar, 2011). For instance, Dai et al. (2009) surveyed the causes of the factors that affect the craft workers' productivity in construction projects. Kisi et al. (2017) presented a two-prong strategy for calculating optimal productivity of labor-intensive constructions in a pilot study and as a result, they shared a framework to calculate the optimal productivity for labor intensive construction works. Goodrum et al. (2009) investigated the correlation between material technology and construction productivity by using labor and factor productivity measures. However productivity of technical staff (i.e. architects and engineers) has not been investigated yet. The objective of this research is identification and ranking of multi-causal factors that affect productivity of technical staff in the construction industry.

Methodology

In this research, a detailed questionnaire survey was taken among 400 professionals in the construction industry. The Likert type scale was used for ranking the factors affecting technical personnel in the construction industry. Weisberg (2005) stated that the usage of a middle scale answer might affect the answer of the respondents by 10 to 20 % or even more. Hence, the questions were designed to be 6 Likert scaled and were gradually rated from 0 to 5 as 0 equals to none and 5 means very good. While defining the productivity factors, 10 industry professionals were asked about the influence of factors, which are collected from literature, via face to face meetings and finally 60 productivity factors were determined for Turkey. The factors were grouped under 4 major categories, that are: (1) Human; (2) Management; (3) External; and (4) Working Conditions. Kaiser-Meyer-Olkin Measure (KMO) of Sampling Adequacy score of the dataset was in a marvelous category with a score of 0.911. The KMO score of the dataset was not only acceptable but also in the best possible category for the analysis. Barlett's Test of Sphericity significance level of dataset is "0" which shows that the dataset is meaningful. The approximate Chi-Square value was found at "8,142.342" and the df value was calculated as 946. The Cronbach's alpha value, which shows the internal consistency level of the dataset, is 0.948. This value shows that by being over 0.9 our data set is excellent with regards to internal consistency.Then, factor analysis is conducted in order find out the relations between the factors and how to define them in fewer factors. Factor Analysis was conducted via the Statistical Package for Social Science (SPSS) software.

Results

Multi-Casual Factors Effecting Productivity of Technical Personnel

Using 59 productivity factors, factor analysis was conducted. After the first run, rotated component matrix was examined and as a result of the first analysis the 59 factors could be represented by 13 components. After evaluating the results, 14 factors were excluded from the analyses. 10 out of 14 were removed due to having absolute value less than 0.45. In the second run, 45 factors were analyzed and as a result of this analysis 9 components was observed to represent 45 factors. Due to having absolute value less than 0.45, "Personnel's job satisfaction" factor was also removed from the analysis. After the final run, only 9 main factors are extracted with the combination of the relevant variables, which will explain the 60.32% of the total variance. According to Hair et al. (2010) the minimum level of total variance explained should be 60%. In this regard, it can be stated that conducted factor analysis is acceptable.

Main Factor 1
The first main factor has 28.23% of the total variances of productivity factors. This factor is representing 8 components (or sub-factors) which are the "unrealistic schedule", "lack of procedures", "lack of co-operation between departments", "interruption and disruption", "discontinuity in crew", "out-of-sequence work", "necessity to re-do work" and "inadequate communication". Due to covering all sub-factors that are directly related to management decisions and behavior this category called as "Management Factors". Since this factor represents almost half of the total explained variances, it is considered as the most important factor.

Main Factor 2

This main factor includes 7% of the total variance of the explained productivity factors. There are 7 sub-factors in this category, which are namely: "changes in drawings and specifications", "changes in contract", "nature of project (size and complexity)", "weather conditions/climate", "method of construction", "owner's representative intervention" and "congested construction area". Since these sub-factors are specific to the project and cannot be controllable by the management, it is called as "External and Owner Related Factors".

Main Factor 3

The third main factor covers the 5.31% of the total variance. There are 7 sub-factors that form the third factor, which are "loyalty to job", "perception/misperception", "personnel's motivation", "loyalty to company", "team spirit of the crew", "personnel's experience and skills", "personnel's attitude and morale". Since all sub-factors are related to motivation of employee this factor is called as "Motivational Factor".

Main Factor 4

Main factor 4 accounts the 4.49% of the total variance explained. This factor consists of five sub-factors that are namely: "lack of recognition program", "salary and benefits", "composition of teams", "end of project effect" and "lack of personnel training and education". Since all sub-factors have monetary affect, this factor is called "Financial Factor".

Main Factor 5

The fifth main factor has 3.56% of the total variance explained. This factor has five sub-factors namely: "excessive shift length", "unsafe working conditions", "unpaid overtime", "demand of over quality work" and "overcrowded work areas". Since all the sub-factors are specific to work place, factor 5 is called "Working Condition Factor".

Main Factor 6

The sixth main factor explains 3.43% of the total variance. The five sub-factors of sixth group are "noise, dust and radiation", "parking facilities", "ventilation system", "cleanliness of working space" and "transportation to work". All sub-factors are related to working comfort of the technical personnel, therefore this factor is called "Welfare and Comfort Factor

Main Factor 7

The seventh main factor covers the 3.01% of the total explained variance. It has three sub-factors that are "non-availability of equipment", "non-availability of materials/software" and "non-availability of information". All of the sub-factors are related with the availability of resources, accordingly this factor is called "Lacking Resources Factors".

Main Factor 8

The eight main factor accounts 2.81% of the total variance explained. The two sub-factors under this factor are "personnel's marital status" and "personnel's age". Since these two factors are the personal specification of the employee, this factor is called "Personal Factor".

Main Factor 9

Lastly, the ninth main factor is covering 2.48% of the total variance explained. The sub-factors under this factor are "lack of workload" and "excessive workload". Due to having two sub-factors related to workload this factor is called "Workload Factor".

Conclusion

The research has been conducted to identify and rank the factors affecting the productivity of technical personnel in construction industry by factor analysis. Based on the conducted factor analysis, statistically 60.32% of the 59 factors could be represented by the identified 9 main factors. When the identified 9 main factors were listed, management factor represents 28.23% of all factors, which is also equal to 47% of the total variance explained. In other words, the management factor covers 47% of the factors which were statistically put in to factor analysis. Hence, in order to improve technical personnel's productivity, industry professionals shall place emphasis to management factors.

It is recommended that the construction industry needs to focus on training future managers that will have direct impact on the factors affecting the productivity. Additionally, the results could not provide any information about individual factors influencing productivity and this finding is also important to change the focus from the "individual" to the "environment". However, "commitment of the company owners" will have a role on this process as well. The owners or upper management of the companies should delegate the financial power to the manager in parallel with the responsibility they delegate. Otherwise, even if the managers identify the factors affecting the productivity of their technical personnel, they might not have enough financial ability to eliminate or minimize these factors.

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Relative Importance of Productivity Factors in Construction Industry

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Abstract

Productivity is one of the most important uncertainty in the construction industry. Most of the companies in the industry do not have any performance measure or efficient criteria for the technical personnel and the work outcomes of the technical personnel are not quantifiable. This study aims to rank the productivity factors of technical personnel in the construction industry. A comprehensive survey was taken among 400 construction industry professionals. Kaiser-Meyer-Olkin Measure of Sampling Adequacy, Barlett's Test of Sphericity which makes Cronbach's Alpha, reliability tests were conducted to the results of the questionnaire survey. Relative Importance Index (RII) was used for ranking the importance level of the factors. 17 factors have RII score over 80% with the mean over 4, were considered as the most important factors affecting the productivity of technical personnel in construction sites. The findings of the study will monitor for increasing the technical personnel's productivity for Turkey.

Keywords: *management factors, questionnaire survey, relative importance index.*

Introduction

During the last decades, Turkish contractor firms have been expanding globally. Accordingly, the demand for technical personnel of the industry is expanding as well (Vogl & Abdel-Wahab, 2015). The construction industry's contribution to GDP at current prices is nearly 5% and the share of the industry in total employment is about %7. According to Turkish Contractors Association (2016), the construction industry's contribution to Turkish Economy reaches up to 30% and the employment rate (excluding agriculture) reaches up to %10, if the direct and indirect impacts on other sectors are taken into account. While having such a great importance at macro level, there are still many ambiguities for the industry to overcome; one of the most important issue is the productivity of the technical personnel. There has been a quite extensive amount of studies related to productivity in the construction industry (Lema, 1995; Li et al., 2016; Nasirzadeh and Nojedehi, 2013; Nguyen et al., 2014; Ranasinghe et al., 2012; Olomolaiye et al., 1998; Srinavin and Mohamed, 2003; Thomas, 1999; Ulubeyli et al., 2014). While the productivity of technical personnel cannot be determined measurably, by identifying the factors affecting it, the productivity of the technical personnel could be maximized. In the research, 60 factors were identified through an extensive literature review and grouped under four main categories namely; Human Factors, Management Factor, External Factors, and Working Conditions Factors. The results were analyzed using Relative

Importance Index. It is believed that findings of this research can help wide range of individuals in the construction industry from project personnel to headquarter personnel.

Scope and Method

In this research, the factors affecting productivity of the construction technical personnel is investigated based on an extensive literature review. While defining the productivity factors, 10 experienced engineers were asked about the impact of dynamics, which are collected from literature, and finally 60 productivity factors were determined. To gather the required data, a structured, close-ended questionnaire was designed. The target population of this questionnaire was the Turkish technical personnel and the only criterion for the respondents was to work in construction industry. The questionnaire was distributed to almost 500 industry professionals via an online form and 400 of them were used for analyses in the research. The Likert type scale was used for ranking the factors affecting technical personnel in the construction industry. Weisberg (2005) stated that the usage of a middle scale answer might affect the answer of the respondents by 10 to 20 % or even more. Hence, the questions were designed to be 6 Likert scaled and were gradually rated from 0 to 5 as 0 equals to none and 5 means very good.

The factors were grouped under 4 major categories that are: Human, Management, External and Working Conditions. Kaiser-Meyer-Olkin Measure (KMO) of Sampling Adequacy, Barlett's Test of Sphericity and Cronbach's Alpha were used for testing the reliability of the collected data. Obtained data was analyzed with Relative Importance Index. RII was calculated via MS Excel.

Table 1. Some of the determined productivity factors.

Category	Factor Description	Resource
Human Factors	Personnel's Motivation	Liberda et al., 2003
Human Factors	Personnel's age	Robbins, 2001
Human Factors	Personnel's Experience and Skills	Liberda et al., 2003
Human Factors	Personnel's attitude and morale	Liberda et al., 2003
Human Factors	Personnel's job satisfaction	Kazaz et al., 2008
Management Factors	Inadequate supervision	Liberda et al., 2003
Management Factors	Delay in Salary Payment	Enhassi et al., 2007
Management Factors	Lack of recognition program	Jarkas & Bitar, 2011
Management Factors	Excessive Workload	Heale, 1993
Management Factors	Delay in Salary Payment	Enhassi et al., 2007
External Factors	Accidents at site as a result of poor site safety program	Jarkas & Bitar, 2011
External Factors	Owner's representative intervention	Jarkas & Bitar, 2011
External Factors	Demand of over-quality work	Liberda et al., 2003
External Factors	Changes in drawings and specifications	Liberda et al., 2003
External Factors	Method of Construction	Jarkas & Bitar, 2011
Working Conditions	Disrespectful treatment (Mobbing)	Liberda et al., 2003
Working	Ventilation System (Heating and Air	Enhassi et al., 2007

Conditions	Conditioning)	
Working Conditions	Unsafe working conditions	Liberda et al., 2003
Working Conditions	Unpaid Overtime	Liberda et al., 2003
Working Conditions	Transportation to Work	Jarkas & Bitar, 2011

*Because of the length limit only five factors for each group were given in Table 1.

Results

The relative importance index, ranks within the corresponding groups, and overall ranks for the 60 factors studied on productivity of construction technical personnel in Turkey, was determined, discussed, and compared with previous literature outcomes. The whole factors are grouped under four major categories as follows: 15, in the human factors category; 25, in the management factors category; 10, in the external factors category; and 10, working condition factors category.

Reliability Tests

For the trustworthiness of the collected data, 3 different kinds of reliability tests have been conducted. As it is explained in the below, subsections all of the three reliability tests resulted with satisfying outcomes which proved the dependability of the dataset.

Kaiser-Meyer-Olkin Measure (KMO) of Sampling Adequacy

KMO score of the dataset was in marvelous category with the score of 0.911. KMO score of the dataset was not only acceptable but also in the best possible category for the analysis.

Barlett's Test of Sphericity

The significance level of dataset is "0" which shows that the dataset is meaningful. Approximate Chi-Square value was found "8,142.342" and df value was calculated as 946.

Cronbach's Alpha

The Cronbach's alpha value, which shows the internal consistency level of the dataset, is 0.948. This value shows that by being over 0.9 our data set is excellent with regards to internal consistency. The Cronbach's alpha measured for each 60 factors; however, as a result of the reliability test it has been observed that "Personnel's gender" factor is not meaningful for the dataset. "Personnel's gender" factor has quite low Corrected Item-Total Correlation value (0,027) than other factors. Additionally, "Personnel's gender" factor was not included in the similar previous studies in construction industry. Therefore, it was removed from the determined factors before conducting factor analysis.

Relative Importance Index (RII)

For defining factors effecting productivity in construction industry, numerous studies have been carried out using relative importance index in order to rank the factors as per the results of questionnaire survey (Lim and Alum, 1995; Makulsawatudom, 2004; Abdulkadir et al., 2005; Enhassi et al., 2007; Kazaz et al., 2008; Brent, 2013). Simply, RII is a tool to rank the factors in accordance with the answers given by the respondents who attend the questionnaire survey.

In this research, to calculate the relative importance of the factors the formula given in Equation 1 was used in this study.

$$RII\ (\%) = \frac{5(n5) + 4(n4) + 3(n3) + 2(n2) + 1(n1) + 0(n0)}{5(n1 + n2 + n3 + n4 + n5 + n0)} \times 100 \qquad (1)$$

In the formula shown Equation 1, n5 to n0 refers to the number of respondents who responded to the related factor with a score of 0 to 5 in which 0 refers to not rated and 5 is very high. Although, n0 has no impact on the numerator, since it increases the denominator it affects the RII of the factor. The score for each factor multiplied number of respondents for each score from 0 to 5. Then, it is divided by the highest rating, which is multiplication of 5 with the total number of respondents. The result of this calculation is multiplied with one hundred in order convert it to an index over one hundred as a percentage.

Factors have RII score over 80% with the mean over 4, which states that participants ranked them between high to very high. 17 factors have RII score over 80% with the mean over 4, could be considered as the most important factors affecting the productivity of technical personnel in construction sites. Among these 17 factors, there are 7 management, 6 human and 4 working conditions related factors. On the other hand, 8 factors have RII score under 60% with the mean less than 3, which assumed to have low effect on productivity of technical personnel. Among these 8 factors, there are 3 “human”, 2 “management”, 2 “external” and 1 factor related with “working conditions”.

“Personnel’s motivation” factor ranked in the first place with the mean as 4.33. As it can be presumed, motivation is very important and driving factor. Motivation can be described as a trigger for human which defines the direction of their acts, thoughts, hopes, beliefs, in short desires, needs and insecurities (Findikci, 2000). Technical personnel can be motivated by adding motivational factors such as interest in work, responsibility in tasks, assignment to higher level tasks, personal growth and rewards. For instance, on time salary payment, bonus payments and good relationship with the supervisors can be evaluated as motivational factors in Turkey. Furthermore, hygiene factors which are usual practices in developed countries, can be considered as motivational factors in developing countries like Turkey.

The following four critical factors that affect the productivity of technical personnel are inadequate supervision, inadequate communication, disrespectful treatment (mobbing) and salary and benefits respectively. On the other hand, personnel’s gender, personnel’s marital status, union rules and influences, parking facilities and personnel’s age are appeared to be the least important factors respectively.

When the average mean of the factors in each category is calculated, the most important factor group appeared to be management factors with a mean of 3.777. Management factors are followed by working conditions with a mean of 3.658. Next, human factors are calculated as the third category with a mean of 3.644, which is very close to the mean of the second category. The fourth category that has the lowest mean value of 3.207 is the external factors category.

Conclusions

The study aims to define the underlying relations between the productivity factors with RII. According to the answers of the 400 respondents, RII indicated that the most important five factors affecting the productivity are "personnel's motivation", "inadequate supervision", "inadequate communication", "disrespectful treatment (mobbing)" and "salary and benefits". On the other hand, as per the ranking of RII of 59 factors the least important five factors are: "personnel's gender", "personnel's marital status", "union rules and influences", "parking facilities" and "personnel's age" for construction industry. Furthermore, the means of the pre-defined four factor groups, which are human factors, management factors, external factor and working conditions factors, were also calculated. Hereunder, most important factor group was identified as management factors, which is followed by working conditions factors, human factors and external factors respectively.

According to the RII means of factors under each predefined four categories, Management factors group identified as the category with the highest mean, which is in correlation with the results of factors analysis. It can be said that the management factors explain the most of the factors that affects productivity of technical personnel in construction industry for Turkey. "Unrealistic schedule", "lack of procedures", "lack of co-operation between departments", "interruption and disruption", "discontinuity in crew", "out-of-sequence work", "necessity to re-do work" and "inadequate communication" are the most important topics that managerial team should consider and improve in a construction firm. As a conclusion of all analysis, it is identified that the most important factors that affects the productivity of technical personnel underlies management factors.

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Identifying Design Specific Factors Affecting the Turnover Performance of the Retail Stores Within a Shopping Mall

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Abstract

Shopping mall projects should be more effective and feasible to be able to survive within a tough business environment, given the high competitiveness in the retail industry. Shopping malls' success depends mostly on the turnover performance of retail stores. This paper aims to identify the design specific factors affecting the turnover performance of the retail stores and to assign the importance levels of these measurement factors. The measurement factors that affect retail store's turnover performance were identified through an intensive literature review. 7 retail experts and 3 customers were interviewed to test identified measurement factors for content validity via expert judgement method. These factors were evaluated by each respondent with the Likert scale (5-strongly agree, 1-strongly disagree). The response to each factor got an evaluation value, thus showing the importance of each factor. Furthermore, additional new factors were suggested while less important factors were eliminated by experts via open-ended questions. The findings of this study revealed a revised list of measurement factors with content validity. In the future, the suggested measurement scale may be constructed to retail store managers in different shopping malls, which in turn will be useful in shopping mall design management data model creation for shopping mall investors.

Keywords: *design management data, retail store, shopping mall, turnover performance.*

Introduction

The retail industry is one of the major economic industries since it covers lots of sub-sectors such as the prêt-a-porter textile sector, food and beverage sector, service sector, electronics, etc. (KPMG, retail sector annual report 2019). Therefore, the efficiency and sustainability of the retail industry become highly important given the fact that its failure or recession will restrain a lot of sub-sectors. The retail industry is mostly governed by the shopping mall investments. Efficient and sustainable shopping mall investments support the retail industry and all its sub-sectors. Consequently, the performance of shopping mall investments becomes a very important subject for economic development.

The retail industry is getting more and more competitive, given the development of e-trade, the increase in the number of shopping centers, the decline in the purchasing power, which are all new obstacles the retail investments face. Regarding all these obstacles, the shopping mall investments need to develop new systems to be well-performing, more productive, feasible, and sustainable. The performance of shopping centers depends on many complex factors such as location, transportation facilities, architectural quality, shop/branch mix, size, shopping center concept type and the most important of all, the performance of its retail stores (Bakhshizadeh et al., 2017). Well-performing retail stores remain in the shopping center and attract visitors to shopping centers and consequently contribute to the shopping mall's performance.

This study focuses mainly on the retail stores' turnover performance within a shopping mall. The criteria that affect the retail stores' turnover performance will be discussed in detail. Among the retail stores' turnover performance criteria; location, shopping mall size and shopping mall type criteria are left aside because these are determined during the investment feasibility period. These criteria are pre-determined design inputs and they cannot be changed after the development of the shopping mall investment. However, turnover performance criteria such as retail store size, store design, lighting design, vertical circulation, are major turnover performance criteria which can differ from one retail store to another.

This paper aims to identify the factors affecting the turnover performance of the retail stores and to assign the importance levels of these measurement factors. The retail store turnover performance factors are determined after an intensive literature review. The determined turnover performance factors are submitted to a test via an expert judgment method. The response to each factor got an evaluation value, thus showing the importance of each factor. The findings of this study revealed a revised list of measurement factors with content validity. The measurement grade of each factor is explained in detail, thus offering a basic model for retail industry investors for feasible shopping mall design.

Research Background

Retail store turnover performance criteria that will enable the measurement of turnover performance factors are determined through intensive literature research. The research background has been limited around keywords such as shopping mall design, design management, retail store performance, and shopping mall performance. The list of retail store's performance factors is created through 14 major scientific papers, from which the most important ones are summarized below.

Kusumovidagdo et al. (2012) focus on the shopping mall visitors' perception of the interior atmosphere of the mall and how this perception affects their shopping habits. From this paper, 12 retail store performance criteria have been derived such as retail store design, proximity to shopping mall main cores (food court, customer wet cores, mall entrance, and delivery yard), number of floor levels, building materials used, floor height, HVAC comfort, general lighting concept, proximity to vertical circulation equipment, car park concept (position and payment), interior signage, brand mix, and marketing activities.

Another leading study was Costa Webber et al. (2018)'s research about the remodeling of the retail store for better performances. The study discusses the multiple criteria that affect shop performance and offers some modification strategies for better shop performances. Shop performance criteria derived from this study are retail store design, the position of the shop in the shopping mall, the architectural design of the shopping mall, floor cladding material of common areas, HVAC comfort in the shopping mall, general lighting concept of the shopping mall, noise level, and interior signage.

The study conducted by Köksal and Tığlı (2018) is a descriptive content analysis which analyzes 20 master's theses, 13 doctoral dissertations and 20 research papers about the consumers' behaviors in shopping centers in Turkey. The proximity to main cores (food court, playground, supermarket, event area, customer wet cores, mall entrances), HVAC comfort, noise level, the physical comfort of resting area, accessibility in the shopping mall, the proximity to vertical circulation equipment, proximity to the car park, service variety offered in the shopping mall, efficient cleaning services, brand mix, presence of an entertainment center, safety and security, and presence of a cultural event center in the shopping mall are major shop performance criteria observed in this study.

The research article by Nebati and Ekmekçi (2018) represents a model of performance evaluation for shopping centers. The performance criteria driven from this study are shop design, the position of the retail store in the shopping mall, smart building technologies, efficient use of water and energy, the architectural design of shopping mall, floor cladding material in common areas, HVAC comfort, daylight in the shopping mall, and brand mix and presence of an entertainment center in the shopping mall.

Çakmak and Yılmaz (2018) discuss the impact of the architectural design of shopping malls on consumer behaviors upon a case study in Konya, Turkey. Major shop performance criteria derived from this study are retail store design (including store lighting design and shop front design), the architectural concept of the shopping mall, efficient energy use, daylight in the shopping mall, and marketing activities of the shopping mall.

The research article by Burnaz and Topçu (2011) emphasizes the importance of planning appropriate tenant mix and placement of the retail stores to maximize their performance. The factors related to planning retail tenant mix are categorized into 4 groups such as target market related, financial, retailer related, and shopping mall related factors.

Abdullah and Jian (2019) propose a model for shopping complex design based on the universal design concept. Universal design is a concept that allows the accessibility of the building for all users equally. According to the universal design concept, proximity to customer wet cores and to mall entrances, the architectural design of shopping mall, the width of the mall corridors, the floor cladding material in the common areas, HVAC comfort in the shopping mall, physical comfort in resting areas, interior accessibility, proximity to vertical circulation equipment, signage elements, service variety in the shopping mall, and safety and security are important to shop performance criteria.

The research made by Bakhshizadeh et al. (2017) discusses the shopping malls' success in a highly competitive environment of Tehran, Iran. 4 shop performance criteria were derived from this research such as the architectural design of the shopping mall, marketing activities in the shopping mall, service variety and effectiveness in the shopping mall, and brand mix.

Chotipanich and Issarasak (2016) focus on facility management operation strategy for better performance in shopping malls. Effectiveness of fire escape scenario, car park concept in the shopping center (position, payment concept), the effectiveness of cleaning services, and safety and security (presence of x-ray equipment and a security guard at the entrances) are main performance factors discussed in the study.

The master thesis of Kısa (2015) shows in detail the occupancy safety in shopping mall architectural design. From this study, 4 important performance factors have been derived namely the effectiveness of fire escape scenario, proximity to fire escape corridors, presence of car park in shopping mall, and presence of x-ray equipment and a security guard at the entrance of the shopping mall.

Unlike the researches in the literature review, this study will try to measure the retail store turnover performance criteria from 3 different latent variable groups (building design, retail store design, building services). Relationships between performance criteria of these 3 latent variables will be discussed.

Methodology

Once the list of retail store turnover performance measurement factors was created based on the literature review, they were grouped according to the 3 main subject areas such as: *'retail store design'*, *'building design'* and *'building services'*. The first latent (unobserved) variable is '*the retail store design*'. This factor group is related to the retail store's interior design and to the allocation of the retail store in the shopping mall. Factors such as '*retail store's lighting design'*, '*shop window design'* and '*proximity of the retail store to the entrances'* are counted in the first factor group. *Building design* latent variable, which is the second group, depends on the architectural aspects and electromechanical design of the shopping mall. They are determined during the building design phase and they are constant for all the retail stores situated in the shopping mall. '*The shopping mall floor height'*, '*the HVAC comfort'* and '*the number of shopping mall entrances*' are examples of the building design factors. The third and last latent variable covers the *'building services'* criteria which are related to the shopping mall services provided by the shopping mall management. The factors such as '*security services'* and '*cleaning services'* are involved in this factor group and are identical for all the retail stores of the shopping mall.

After the categorization of the retail store performance measurement criteria, the factors are transformed into statements those questioning the importance of each factor to the responders experienced in various sectors related to retail industry. The statements for questioning factor groups represent the importance of the latent variable. The final list comprises of 3 latent variables and 52 factors.

To validate the content of the '*retail store turnover performance'*, an expert group was interviewed with the expert judgement method. The expert group was formed by the professionals experienced in the various sub-sectors of the retail industry for over 10 years. The expert opinions group is constituted by 7 people such as 1 renowned architect, 1 shopping mall manager, 1 retail centers' operation director, 1 leasing director (deputy general manager) and 3 tenants. Moreover, 3 shopping mall customers were added to this expert group to measure the point of view of customers. The respondents were asked to evaluate the retail store turnover performance measurement factors using the Five-Point Likert scale (5-strongly agree, 1-strongly disagree). The response to each factor got a factor loading, thus showing the level of impact of each factor. At the end of the questionnaire, the respondents were also asked 4 open-ended questions with which they can suggest new performance measurement factors with their experienced insights.

After the 10 interviews with experts, the importance of each latent variable and each factor were calculated by arithmetic mean. New performance measurement factors suggested by the respondents were evaluated and added to the list via open-ended questions, while less important factors were eliminated by expert judgement. Consequently, a consolidated and reviewed list of retail store turnover performance measurement instrument emerged with content validity.

Findings

Retail store turnover performance is affected by a variety of factors categorized under 3 main subject areas such as *retail store design, building design,* and *building services* which were measured by 52 factors. Retail store design latent variable is measured by 21 factors, building design latent variable by 19 factors and building services latent variable by 12 factors.

In the retail store subject area, the expert group ranked *'the retail store interior design'* and *'the visibility of the retail store'* as the most important factors affecting the retail store turnover performance. Moreover, the least important factor was defined as *'the proximity of the retail store to the customer wet cores', and 'the proximity of the retail store to the food court'* according to the expert group.

The building design latent variable's most important factor affecting the retail store turnover performance was ranked as *'the presence of car park in the shopping mall'*. On the other hand, the expert group defined *'the efficiency of the fire escape scenario'* as the least important factor.

'The brand variety in the shopping mall' was considered by the respondents as the most important factor affecting the retail store turnover performance in the field of building services. Among the 12 factors measuring the building services latent variable, *'the presence of kiosques'* was ranked at the bottom level by the expert group.

Regardless of latent variables category, according to the expert group, the top 3 ranked factors were *'the presence of car park' (5.00* mean score*), 'the brand variety' (5.00* mean score*), 'the retail store interior design' (4.90* mean score*), 'the visibility of the retail store' (4.90* mean score*), 'the marketing activities held in the shopping mall' (4.80* mean score*), 'the lighting design of the retail store' (4.80* mean score*),* and *'the efficiency of the cleaning services' (4.80* mean score*)*. Without considering the latent variable categories, the last 3 ranked factors stated as the least important factors affecting the retail store turnover performance were found as *'the proximity of the retail store to the customer wet cores, to the food court, to the delivery* *yard, to the event area, to the fire escape corridors, and to the kids' playground'* respectively and *'the efficiency of the fire escape scenario'*.

Table 1. Results of 3 Latent Variables.

Retail Store Design		Building Design		Building Services	
Factors	Average	Factors	Average	Factors	Average
retail store interior design	4,90	presence of car park	5,00	brand variety	5,00
visibility of the retail store	4,90	architectural design of the shopping mall	4,60	marketing activities	4,80
lighting design of the retail store	4,80	HVAC comfort in the shopping mall	4,60	efficiency of cleaning services	4,80
shopwindow design of the retail store	4,70	physical comfort in the shopping mall	4,40	whether the car park is free of charge or not	4,60
location of the retail store in the shopping mall	4,40	shopping mall corridor width	4,40	branch mix in the shopping mall	4,40
proximity of the retail store to the vertical circulation	4,30	noise level in the shopping mall	4,40	presence of ATM machines	4,40
retail store dimensions	4,20	physical comfort of resting areas	4,30	presence of infodesk	4,30
floor level of the retail store	4,10	lighting design concept of the shopping mall	4,20	variety of management services	4,20
proximity of the retail store to the entrances	4,00	efficiency of the guidance signboards	4,10	presence of x-ray machines and securtiy guards	4,10
proximity of the retail store to the main cores	3,90	open-air vs enclosed mall concept	4,00	presence of a cultural center	4,00
proximity of the retail store to the car park	3,80	building materials used in the shopping mall	3,90	presence of an entertainment center	3,90
floor height of the retail store	3,60	number of floor levels of the shopping mall	3,90	presence of kiosques	3,80
proximity of the retail store to the entertainment center	3,30	shopping mall floor height	3,90		
proximity of the retail store to the supermarket	3,10	accessibility of the shopping mall by handicapped people	3,90		
proximity of the retail store to the cultural center	3,10	smart building technologies used in the shopping mall	3,70		
proximity of the retail store to the kids playground	3,00	shopping mall common area floor cladding material	3,60		
proximity of the retail store to the fire escape corridors	3,00	daylight perception in the shopping mall	3,10		
proximity of the retail store to the event area	2,70	efficient use of water and energy	3,10		
proximity of the retail store to the delivery yard	2,70	efficiency of the fire escape scenario	3,00		
proximity of the retail store to the food court	2,50				
proximity of the retail store to the customer wet cores	2,50				

Discussion

The top-scored factors are *'the presence of car park'* and *'the brand variety'* with a full score (5.00). Both of these factors affecting the turnover performance of the retail store are independent of the retail store itself but are dependent on the building design and on the building services latent variables. The most important factors affecting the turnover performance of a retail store are provided by the environment of the shopping mall, and by the presence of the retail store within a shopping mall. Moreover, *'the presence of car park'* factor shows that accessibility by car is a major stimulus for customers visiting the shopping mall, similarly as stated in the researches by İpekçi (2014) and by Kusumovidagdo (2012). However, '*the proximity of the retail store to the car park'* factor received only 3.80 mean score, showing that the distance from the car park to the retail store is not a big obstacle for customers once they reached the shopping mall. *'Whether the car park is free of charge or not'* factor received 4.60 mean score at the 5th rank and thus it becomes a more important factor than '*the proximity of the retail store to the car park'*.

Sharing the top rank with *'the presence of car park'* factor, *'the brand variety in the shopping mall'* creates a synergy and attracts people to the shopping mall, thus affects the turnover performance of the retail stores abundantly. The findings of this study, similar to the study by Burnaz and Topçu (2011), show that customers are attracted by the idea that they can reach a wide variety of products in one single place, which is the shopping mall.

The 2nd top rank is fully dedicated to 2 retail store design latent variables which are *'the retail store interior design'* and *'the visibility of the retail store'* with 4.90 mean score. The interior design of a retail store has two important roles: first, to attract customers into the retail store; second, to make customers spend more time in the retail store. Both these two issues affect directly the turnover performance of the retail store (Costa Webber et al., 2018). Although the interior design of the retail store is considered as one of the most important factors, '*the floor height of the retail store'* factor received only 3.60 mean score, ranking the 14th out of 19 ranks. Regarding the fact that people are directed through the scope of their visual perception, *'the visibility of the retail store'* factor is considered as one of the most important factors affecting the turnover performance of the retail store, parallel to the study conducted by Costa Webber et al. (2018). However, '*the shop window design of the retail store'* is considered less important with 4.70 mean score at the 4th rank.

'The marketing activities held in the shopping mall', *'the efficiency of the cleaning services'* and *'the lighting design of the retail store'* factors share the 3rd rank with 4.80 mean score. As at the top rank, the building services factors take the lead over the retail store design variable at this level. The marketing activities organized periodically by the shopping mall management and the efficiency of the cleaning services attract visitors, thus contribute positively to the retail store turnover performance. The lighting design of the retail store (the efficacy, the light intensity, the color of the light) has a tremendous effect on people's shopping behaviors (Nebati and Ekmekçi, 2019). Similarly, the respondents of this study graded this factor as the 3rd important factor affecting the turnover performance of the retail store. However, '*the lighting design of the shopping mall*' has less important impact on the turnover performance, ranking only 8th out of 19, with 4.20 mean score.

'The architectural design of the shopping mall' and *'the HVAC (heating-ventilation-air conditioning) comfort of the shopping mall'* are the 5th most important factors affecting the

retail store turnover performance. Customers tend to shop and spend time in a well-designed and well-acclimatized environment, similarly found in the study by Costa Webber et al. (2018). Furthermore, this result consolidates the idea that the design of a shopping mall needs an integral design solution covering the architectural and electromechanical features.

The 6th rank (with 4.40 mean score) is shared by 6 various subject area factors such as *'the location of the retail store in the shopping mall', 'the branch mix in the shopping mall', 'the physical comfort of the shopping mall', 'the noise level in the shopping mall', 'the shopping mall's corridor width',* and *'the presence of ATM machines'*. The first 4 factors were stated as important factors for the success of a shopping mall in lots of previous studies in the literature. However, the last 2 factors, *the shopping mall corridor width* and *the presence of ATM machines* reveal special results for the importance level of the factors affecting the retail store turnover performance. The presence of ATM machines and the proper mall corridor width are found as important as the location of the retail store.

As the shopping malls have enlarged their scope of definition in the highly competitive environment of the retail industry and they are mostly defined as "life centers" in the 21st century, *'the presence of a cultural center in the shopping mall'* factor received 4.00 mean score in the importance level and is ranked at the same as *'the proximity of the retail store to the mall entrances'*. According to the respondents, '*the presence of a cultural center*' and *'the proximity of the retail store to the mall entra*nces' affect the turnover performance of the retail store at the same level. However, *'the proximity of the retail store to the cultural center'* is not considered to affect the turnover performance of the retail store so much (only ranked 16th out of 19).

Daylight is considered to have a positive effect on customer shopping behaviors in several scientific studies (Nebati and Ekmekçi, 2019; Çakmak and Yılmaz, 2018). However, *'the daylight perception in the shopping mall'* factor is only ranked 13th out of 19 ranks with 3.10 mean score in this study. The respondents do not consider the daylight perception as a major factor affecting the turnover performance of the retail store, although *'the lighting design concept of the shopping mall'* was considered much more important at the 8th rank.

Fire escape regulation is one of the most important regulations that the shopping mall design has to follow. Thus, the shopping mall building design always respects the fire escape regulation in order to get the building permit. However, the fire escape issue does not seem to be a major concern for customers, as the respondents ranked '*the efficiency of the fire escape scenario*' and '*the proximity of the retail store to the fire escape corridors'* factors to the 17th level out of 19 ranks with only 3.00 mean score. These two factors do not seem to affect the retail store turnover performance much.

Although the location of the retail store is ranked the 6th important factor, the proximity of the retail store to the main attraction areas are not considered as important factors affecting the retail store turnover performance. '*The proximity to the entertainment center, to the supermarket, to the kids' playground, to the event area, to the delivery yard, to the food court, to the customer wet cores'* are ranked from 16th to the bottom line (19th). These are the least important factors affecting the retail store turnover performance. Especially, the proximity to the food court and to the customer wet cores received the least score (2.50 mean score). These factors could be considered to be left out of the questionnaire in further studies.

Open-ended questions of the survey led to 4 additional measurement factors suggested by the expert group. The additional factors suggested by the expert group those have a probable effect on the retail turnover performance are *'the climate-adaptive building design', 'the abundant use of landscape elements inside the shopping mall', 'the connection of the shopping mall with a public space or a public transportation facility'*, and *'the advertisement panels used in the shopping mall'*. Thus, a revised list of measurement factors with content validity revealed for further studies.

Conclusion

In this study, major factors affecting the turnover performance of the retail stores within a shopping mall have been revealed from an intensive literature review. The study aimed to identify the factors affecting the turnover performance of the retail stores and to assign the importance levels to these measurement factors. The factors were grouped into 3 latent variables such as the retail store design variable, the building design variable, and the building services variable to measure the turnover performance of the retail stores within a shopping mall. The list of 52 measurement factors was evaluated by a group of 7 retail industry experts and 3 customers via the Five-Point Likert scale and with additional open-ended questions. The evaluation values identified for each factor was discussed within the scope of importance level to affect the turnover performance of the retail store. Finally, the additional factors suggested by the respondents via open-ended questions revealed a revised list of measurement factors with content validity. Overall, this study deduced the ranking position of 52 factors affecting the turnover performance of the retail store. The ranks between the latent variables were also discussed.

This expert judgment study was limited to a group of 10 respondents and the questionnaire was composed of 52 measurement factors. The 4 new factors suggested by the experts may be measured in further studies. In the future, the group may be enlarged and the suggested measurement scale may be constructed to retail store managers in different shopping malls, locally and internationally to compare the retail store performance indicators' differences depending on local and global points of view. The results may be compared through various shopping malls in various regions. The similarities and the differences may be very useful to create a shopping mall design management data model for retail industry investors, which may be very functional for creating and developing more feasible and competitive retail investments.

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Minimizing cooling energy demand of an office building with respect to green roof types and the angle of sun shading elements: A case study in Izmir, Turkey

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Abstract

The growth of urbanization is a global problem that results in increased air temperatures in urban settings, as compared to the surrounding rural areas, which is commonly known as the Urban Heat Island (UHI) effect. Climate change is also contributing to increasing temperatures and problems of overheating, as a result of anthropogenic greenhouse gas emissions. As a result, cooling energy use of buildings has been escalating rapidly in the recent years. Therefore, implementing sustainable solutions for minimizing energy consumption of buildings is a pressing need in the built environment. Increasing green surfaces and the use of shading elements on building façades are effective means to reduce cooling loads in summer. In this paper, simulation-based explorations that aim to reduce building cooling energy use by means of different green roof types and shading element configurations are presented. Parametric variations of sun shading configurations and green roof types (i.e., extensive, semi-intensive, intensive) are analyzed to obtain minimum cooling load of an office building in Izmir, Turkey. Finally, the optimal combination of green roof types and the angle of sun shading is determined in order to reduce cooling load in the modelled building.

Keywords: *building energy consumption, green roof, shading elements.*

Introduction

In the recent years, urbanization has extensively increased the effects of Urban Heat Island (UHI), which is identified as one of the most critical problems in cities. Modifications in land use based on opening new areas for constructing new buildings accelerate immigration into metropolitan areas (Wang et al., 2007). Cities accommodate half of the world's 6.6 billion population, and are expected to house nearly 5 billion people by 2030 (Ash et al., 2008). Accordingly, increasing hard surfaces for new settlements give rise to warmer city centers as compared to rural areas. The difference between temperatures of urban land and its surrounding suburban areas refers to Urban Heat Island effect (Jiang et al., 2014). UHI is mainly caused by using heat absorbing materials, constructing mass concrete buildings and reducing green areas. Since limited open spaces due to rapid urbanization, adding greenery to cities has become a problem although urban vegetation has an important role for mitigating the effect of UHI. Moreover, urban heat island has impacts on building energy consumption due to increasing temperature at cities. Green roofs can be mainly categorized under three types that are intensive, semi intensive and extensive, regarding of different vegetation and soil levels (Ezema et al., 2016). In addition, shading elements, which contributes to the minimization of cooling energy consumption in buildings, should be taken into account with green roofs as well. Solar shading is classified in three categories, which are the physical features of shading elements, effects on daylighting and assessment of energy performance of buildings (Dubois, 1997). The objective related with the shading element in this study is investigating the best angle to reduce cooling load while using different green roof types (intensive, semi intensive and extensive). In this paper, it is aimed to determine which angle of shading element and type of green roof make maximum improvement in minimizing cooling loads of a chosen building in summer time of Izmir, Turkey.

Literature

Aforementioned studies about effects of building's cooling load is divided into two main areas of green roof types and sun shading devices. Recent work on sun shading devices mostly focused on three types of cooling loads: (1) Whether sun shading device is used or not, (2) shading devices' static or dynamic features and (3) shading device dimensions. Kim et al. evaluated the daylighting performance and cooling loads using sun shading device in the target building located at the Songdo Campus of Yonsei University. The sun shading device provides 35.1% reduction in the total cooling load (Kim et al., 2015). According to Lechner, the south windows of the buildings are exposed to the solar radiation in summer period of the year, and dynamic shading devices rather than fixed ones should be used (Lechner, 2015). Grobman et al. conducted a study on comparison between performances of various louver types in static and dynamic operation scenarios, and the performance and applicability of the tool. The results show that dynamic horizontal louvers perform considerably 6%–34% better than the static horizontal louvers (Grobman et al., 2020). Choi reported that louver should be designed by considering the design's thermal performance not by an architect's intuitive design decision. The study aims finding the best performing louvers for any given site, and suggesting solutions to reduce energy demands of the building (Choi et al., 2018). Bellia et al. analyzed the influence of sun shading devices on the energy requirements of a typical office building for different climates. Energy requirements for cooling, heating and lighting have been simulated by EnergyPlus. The results show that the energy requirements of the building can be reduced by changing dimensions and types of the sun shading device (Bellia et al., 2013). Previous studies compared cooling loads mainly according to the type and static or dynamic features and angle of shading devices.

The second issue researched in the paper is green roof types and their effects on cooling load of the building. According to Tan et al., green roof can reduce the heat transmission into the building. It can also reduce the effects of UHI through outdoor temperature (Tan et al., 2017). Dahanayake studied how the decision of choosing green roof and green wall should be made. The results show that the area of the greenery coverage, the orientation, the scale of the building, the surrounding environment, and the geographical location should be considered carefully (Dahanayake et al., 2018). Silva stated that the height of plants, leaf area index (LAI) and soil depth are the key parameters in green roofs to reduce the cooling and heating load of the buildings (Silva et al., 2016).

These studies discuss energy consumption in buildings by separated perspectives such as only implementing shading device or green roof types. Nonetheless, examining these two issues together would provide better understanding to minimize energy usage in buildings.

Scope and Methodology

The general workflow of this study consists of two parts that the main objective is to reduce cooling energy demand of the chosen building located in Izmir. Firstly, a typical six floor and fully glazed office building is chosen with its surroundings. The building is modelled in Rhinoceros, a 3D computer-aided design (CAD) application. The building is 18 meters high and has a 300 square meter footprint. Three different types of green roofs (intensive, semi intensive and extensive) are considered in order to calculate cooling load of the building. In the literature, it is widely argued that fully glazed buildings, which are sensitive to solar environmental conditions, result is poor energy efficiency (Roaf et al., 2009; Poirazis et al., 2008). Therefore, horizontal shading devices are implemented on south side of the facade as a second design consideration in this study. The reason of the decision about facade direction is due to being exposed by the sun more than other facades during the day. In this research, horizontal sun shading design has only plain 100 cm wide and 150 cm long rectangles. Their angle of rotations are 0, 30, 45 and 60 degree. Honeybee plug-in of Grasshopper run within Rhinoceros, and EnergyPlus are used for energy analysis.

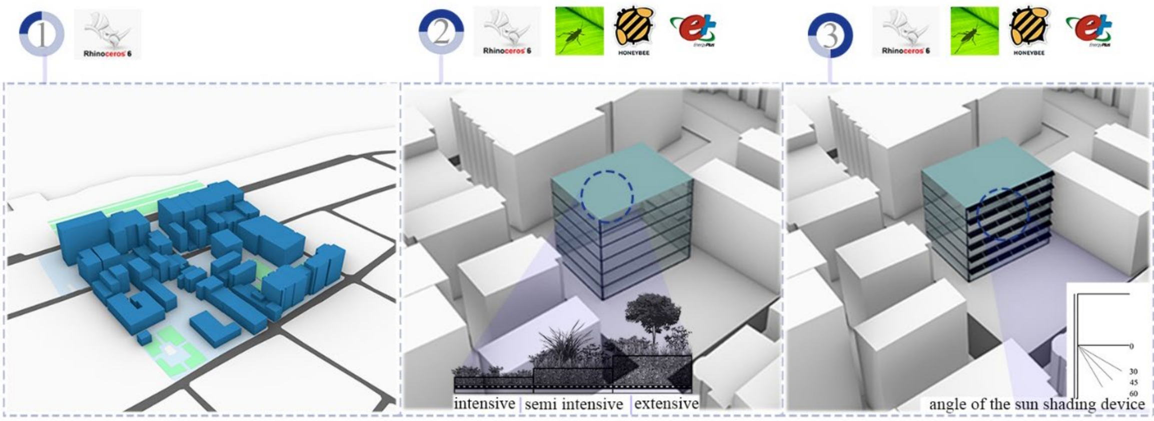

Figure 1: The framework of the methodology.

While making a series of analysis, the glazing ratio is set to 90%, while the glazing material remains unchanged in all alternatives. In the perspective of green roof types, the section contains main layers that are interior plaster (2cm), reinforced concrete (20cm), levelling concrete (4cm), waterproofing (3mm), roofing felt (1cm), thermal insulation XPS (6cm), drainage (2cm), roofing felt (1cm) and roof vegetation, respectively. Only the roof vegetation layer differs in the calculations, as can be seen in Table 1.

Table 1. Green roof types.

Green Roof Types	Height of Plants	Leaf Area Index	Thickness of Soil
Extensive	5 cm	1	10 cm
Semi Intensive	10 cm	2	20 cm
Intensive	15 cm	3	100 cm

Finally, average cooling loads (kWh/m2) for each level of the building depending on green roof types and angle of shading elements are calculated. The framework of the methodology can be seen in Fig. 1.

Results

Cooling energy demand analysis of the office building by using Honeybee plug-in of Rhinoceros and EnergyPlus is presented in this section. One of the essential inputs for the calculations is the weather files (EPW format). In this research, EPW data set of Alsancak, Izmir is used for the simulations. While investigating energy consumption, the analysis period is defined for 3 months, from the month of June to August. The office building is divided into 6 horizontal zones namely Zone 0, Zone 1, Zone 2, Zone 3, Zone 4, and Zone 5 according to its level. While Zone 0 represents the ground floor, Zone 5 shows the sixth floor. In Fig. 1, perspectives show how cooling load (kWh/m2) of the building varies with respect to different green roof types and angles of the shading devices.

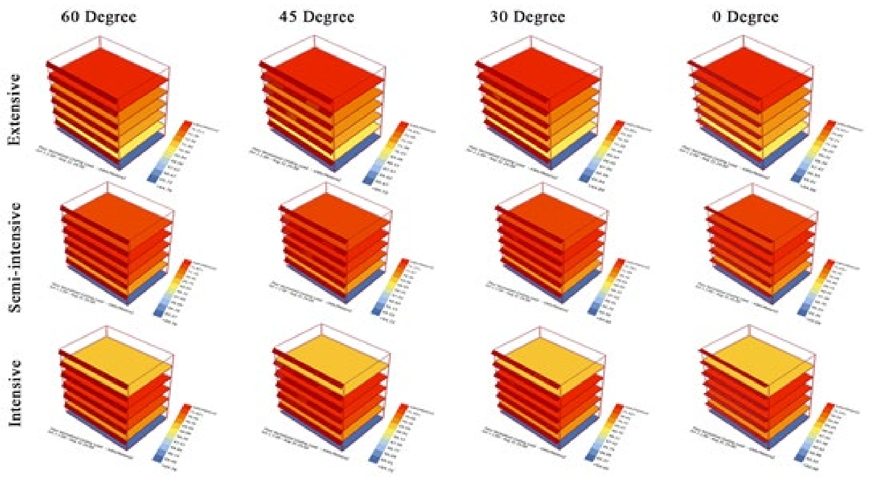

Figure 2: Perspective views of the office building shows cooling energy demands for each zone depending on both green roof types and angles of the shading devices.

At the beginning of the analyses, three different green roof types, which are intensive, semi intensive and extensive, are included to obtain average cooling loads for each zone while exterior shading devices are excluded. Zone 0 has the least cooling load due to being the ground floor affected by soil temperature directly. On the other hand, Zone 5 is the most influenced level by changing green roof types in the view of cooling energy demand. Intensive green roof implementation indicates that it is the most effective option for reducing energy consumption for Zone 4 *(11.35 kWh/m2)* and Zone 5 *(10.86 kWh/m2)* among other green roof types. Blue vertical rectangles frame how the cooling load values differ according to green roof types.

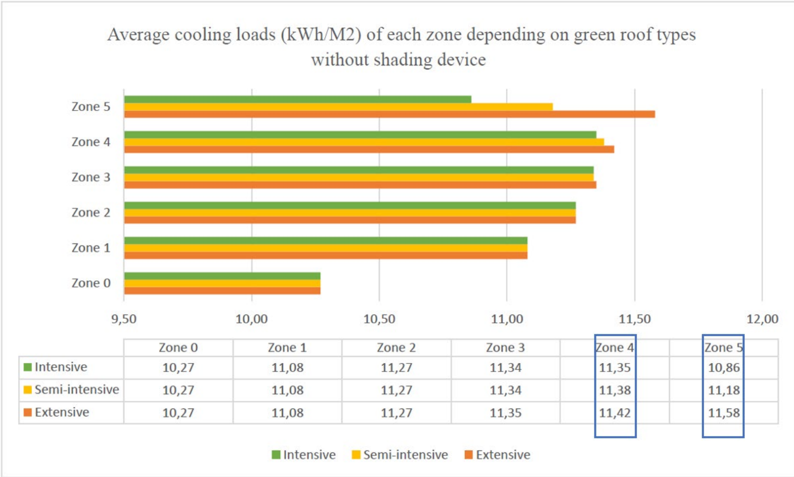

Figure 3: Average cooling loads of each zones depending on the green roof type.

Secondly, four different degrees, which are 60°, 45°, 30°, 0°, have been used in the angle of rotation parameter for the exterior shading elements with green roof types. The result shows that 0° angled shading element has better performance on minimizing cooling load of Zone 5 (9,32 kWh/m2) than other angles. The red rectangle indicates the minimum kWh/m2. 60° angled shading element has the highest cooling energy demand with each green roof types. Each combination results between angle rotations and green roof types can be seen on Fig. 4.

Figure 4: Average cooling loads of each zones depending on green roof types and angle of shading devices.

Lastly, green roof types and angles of shading elements are illustrated in columns to compare how implementing 0° degree angled shading elements effect to reduce cooling load of the office building with green roof types in summer. The decision about preferring to use 0° degree angled solar shadings on south side of the facade benefits more 14,42% for extensive, 14,60% for semi-intensive and 14,68% for intensive green roof.

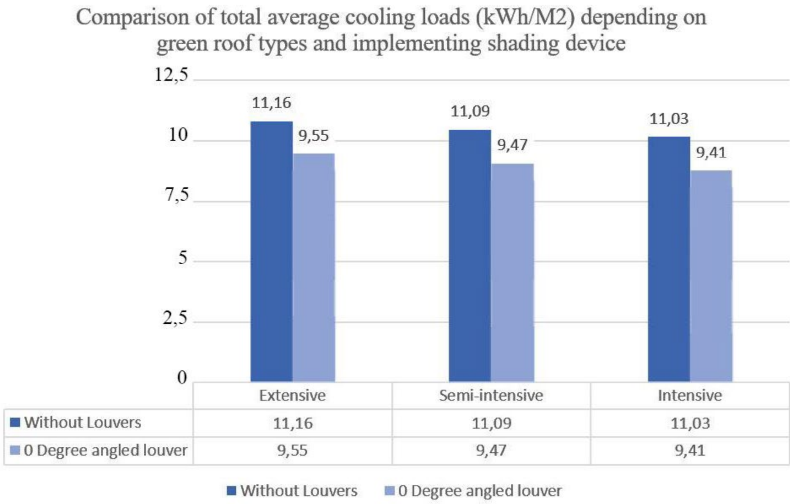

Figure 5: Comparison of total average cooling loads depending on both green roof types and the best performed shading devices.

Conclusions

The research examined the cooling load of the selected building considering the angle of sun shading devices and green roof types. The analysis was conducted on a fully glazed six-floor office building in Izmir, Turkey.

Firstly, three green roof types, which are intensive, semi-intensive and extensive, are applied to the building in order to have reduction in cooling load of the building. The results are in line with the studies reviewed in the literature, which show that changing green roof types effect cooling energy demand. Kamarulzaman studied that using green roof installation helps to minimize energy usage of a building and makes interiors be more comfortable during hot seasons (Kamarulzaman et al., 2014). According to this paper, intensive green roof is observed as more effective than the other green roof types in terms of decreasing cooling energy consumption.

The second important result is the effect of angle of the sun shading devices. South facade of the building is selected for the orientation because it is highly exposed to solar radiation especially in the summer period. Therefore, horizontal shading devices, which are rotated 0, 30, 45 and 60 degree, are implemented on south side of the facade. Choi states that 0 degreed solar shading devices on the south facade is a good option to minimize both solar radiation and cooling loads in summer time (Choi et al., 2014) In terms of rotation of the shading devices, the results show that 0 degree rotation performs significantly better than the other operations in order to obtain minimum cooling load.

Then, combination of the best angle (0 degree) of the sun shading devices and green roof types for reducing cooling load is explored. It is found that the percentage in decreasing of cooling load is more for the intensive green roof (14.68%). On the other hand, 0 rotated solar devices perform only 14.42% more with extensive green roof. As a result, intensive green roof benefits 0.26% more rather than extensive green roof that it is a better installation choice to decrease the cooling load of the building in summer. In this study, types of the green roofs and different angled sun shading devices are implemented together to understand better effects on reducing cooling load. The results show that only using one of green roof types is not as sufficient as its combination with shading devices on the facade. However, these two different issues are examined as separate subjects in the literature.

For further studies, all simulation results about cooling energy demand should be included in cost estimation of this building for the summer time. In addition, the analyses of this study conducted over a single building can be carried out in the urban scale to minimize effect of Urban Heat Island.

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Energy Performance Evaluation of Different Glazing Systems in a Convention Center

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Abstract

The buildings consume 40% of the total energy consumption and 36% of the greenhouse gasses in the world. In recent years, the exhibition industry showed a significant development which further increases the adverse effects on the environment. Besides, during the usage period, the exhibition centers consume a high amount of energy due to the extensive usage of artificial lighting and HVAC systems. By taking only passive energy efficiency measures, it is possible to reduce energy consumption and decrease the negative effects of the buildings. For this purpose, this study investigates the energy performances of mostly preferred glazing types by considering its combination with the building orientation. The DesignBuilder software is used for the energy simulation of the building. The results of this study may help designers in selecting the most efficient glazing type and building orientation for a convention center.

Keywords: *building energy simulation, building glazing systems, convention center, energy efficiency.*

Introduction

The buildings are responsible for 35% of the total energy consumption in Turkey (Ashrafian et al., 2016). Commercial buildings have a large share of meeting the energy requirements of European Union countries (Aste & Del Pero, 2013). Among these commercial buildings, convention centers are one of the most energy-intensive buildings due to the vast usage of artificial lighting and complex HVAC systems for indoor temperature control; although they are in use at 80 to 120 days in a year. The energy consumption of many of these buildings can be decreased by taking active or passive energy efficiency strategies (Sadineni et al., 2011). The glazing system, which is one of the main elements of passive energy efficiency strategies, has a crucial role in providing visual and thermal comfort to the building occupants. Nevertheless, the solar radiation through glazing system may be the major source of an increase in building cooling loads, and the use of efficient glazing system can significantly reduce the energy demand for cooling in summer (Huang & Niu, 2015).

The glass is a widely preferred material on glazing system due to its cheap and transparent feature (Khalaf et al., 2019). The total energy consumption of a building may decrease by changing only the glass types of windows. For example, Ihm and Krarti (2012), showed that the use of double low-e glazing system instead of single bronze glass in residential buildings might reduce the total energy consumption 6.1%. Also, the use of double-layered glazing is preferable due to its comfort performance while preventing the entrance of solar irradiation into the building (Cappelletti et al., 2014). Alaidroos and Krarti (2015) conduct a more detailed comparison among glass types; it is proved that the energy-saving potential for the use of double or triple glazing may reduce the energy consumption by 3% and 5% respectively.

The building orientation also has a significant effect on building energy consumption. Fallahtafti and Mahdavinejad (2015) investigated the optimization of building orientation, considering the glazing percentage and showed that the energy could be saved up to 71%. Singh and Garg (2009) investigated the energy ratings of different glazing considering their orientations in a conventional building and obtained 7% to 22% energy saving rate based on the combinations. Ariosto and Memari (2013) compared the effect of different glazing system on residential and commercial buildings in five different climates and mentioned that glazing with low solar heat gain coefficient (SHGC) should be prioritized in cooling dominated climates.

In recent years, the exhibition industry has shown a rapid development which caused higher energy consumption and environmental damage (Shen et al., 2011). Although the adverse effects of exhibition centers on nature, the studies regarding the energy-efficient conventional remain in the background. For an accurate energy analysis of a large-scale exhibition center, operating schedules should be taken into account sensitively. Srinivasan et. al. (2011) made a calibrated simulation considering the role of event calendar by benefit from the ASHRAE hourly operating schedules.

This study aims to provide an energy analysis for an exhibition center, located in the Mediterranean climate. The energy-saving potential of the glazing system, combined with the building orientation, on heating, cooling, lighting and total energy consumption of the building is discussed. For this purpose, building energy simulation software, DesignBuilder has been used. Besides, the crucial features of investigating the energy performance of an exhibition center will be explained. The results of this study may give a suggestion to designers for selecting the most efficient glazing type and building orientation for a convention center.

Methodology

To investigate the effects of glazing system types on energy consumption of a convention center, this paper considers a case study which is located in a Mediterranean climate. The energy simulation of the case building is conducted by using DesignBuilder version 5.5.2, which is a user-friendly energy simulation program. The model input data is derived from existing 2D AutoCAD drawings, and the building is modelled in the software by benefit from the imported floor plans. Then, all the information related to the construction materials and HVAC system is entered into the system. Once the building layout is done, activity information is identified in the software. The required information related to the occupancy density and event calendar was obtained from the expert, who is responsible for the convention center.

Six types of mostly preferred glazing systems were selected to find the best option, which may reduce the energy consumption of the building in hot climates, as shown in Table 1. These glazing types were compared to each other by also considering their use on different orientations. As a result, simulation of 24 different combinations were analyzed.

Table 1. Glazing types used within the case study.

Glazing Types	U-value(w/m2-K)	Abbreviation
Double Clear 6/12 Air	2.704	DC
Double LoE(e2=1) 6/12 Air	1.771	DLE
Trp Clr 3/12 Air	1.785	TC
Trp LoE(e2=e5=1) 3/12 Air	1.019	TLE
Thermochromic Glazing	2.13	TM
Planibel Grey Glazing	2.697	GG

After making the needed adjustments for the building energy model, simulations are carried out to obtain the annual heating, cooling and lighting energy consumptions. Each glazing type was analyzed for their use in different orientations. For the best building orientation case, the effect of the shading element on energy consumption is investigated.

Case Study of a Convention Center

The case building is located in Belek, Antalya, and consists of two storeys. The total area of the convention center is approximately 20.000 m^2. The building has 6m eaves on the roof, which provide shading to the building, as shown in Figure 1. There is a main hall with 6000 m^2 on the first floor, a meeting hall with 5000 m^2 on the ground floor. The building also has 24 workshop spaces and foyer with a total 3200 m^2 floor area. The main hall and meeting hall can be separated into small segments with a unique operable partition system when needed. The undivided condition of the halls is considered during the analysis. Generally, the exhibition centers have a small window to wall ratio due to the need for lightless spaces inside. Thus, only the East side of the first floor is covered with large-scaled windows, while the other sides of the building have less and comparatively small-sized windows. The construction material information can be seen in Table 2.

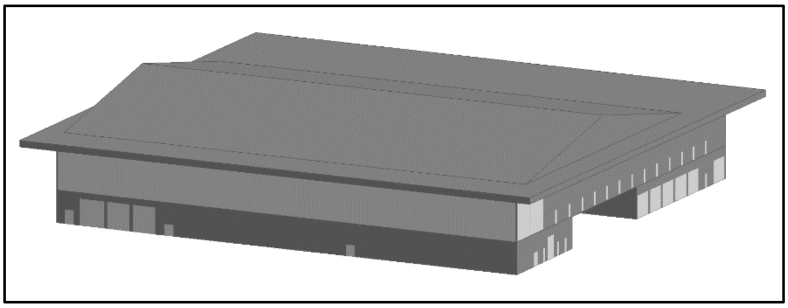

Figure 1: The model of the case study building in DesignBuilder.

Table 2. Building construction material list.

Building Element	Material	Thickness (mm)
External Walls	Aerated concrete block	300
Internal Patricians	Aerated concrete block	300
Flat Roof	Loose fill gravel	100
	Roofing Felt	1.5
	XPS	50
	Cast concrete	100
Pitched Roof	Metal aluminum cladding	1
	EPS	100
	Metal aluminum cladding	1

The heating and cooling are provided by VAV reheat water-cooled chiller with a chilled water storage system. All the zones are heated or cooled by the same system provided. The thermostat set point is 22 C degrees for both heating and cooling. According to the Energy Performance Regulations on Buildings (2010), the illuminance level of the building is adjusted to 500 lux as it for the fair and congress centers.

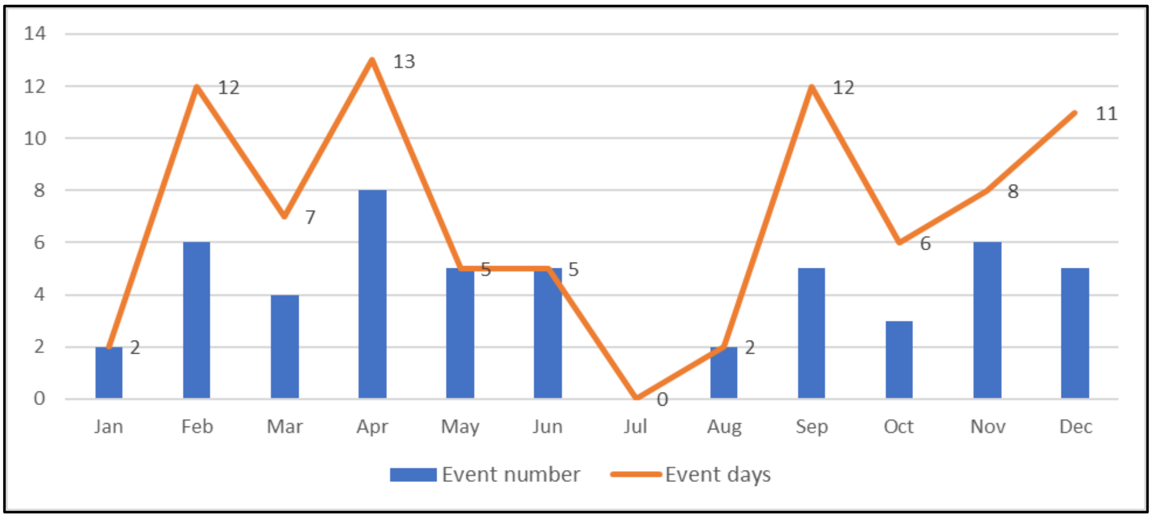

Figure 2: Event numbers and durations per month.

The energy usage in exhibition centers mainly relies on the energy that is consumed during the event days. The occupancy schedule should be specified sensitively to conduct an accurate energy analysis. For this purpose, the event calendar for 2019 was obtained from the expert. Fig. 2 presents the number of events and their total durations per month for the case building. The total usage of the convention center is 82 days/year, which is the minimum expected usage of these type of buildings, as mentioned in the previous section. The occupancy rate also shows changes based on event type and should be considered for the occupancy schedule. The actual numbers of participants who attended the events could not be derived due to the privacy policy of the owner. Thus, the expected numbers of participants, as shown in Table 3, based on the expert's opinion, was considered during the analysis. For example, it is expected to have a maximum 1500 people for one-third of the total events. The occupancy schedule was created according to 3500 people, which represents the optimum number of participants, as shown in

Table 4. Only the event days were considered during the analysis due to the occupancy rate on non-event days remain less compared to the event days.

Table 3. Occupancy schedule.

Occupancy of all days		
Until	07.00	0
	08.00	0.25
	09.00	0.6
	13.00	1
	15.00	1
	17.00	0.6
	19.00	0.25
	24.00	0

Table 4. Estimated occupancy numbers.

Percentage of events	Estimated occupancy (person)
1/3	1500
1/3	3000
1/3	6000

Results

As mentioned in the previous section, the energy simulations are carried out to obtain the lighting, cooling, heating and total energy consumption. The primary purpose was to investigate energy consumptions annually based on the combinations.

Six types of mostly preferred glazing types, which are used in energy analysis, are listed in Table.1. Thermochromics and colored glazing systems are selected for the study due to the fact that they decrease the heat absorption into the building (Arutjunjan et al.,2006; Meyer & Sans, 1989). Low emittance (Low-e) glasses are also chosen as an option due to they reduce the ultraviolet light that comes through the windows inside while enabling sunlight to interior spaces (Giovannetti et al., 2014).

The lighting, heating, cooling and total energy consumptions per meter square are shown in Table 5. The graphical presentations of the results can be seen in Fig. 3.

According to results:

- The heating energy demand represents only 20 percent of the cooling load due to the building is located in the Mediterranean climate.
- The cooling energy demand mostly depends on the orientation of the building rather than the type of glazing system. For example, the cooling energy consumption decreases 4.3% from DC to GG type of glazing, while it reduces 44% from north direction to east direction.

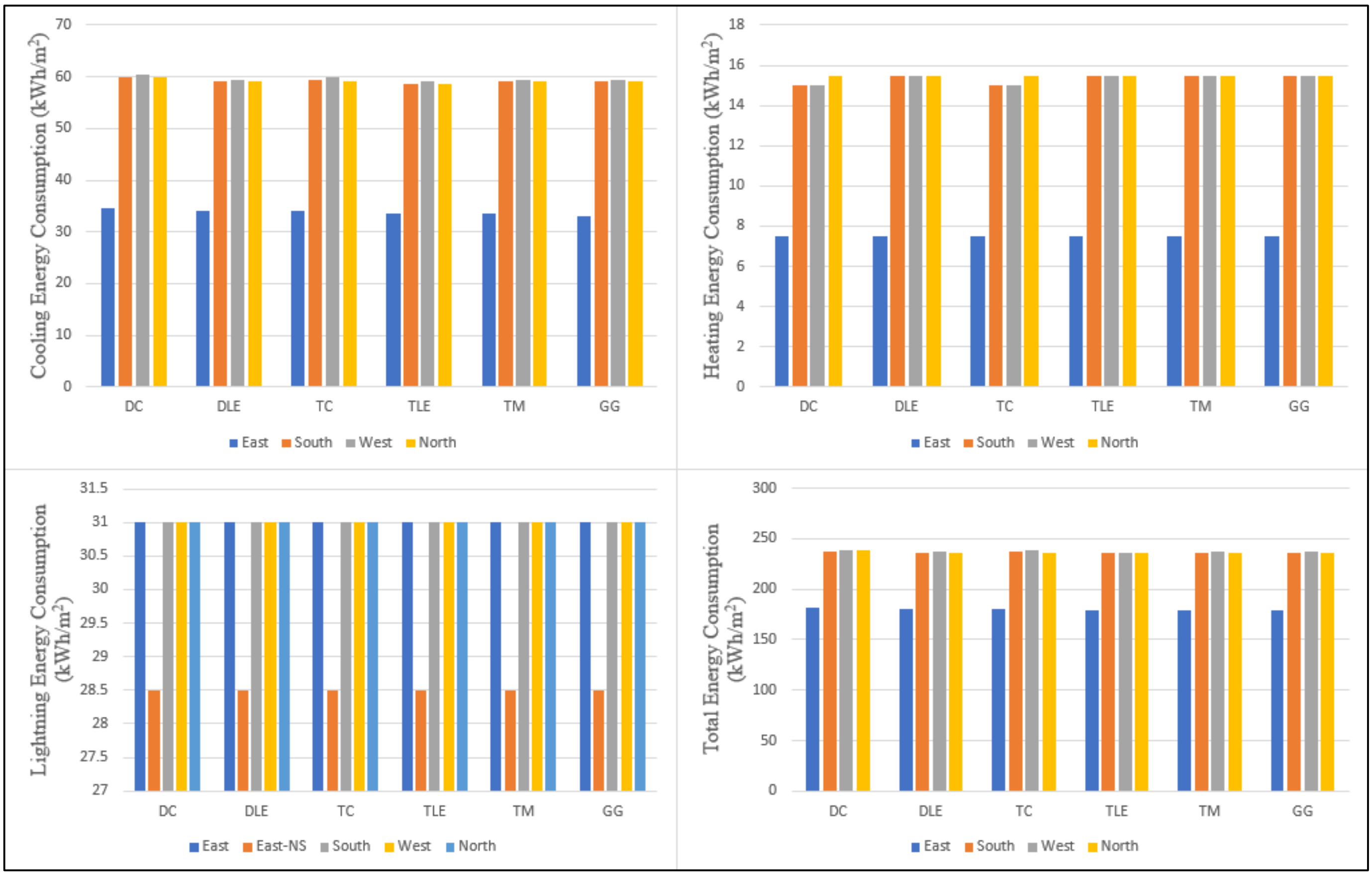

Figure 3: Glazing system and building orientation effect on building energy demand.

- Similar to cooling energy demand, the heating energy demand also depends mainly on building orientation. The East orientation offers the best energy performance compared to other directions.
- The lowest cooling energy consumption with a 33 kWh/m^2 energy demand per year, is obtained on East direction with Grey glazing and the consumption is nearly half of the other directions. The effect of different glazing systems on East side can be seen in Fig. 4.

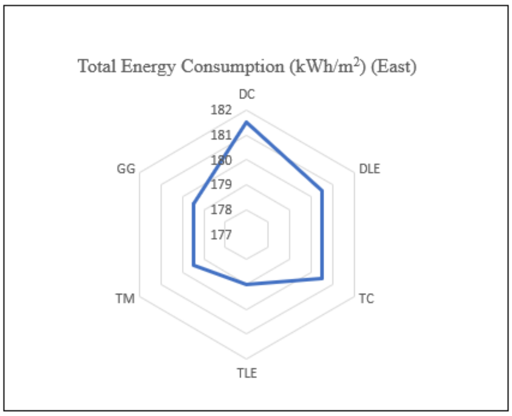

Figure 4: The effect of different glazing systems on East side in terms of total energy consumption.

- Generally, in commercial buildings glazing system has a positive effect on lighting energy consumption due to it provide daylight to the building (Johnson et al., 1984). Yet, different from commercial buildings, convention centers have less window to wall ratio, due to the need for dark spaces inside the conference halls. Due to this reason, the analysis showed that the glazing type did not cause a significant difference in lighting energy consumption. Yet, once the eagers on the roof are neglected, the lighting energy demand decreased 8%.

By considering the all fuel consumption loads, the total energy consumption is calculated for per square meter. The lowest energy consumption is obtained on triple glazing with lowE (TLE) system on East direction. Combination of East orientation and TLE type of glazing can save the 50kWh/m^2 annually. As a result of the study, TLE type of glazing may be a better option to be used in Mediterranean climate due to it shows the best performance on total energy consumption.

Table 5. The lighting, heating, cooling and total energy consumptions per meter square. (NE represent the non-eager situation).

Cooling Energy Consumption (kWh/m²)						
	DC	**DLE**	**TC**	**TLE**	**TM**	**GG**
East	34.5	34	34	33.5	33.5	33
South	60	59	59.5	58.5	59	59
West	60.5	59.5	60	59	59.5	59.5
North	60	59	59	58.5	59	59
Heating Energy Consumption (kWh/m2)						
	DC	**DLE**	**TC**	**TLE**	**TM**	**GG**
East	7.5	7.5	7.5	7.5	7.5	7.5
South	15	15.5	15	15.5	15.5	15.5
West	15	15.5	15	15.5	15.5	15.5
North	15.5	15.5	15.5	15.5	15.5	15.5
Lighting Energy Consumption (kWh/m2)						
	DC	**DLE**	**TC**	**TLE**	**TM**	**GG**
East	31	31	31	31	31	31
East-NE	28.5	28.5	28.5	28.5	28.5	28.5
South	31	31	31	31	31	31
West	31	31	31	31	31	31
North	31	31	31	31	31	31
Total Energy Consumption (kWh/m2)						
	DC	**DLE**	**TC**	**TLE**	**TM**	**GG**
East	181.5	180.5	180.5	179	179.5	179.5
South	238	236.5	237	235.5	236.5	236.5
West	239	238	238.5	236	237.5	237.5
North	238.5	236.5	236.5	235.5	236.5	236.5

Conclusion

The exhibition centers consume higher energy due to the extensive usage of artificial lighting and HVAC systems even they are in use a maximum half of a year. The energy consumption of convention centers can be decreased by taking proper energy efficiency measures. This study investigates a case exhibition center located in Antalya, to provide energy analysis for the use of 6 different types of glazing system and building orientation. The modelling and energy simulation is conducted using DesignBuilder software. The occupancy schedule was created using the actual event calendar of the exhibition center in order to get more accurate results.

As we can see from the case convention center has high energy consumption even it is in use only for 82 days in the year 2019. The results showed that the building orientation had more effect on building energy consumption when it compared to the glazing type. The reason behind the low impact of glazing system may be the small window to wall ratio on convention centers. For hot climates, triple glazed low emission window type can offer decreased energy consumption. The best building orientation is obtained on the East direction.

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Normative Regulations Used For Adaptive Facades

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Abstract

Facades can be seen as interfaces between the outer environment and the buildings inner environment. As an overall aim, facades have to withstand several types of exterior, interior and intrinsic loads such as noise, rain, wind, heat and cold, air humidity, self-weight and structural loads. In order to standardize and compare certain systems and values, the introduction of regulations has become inevitable. Promulgating regulations for facade systems support the achievement of the desired energy efficiency and sustainability of buildings while enhancing the best possible indoor climate for users. So far, there aren't any regulations yet, which refer specifically and only to adaptive facades. However, many of their characteristics can be compared to those of traditional facade elements. The aim of this study to present a better understanding of the potential normative regulations which can be used for adaptive facades.

Keywords: *building envelopes, dynamic facades, German regulations, international regulation, Turkish regulations.*

Adaptive Facades

Facades can be seen as interfaces between the outer environment and the buildings inner environment. As an overall aim, facades have to withstand several types of exterior, interior and intrinsic loads such as noise, rain, wind, heat and cold, air humidity, self-weight and structural loads. (Knaack et al., 2007).

Facades must face numerous challenges as they resemble the interface between the outer climate and environment and the inside of the building. The exterior and interior influences hit the outer or inner surface of the facade element and affect the adjacent and possibly further layers. Thus, different layers must fulfil individual functions which satisfy the individual needs and purposes of the users. In order to do so, the market provides a wide range of facade technologies. They may differ in regard to the structure, physical properties, assembly, costs, sustainability, fatigue life, appearance, etc. Within the scale of this study, the term ''facade'' not only refers to the outmost envelope layer but the entire exterior wall construction.

One of the many branches is innovative and full of potential - adaptive facade technology. Now, with the invention of adaptive facades, active measures can be realized by facade systems too. Due to individual circumstances and needs, like the building use, location etc. the extent of facade functions needs to be adjusted. Adapting to environmental conditions and occupants demands on an hourly, daily and annual base can only be achieved by active, adaptive systems. Its diverse possibilities and potential for the future is undisputable and therefore highly researched in science and becoming more and more common in practice.

Normative Regulations for Facades

In order to normalize and compare certain systems, the regulations have become inevitable. In order to achieve the desired energy efficiency and sustainability of buildings, regulations should be designed. There are neither officially approved definitions nor preset values, which define if a facade is formally adaptive or not. For each inspected category, adaptive facades must observe the same restrictions and standards as the non-adaptive facades in the specific 10 regulation. Notwithstanding, the pertinence of the named regulations for traditional facade systems as well as the applicability needs to be examined for adaptive facade systems. Since the amount of regulations seems endless, a brief overview of the main regulations and organizations will be given. The international and German regulations might differ in the quantities of the materials for the detection methods or examination procedures as well as their entire build-up itself. In Fig. 1 the most important regulations with respect to their geographical validity is given.

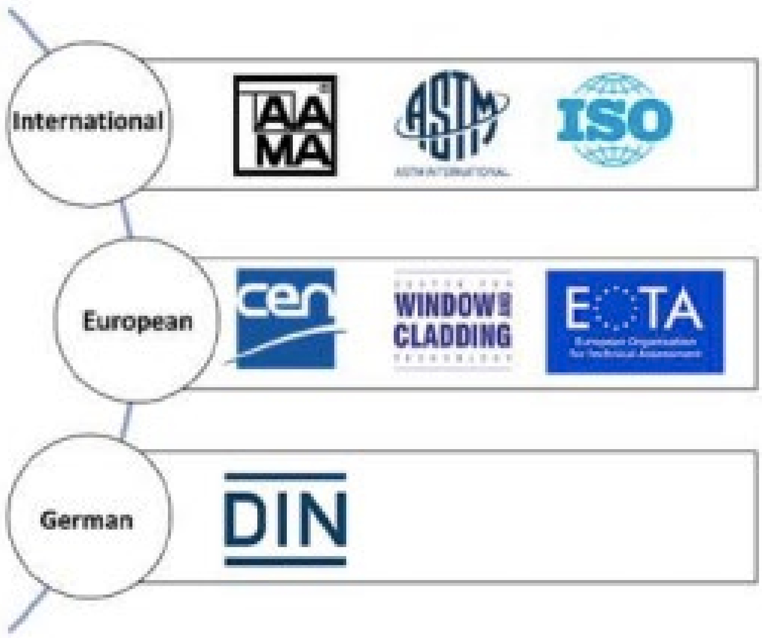

Figure 1: National and international overview of the standards.

International Regulations

Some regulations are known as worldwide standards, such as “AAMA- American Architectural Manufacturers Association” and “ASTM- American Society for Testing and Materials”. The fundamental test criteria air permeability, resistance to wind load and water tightness are covered by AAMA 501-1 to AAMA 501-6 and ASTM E 283:2004, ASTM E 330:2010, ASTM E 331:2009 (Lass, 2014).

At European level "CWCT- Centre for Window and Cladding Technology" and "CENEuropean Committee for Standardization" are mostly common. Both of them focus especially on glazed facades. Moreover, the ISO- regulations by the "International Organization for Standardization" are used internationally.

EOTA, the European Organization for Technical Assessment, issued the ETAG 034 "Guideline for European Technical Approval for Kits for External Wall Claddings" which refers to requirements such as water permeability, fire resistance, etc. On the international 11 and European level this guideline is a useful tool to compare the qualities and requirements of different facade systems. Norms with the European Norm identification ''EN'' are accepted on a European level, if they contain the identification of the International Organization of Standardization ''ISO'' they are valid worldwide.

When it comes to the demands on the structural performance, a facade must meet the requests for a sufficient structural safety and a certain resilience. Nonetheless, so far generally applied regulations and guidelines do not exist yet. The existing regulations for structural criteria are the Construction Products Regulation (CPR, no. 305/2011) and the national building standards (EN 1990).

German Regulations

As facades have a determinant impact on the building's efficiency, the German Energy Saving Ordinance (EnEV, 2014) is of vital importance. It contains standards for the annual primary energy requirement, transmission heat losses, minimum air exchange, and air tightness of the building. It is valid for new and major renovations of existing residential and non-residential buildings. The main aim is to save energy in order to ease the energetic and economical optimization of buildings. Furthermore, Germany`s energy policy targets a nearly climate-neutral built environment until 2050.

The Energy Performance Certificate, shown in Figure 2, is a tool of EnEV, which provides information about the energy efficiency of a building. It gives an overview of the energy demand, energy consumption and potential interventions for a modernization and increase of energy efficiency. Using the Energy Performance Certificate makes it more practical to compare the energy performance of buildings in Germany. Its validity is restricted to ten years.

Also, based on German regulations, facades are categorized into fire resistance classes due to their building material class. Suitable connections must ensure the room-tight execution of the transition of a facade to the shell construction to prevent the propagation of smoke and gases.

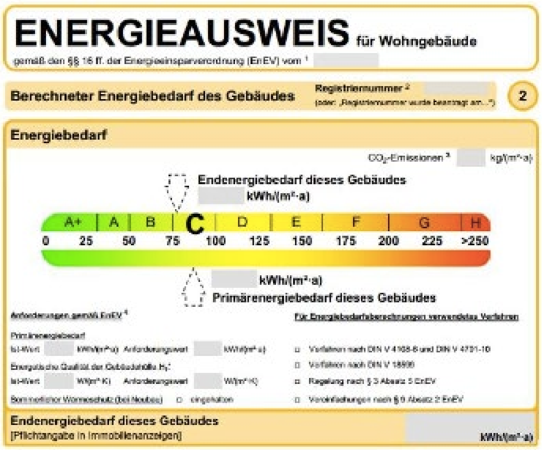

Figure 2. Sample of energy performance certificate of a residential building, extract of the energy demand (EnEV, 2014).

Besides EnEV, the German Federal Government established "DIN- Deutsches Institut für Normung", the German Institute for Standardization. The majority of the DIN regulations has been adopted as international standards, either on a European level (EN) or an international level (ISO).

"DIN EN 13830:2015 Curtain walling-product standards" is a fundamental, accepted German and European regulation for radiation properties, water tightness, air permeability, fire resistance and further properties. It is employed for traditional curtain walling facade systems and can be used to determine the properties of some adaptive facade systems. Exact regulations on the influence of the color choice are not given in DIN 4108-2. Despite the low relevance, the color selection is one of the influencing factors of the thermal impact on the building and should not be ignored in the planning phase.

Turkish Regulations

Turkish regulations do not schematize and define boundary conditions for the adaptability of facade systems so far. The standard TSE 825:2008 by the Engineering Service Expertise Group of the Turkish Standards Institute focusses on the thermal insulation requirements for buildings.

It not only considers the principles of international standards but also adapts the regulation to the conditions of Turkey. It aims to reduce the heating energy need by providing calculation rules and using the best thermal insulation solution for each individual case. (TSE 825:2008-Thermal Insulation Requirements for buildings, 2008). The concept of adaptability has not been implemented in TS 825 and thus is suitable to only a limited extent.

Conclusion

The initial idea of normative regulations in the building sector in general is the guarantee of valid quality standards. So far, regulations for adaptive facade elements, material properties, assembly etc. have not been adopted yet. Apart from this, adaptive facade systems are highly diverse in their structure and functioning, which makes it harder to create commonly valid standards.

In conclusion, official regulations, specifically for adaptive facades, do not exist yet. However, the potential of adaptive facade systems and the necessity for further research about the normative standards are indisputable.

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Usage of Information Modelling and Digital Technologies on Construction Sites

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Abstract

The digitalization of the information has started to be accepted in the construction sector. Stakeholders are using digital technologies for creating, sharing, storing, and reusing of the information. However, building information models are not effectively used by the construction site crews. Construction sites are dynamic production areas, and these areas have their unique working styles. Thus, these areas need dynamic information models and digital technologies. In this study it is aimed to determine good practices on the use of building information modeling and digital technologies on construction sites. A systematic literature review method is used to reach this aim. Research on the area is focused on; Construction-site control, construction-site collaboration by knowledge, health-safety issues, time, cost, value, and quality systems, workflow control, users' determination about BIM systems, and as-build projects. The future research directions proposed by the authors may help to develop a greater understanding of the usage of what kind of information do the construction sites need and how this information should be shared with the teams.

Keywords: *collaboration, construction sites, digital technologies, information models, site crews.*

Introduction

The design process of a building ends with a package of modeled information which needed to construct the building. Unfortunately, the construction of a building creates much more information than the design package. The construction site is a dynamic production area. Construction teams use mainly the design package information. Unfortunately, during the production process, design changes occur. These design changes cause multiple changes in the design package until the end of the construction. This situation causes an information jungle. Construction teams are the explorers of this jungle, and they own the information where they explore. In the end, complete information gathers in the constructed building and the building kept all information by itself.

The digitalization of the information has started to be accepted in the construction sector. Stakeholders are using digital technologies for creating, sharing, storing, and reusing of the information. However, building information models are not effectively used by the construction site crews. Construction sites are dynamic production areas, and these areas have their unique working styles. Thus, these areas need dynamic information models and digital technologies.

The complexity of construction projects, shortening of project delivery times, the demands for reducing costs and the increase in demand for quality make it necessary to use modeled information in construction sites. In this study, the studies conducted in the field related to the use of BIM in construction sites will be examined and answers will be sought for the research questions below.

1. What kind of research has been done on the use of BIM on construction sites?
2. For what purpose is BIM used on construction sites?

In this study it is aimed to determine good practices on the use of building information modeling and digital technologies on construction sites. A systematic literature review method is used to reach this aim.

Methodology

The paper proposes a systematic review of literature on the topic of Usage of Information Modelling and Digital Technologies on Construction Sites. This approach allows us to categorize a large number of records to identify the main trends in Building Information Modelling. ASCE Library and Emerald scientific databases are used for research. The keywords “construction site” and BIM (All Fields) are used for literature search both for ASCE Library and Emerald databases. On both databases, the results are limited to “article” and “Proceedings.” The research is performed on 20th of July 2020. The research on ASCE 252 proceedings and 218 articles and from Emerald 268 articles returned. Result lists are saved for future revisits. After collecting the records, the first scanning is performed. The relevant research considers 90 articles and 32 proceedings papers (Fig. 1).

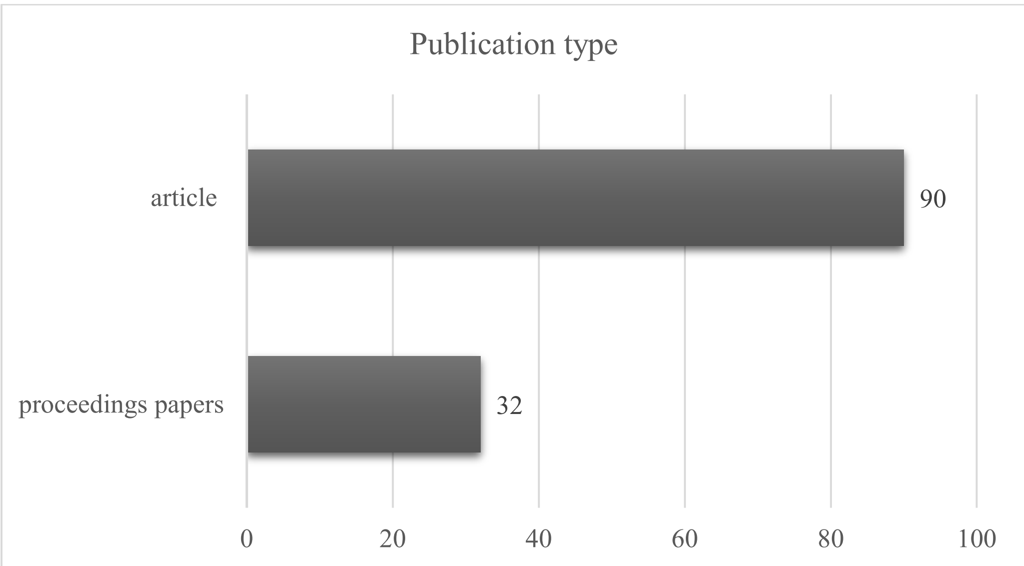

Figure 1: ASCE Library and Emerald databases research results.

In database research before 2009, there is no relevant research available about the subject. Research in the area starts after 2009 and increases in the last years (Fig. 2). Thus, the literature review is limited, with only two databases. In this condition, this research only could show us the research trends in the area.

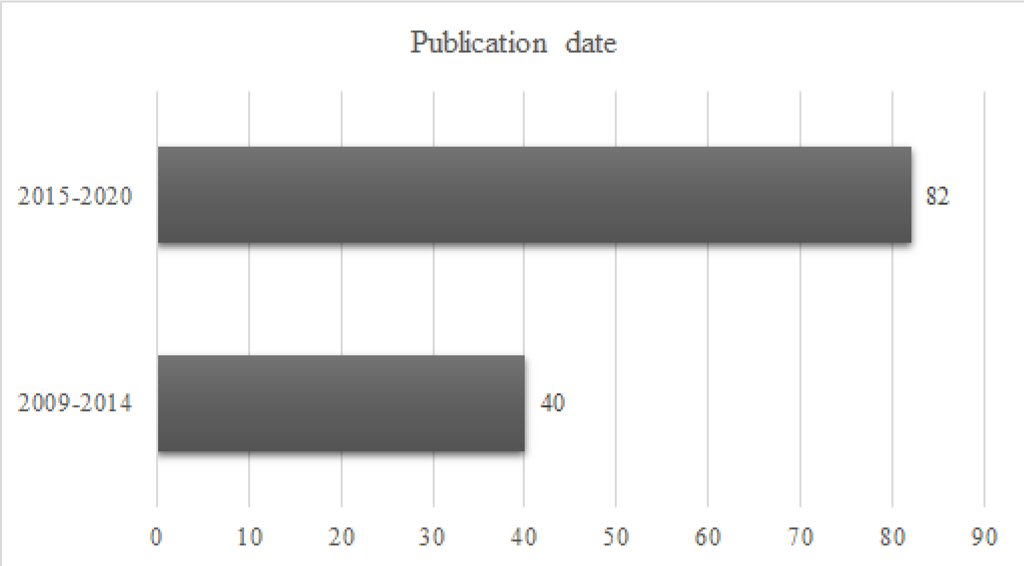

Figure 2: Publications according to years.

Results

Research area categories identified from previous literature. After the categories have been selected, a preliminary selection of collected material is carried out, and categories that are not suitable for the analysis are discarded, and new ones are chosen. Total seven research topics are identified. These topics are construction-site control, construction-site collaboration by knowledge, health-safety issues, time, cost, value, and quality systems, workflow control, users' determination about BIM systems, and as-build projects (Fig. 3). Robotized construction processes are eliminated from this literature research; thus, researchers would like to learn modeled information usage of the site crews. Some research papers are suitable for several topics; thus, these papers are discussed in different research areas. Construction-site control, construction-site collaboration by knowledge, and health-safety issues are the most searched areas in the field (Fig. 3).

Construction-Site Control

Site layout planning is the first step for the management of the construction sites. Knowledge of construction professionals experienced in the field is a significant factor for the planning of the construction sites. Unfortunately, The complexity of construction projects necessitates modeled information in planning. Studies in the field are listed as follows, site layout planning (Astour & Franz, 2014; Le et al., 2019), current practices for site layout planning (Xu et al., 2020; Zolfagharian & Irizarry, 2014), estimating the size of temporary facilities (Razavialavi, Abourizk, & Alanjari, 2014), material storage space planning (Said & El-Rayes, 2012), and simulation of the construction activities with mobile cranes (Li et al., 2012, 2015; Shapira et al., 2014).

Monitoring the construction sites are also part of the site controlling and managing. Transferring up-to-date information collected from the construction site to construction professionals with a specific systematic process contributes to decision-making processes. Monitoring construction sites (Edirisinghe, 2019; Han & Golparvar-Fard, 2014; Ibrahim et al., 2017; Luo et al., 2018; Sezer & Bröchner, 2019; Vegad et al., 2014), inspection of the productions (Falorca & Lanzinha, 2020; Hamledari et al., 2018; Tsai et al., 2014), laser scanning controlling construction sites (Turkan et al., 2014), path planning visual data collection by aerial robots (Ibrahim et al., 2017),and waste management (Arif et a., 2012, Kim et al., 2020) are the research topics in the area.

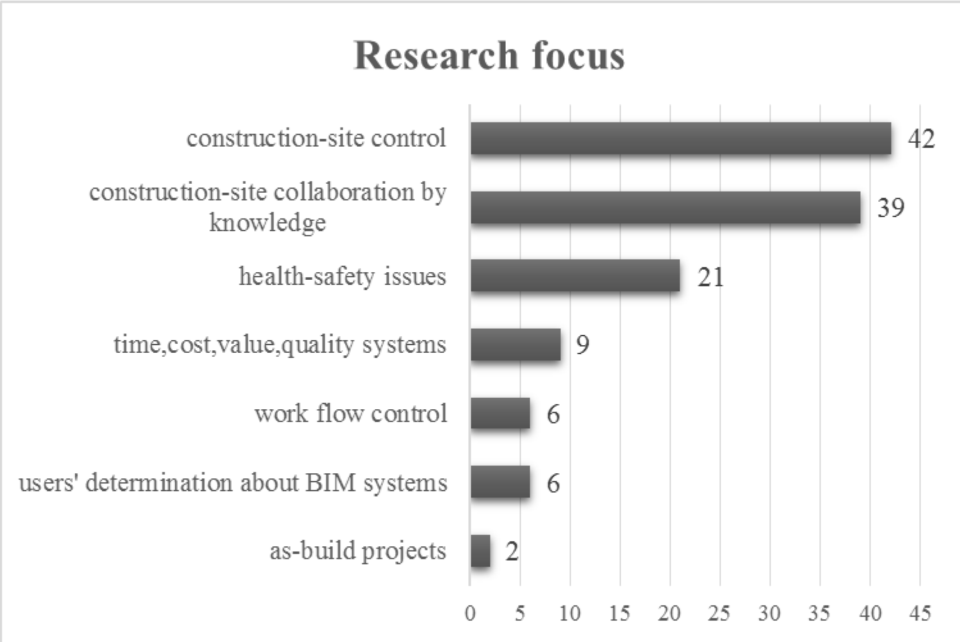

Figure 3: Research areas in BIM usage on construction-sites.

Construction-Site Collaboration By Knowledge

In order to ensure cooperation between construction site teams, it is necessary to organize social relations between teams. Also, there should be healthy information sharing between teams in order to ensure cooperation (Chiu & Lai, 2020; Getuli et al., 2020; Keskin et al., 2020; Nguyen et al., 2019, Wen & Gheisari, 2020).

Koseoglu and Nurtan-Gunes (2018) during the construction of Grand İstanbul Airport, the effectiveness of mobile BIM applications was investigated through lean construction principles. Results showed that with the help of the modeled information send to the tablets the site teams had accurate application information. Keskin et al. (2020) were found the benefits of BIM in document management real-time sharing data and in construction coordination, accessing up-to-date models on-site.

Health-Safety Issues

Although the research on health-safety issues at construction sites is high, construction site accidents continue to occur. Modeled information technologies are used to train construction site crews on health-safety issues (Jeelani et al., 2020; Lu & Davis, 2018; Marefat et al., 2019). Furthermore, safety monitoring systems are helping to prevent risks on construction sites (Edirisinghe, 2019; Guo et al., 2014; Liu et al., 2020; Park et al., 2017; Rashid & Behzadan, 2018; Xu & Wang, 2020; Zhao et al., 2012).

Time, Cost, Value, Quality, and Systems

Building information models are primarily used by the sector for time, cost, value, quality control (Olatunji & Sher, 2015). Studies in the area are predicting cost reduction and construction period acceleration (Kim et al., 2017). Fanning et al. (2015) searched two bridges constructions and found that BIM may have provided approximately 5–9% cost savings during construction by contributing to reduced change orders and rework. Visualization of construction project time planning with 4D tools is an alternative or supporting system for critical path method (Li et al., 2015). Prefabricated production processes are also using information modeling tools to estimate costs (Linner & Bock, 2012).

Workflow Control

Workflow and construction projects progress tracking research in the area based on mobile applications and 4D models (Benjaoran & Bhokha, 2009; Chalhoub et al., 2018; Chen et al., 2020; Usmani et al., 2019; Zaher et al, 2018). The main idea of the researches is the visualization of the project on the construction site.

Users' Determination About BIM Systems

User-friendly interfaces must be designed in order to ensure the effective use of BIM systems in construction sites. Teams are thought to access modeled information at different levels. For example, a field engineer can access information via mobile phone, while field teams can access information through kiosks. The issue of who accesses information using which tool should be planned in construction sites. As the benefits of using BIM tools on construction sites are seen, the motivation of the teams to use these tools increases (Alomari et al., 2016; Dossick & Neff, 2010; Edirisinghe, 2019; Kasireddy et al., 2016; Sezer & Bröchner, 2019; Tian & Xue, 2014).

As-Build Projects

As-build projects are vital for buildings' operational life. Production crews leave the building after construction work, and users move in. Unfortunately, construction work continues with refurbishment and renovations in the building. In this level of life of the building, as-build projects are needed to make these renovations. BIM tools also provide as-built projects at the end of construction projects (Asadi & Han, 2018; Usmani et al., 2019).

Conclusion

The complexity of construction projects requires the development of methods for modeling information. In construction sites, which constitute an important stage of building production, the right information must be shared with the right team at the right time. Knowledge management is essential for cost, quality, and time control of the projects. In this study it is aimed to determine good practices on the use of building information modeling and digital technologies on construction sites. A systematic literature review method is used to reach this aim. Research on the area is focused on; Construction-site control, construction-site collaboration by knowledge, health-safety issues, time, cost, value, and quality systems, workflow control, users' determination about BIM systems, and as-build projects. When the researches are examined, it is seen that the use of BIM in construction sites has increased in last ten years. The increase in the use of BIM applications shows that the market is benefiting from BIM. Despite all these positive developments, BIM has yet to enter construction sites at the beginning level. It is expected that applications will develop and their use will become widespread with the use of applications in construction sites in the upcoming period.

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Thermal Comfort Assessment of Hospital Buildings via Objective and Subjective Measurements

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Abstract

Hospitals are complex buildings where indoor environmental conditions have to not only comply with the standards but also ensure occupant comfort. However, addressing these objectives in hospital buildings is a challenging task since these buildings accommodate several departments used by diverse occupant profiles including healthcare workers, patients and visitors. In this study, objective and subjective measurements were conducted at a hospital building located in Izmir, Turkey. Indoor environmental conditions were recorded to assess the compliance of indoor environmental conditions with ASHRAE Standard 55 and ISO 7730 Thermal Comfort Standards. Predicted Mean Vote (PMV) indices were calculated to estimate occupants' thermal comfort suggested by the standards. In addition, point-in-time surveys were conducted to understand thermal perception of different occupant profiles and Actual Mean Vote (AMV) indices were calculated to investigate the perceived thermal comfort of occupants. Furthermore, PMV and AMV indices were compared to investigate the relationship between predicted and perceived thermal sensation of occupants. The results show that none of the indoor air temperature measurements comply with the standards whereas all relative humidity measurements were within the thresholds suggested by the standards. 53.33% of the CO_2 measurements were below the maximum allowable level specified in the ASHRAE Standard 62.1. In addition, the difference between PMV and AMV values was not statistically significant.

Keywords: *AMV, CO_2 levels, hospital buildings, PMV, thermal comfort.*

Introduction

Thermal comfort and air quality are among the most important factors within the built environment. Thermal comfort can be defined as the state in which the occupants feel physically and mentally comfortable within the existing indoor environmental conditions. It is stated that thermal comfort significantly affects satisfaction, productivity, well-being, physical and psychological health of occupants in buildings (van den Berg, 2005; Verheyen et al., 2011). In educational buildings, studies show that thermal comfort affects attention, perception and learning levels of students (Calis & Kuru, 2017; Calis et al., 2017; Kuru &

Calis, 2018). In office building, thermal comfort is strongly correlated with the productivity of workers (Al Horr et al., 2016; Antoniadou et al., 2017; Feige et al., 2013). In hospital buildings, thermal comfort is important since it affects healthcare personnel's productivity and their probability of making occupational mistakes (Chang & Liu, 2008; Derks et al., 2018; Ho et al., 2009; Verheyen et al., 2011) as well as patients' recovery phase (Verheyen et al., 2011).

It is stated that the complaints of physicians, nurses and other healthcare personnel in hospitals are mostly caused by indoor environmental conditions (Applebaum et al., 2010; Kotzer & Arellana, 2008). Vieira et al. (2016) conducted a survey with 128 healthcare workers including physicians, nurses, physiotherapists and technicians due to understand their perception, satisfaction and state of health. In addition, the field measurements were conducted to obtain indoor environmental conditions of intensive care units. The results show that thermal comfort is the main risk source compared to other comfort features for the inspected intensive care units. Van Gaever et al. (2014) presented the data of the survey study to compare the predicted thermal comfort levels with the actual thermal comfort of the surgical staff in four major hospitals located in Belgium. The results show that the current thermal comfort standards and ventilation systems could not provide suitable indoor environmental conditions due to the different needs of all members of the surgical team in the surgery rooms. Similarly, the results of another study show that various international standards, regulations and guidelines failed to maintain optimum indoor thermal conditions required or recommended in most of the surgery rooms (Balaras et al., 2007). It can be concluded that standards with defined comfort ranges cannot ensure satisfactory indoor environmental conditions in hospital buildings due to different needs of diverse occupant profiles (i.e. physicians, nurses, patients) and the diversity of healthcare areas (i.e. staff rooms, surgery rooms, patients rooms). Therefore, parameters related to the indoor environmental conditions affecting occupants' comfort, well-being and productivity in different healthcare areas of hospital buildings are still need to be investigated (De Giuli et al., 2013; Liu et al., 2018; Sattayakorn et al., 2017).

This study aims at (1) assessing the compliance of indoor environmental conditions with ASHRAE Standard 55 and ISO 7730 Thermal Comfort Standards, (2) comparing the predicted and actual thermal perception of occupants. Within this context, thermal comfort conditions and CO_2 levels were investigated via objective and subjective measurements in a hospital building located in Izmir, Turkey. The following sections introduce material and methods including field measurements and surveys. Then, results and conclusions are presented.

Material and Methods

In this study, objective and subjective measurements were conducted simultaneously in various healthcare areas of a hospital building located in Izmir, Turkey. The study was carried out on February 27, 2020, which is the heating season for the Mediterranean climate. This section describes the methodology carried out during objective and subjective measurements.

Objective Measurements

Objective measurements included indoor air temperature, mean radiant temperature, relative humidity, air velocity and CO_2 levels, which were measured via the probes connected to two TESTO Thermo-Anemometers (Model 435-2). The anemometers were positioned at a height of 1.1 m above ground level, which is in strict accordance with the prescriptions of ASHRAE Standard 55 (2017) and ISO 7726 (2001). The compliance of the measurements were assessed with respect to the ASHRAE Standard 55 (2017) and ISO 7730 (2005) standards.

ASHRAE Standard 55 (2017) and ISO 7730 (2005) standards suggest the Fanger's model (Fanger, 1967), in which the PMV and PPD indices are used for assessing and predicting thermal comfort in indoor environments (Del Ferraro et al., 2015; Dudzińska & Kotowicz, 2015; Hawila et al., 2018; Kocaman et al., 2019; Natarajan et al., 2015; Wu et al., 2018). The CBE Thermal Comfort tool (Hoyt et al., 2017) was used to calculate the PMV and PPD indices, in which the input parameters are indoor air temperatures (°C), relative humidity (%), mean radiant temperature (°C), air velocities (m/s), clothing insulation values (clo) and metabolic rate of the occupants (met). The checklist of clothing in the ISO 7730 (2005) was used to obtain the clothing insulation (clo) values, which were determined according to the most likely garments to be worn. Subsequently, the clo values were determined as 0.61, 0.66 clo and 0.71 clo. Metabolic rates and clothing insulation values of occupants were calculated by using the corresponding tables in ISO 7730 (2005). Subsequently, the metabolic rate was determined as 1.2 and 1.6 met. Moreover, the operative temperature was required to check the compatibility of this parameter with the recommended values in the ISO 7730 (2005). It was calculated by using Equation 1 which is in the ASHRAE Standard 55 (2017).

$$T_o = A \times T_a + (1-A) \times T_r \tag{1}$$

In the Equation 1, T_o represents operative temperature; A is the weighting factor that depends on air velocity (V_r) and was determined as 0.5 according to the ASHRAE Standard 55 (2017).

Subjective Measurements

A survey was designed based on the ASHRAE Standard 55 (2017) in order to understand occupants' perception about the built environment. In particular, users' thermal preference and thermal satisfaction regarding the indoor temperature, relative humidity, air velocity, and air quality were collected via requesting them to rate on the Fanger's seven-point scale. The participants of the survey were selected among physicians, nurses and other healthcare personnel, whose gender, age and position vary. The responses of the survey were used to calculate the AMV indices, which is beneficial to understand the perceived thermal comfort of different occupant profiles. Then, the AMV indices were compared to the PMV indices in order to understand the relationship between the predicted and perceived thermal sensation.

A total of 37 responses were collected and incomplete surveys were omitted. Thus, a total of 35 surveys were included in the analysis. The majority of occupants were between 25 and 34 years old. Moreover, most of the participants were nurse (62.86%) and the participation rate was higher for females (85.72%).

Results

Assessment of Indoor Environmental Conditions

This section presents the assessment of indoor environmental conditions against related standards. Indoor air temperature (°C), operative temperature (°C), relative humidity (%), air velocity (m/s) and CO2 level (ppm) were taken into account in the analysis. Table 1 shows indoor environmental conditions in various healthcare areas.

Table 1. Indoor environmental conditions.

	Indoor air temperature (ºC)	Operative temperature (ºC)	Relative humidity (%)	Air velocity (m/s)
Hospital school	25.50	25.70	49.5	0.01
Nurse station (1)	26.50	27.05	50.7	0.00
Physician room (1)	26.60	27.35	49.6	0.00
Physician room (2)	26.40	27.10	49.9	0.02
Treatment room (1)	26.10	27.15	46.7	0.04
Nurse station (2)	25.70	26.60	60.0	0.02
Physician room (3)	26.10	26.85	50.1	0.00
Nurse station (3)	26.40	27.15	48.9	0.00
Nurse station (4)	26.60	27.20	50.6	0.00
Nurse station (5)	25.80	26.65	42.1	0.05
Physician room (4)	26.00	26.55	50.4	0.01
Nurse station (6)	26.00	26.65	50	0.00
Treatment room (2)	26.30	27.25	59.4	0.01
Treatment room (3)	25.60	26.60	47.3	0.00
Nurse station (7)	25.00	25.75	46.7	0.01
Reference value	**20 – 23.3[a]**	**20 - 24[b]**	**30-60[a] / 30-70[b]**	**0.16[b]**

* (a) reference values of ASHRAE Standard 55 (2017), (b) reference values of ISO 7730 Standard (2005)

As can be seen from the table, the maximum and minimum allowable indoor air temperatures recommended by the ASHRAE Standard 55 (2017) are 20 ºC – 23.3 ºC for heating season, respectively. The results show that none of the indoor air temperature measurements were within the recommended values. The maximum indoor air temperature (26.6 ºC) was observed in the Physician room (1) and the Nurse station (4). The minimum indoor air temperature (25 ºC) was observed in the Nurse station (7).

The minimum and maximum allowable relative humidity ratios by the ASHRAE Standard 55 (2017) are 30% - 60% and by ISO 7730 (2005) are 30% - 70% for the heating season, respectively. All relative humidity ratios were within the recommended values according to both standards. The maximum relative humidity ratio (60%) was observed in the Nurse station (2). The minimum relative humidity ratio (42.1%) was observed in the Nurse station (5).

The allowable air velocity by ISO 7730 (2005) is less than 0.16 m/s for the heating season. Air velocity measurements were within the recommended values in all healthcare areas. The maximum air velocity (0.05 m/s) was observed in the Nurse station (5). On the other hand, there were 7 healthcare areas where no air velocity was observed. These areas include the Nurse station (1), the Physicians room (1), the Physicians room (2), the Nurse station (3), the Nurse station (4), the Nurse station (6) and the Treatment room (3).

Assessment of CO_2 Levels

This section presents the assessment of CO_2 levels against ASHRAE Standard 62.1 (2019). It should be noted that the maximum allowable CO_2 level by ASHRAE Standard 62.1 (2019) is 1000 ppm for the heating season. Table 2 shows the measured CO_2 levels in various healthcare areas.

Table 2. CO_2 levels.

Healthcare areas	CO_2 (ppm)	ASHRAE Standard 62.1
Hospital school	780	✓
Nurse station (1)	1104	X
Physician room (1)	800	✓
Physician room (2)	882	✓
Treatment room (1)	1025	X
Nurse station (2)	915	✓
Physician room (3)	916	✓
Nurse station (3)	952	✓
Nurse station (4)	1130	X
Nurse station (5)	835	✓
Physician room (4)	1104	X
Nurse station (6)	1106	X
Treatment room (2)	2228	X
Treatment room (3)	1245	X
Nurse station (7)	873	✓

As can be seen from the table, 53.33 % of the CO_2 measurements were within the recommended values. The maximum CO_2 level was observed in the Treatment room (2) with a value of 2228 ppm. The minimum CO_2 level was observed in the Hospital school with a value of 780 ppm, which is below the maximum allowable CO2 level by the standard.

Assessment of PMV and AMV indices

This section presents the comparison of PMV and AMV indices as well as the compatibility of PMV and PPD values with ASHRAE Standard 55 (2017). It should be noted that if PMV values are between -0.5 and +0.5 and PPD (%) values less than 10%, the indoor environment is accepted as thermally neutral according to ASHRAE Standard 55 (2017). Table 3 shows PMV and PPD values and their compliance with ASHRAE Standard 55 (2017) standard.

Table 3. PMV and PPD values.

Healthcare areas	PMV	PPD (%)	ASHRAE Standard 55
Hospital school	0.65	14%	X
Nurse station (1)	1.27	39%	X
Physician room (1)	1.1	30%	X
Physician room (2)	0.92	23%	X
Treatment room (1)	1.26	38%	X
Nurse station (2)	1.23	37%	X
Physician room (3)	0.91	23%	X
Nurse station (3)	1.28	39%	X
Nurse station (4)	1.3	40%	X
Nurse station (5)	1.13	32%	X
Physician room (4)	1.16	33%	X
Nurse station (6)	1.18	34%	X
Treatment room (2)	1.04	28%	X
Treatment room (3)	0.76	17%	X
Nurse station (7)	0.51	10%	X

As can be seen from the table, none of PMV and PPD values indicated a thermally neutral indoor environment, and, thus, it can be concluded that indoor environmental conditions were not satisfactory for the occupants.

Table 4 shows the comparison of the predicted and perceived thermal sensation. It should be noted that the perceived thermal sensation is calculated based on the survey responses which range from -3 (cold) and +3 (hot) on the 7-point scale. According to Fanger's theory, votes between -1(slightly cool) and +1 (slightly warm) describe thermally acceptable environments.

Table 4. Comparison of the predicted and perceived thermal sensation.

Healthcare areas	PMV	Predicted Thermal Sensation	AMV	Perceived Thermal Sensation
Hospital school	0.65	Slightly warm	2.00	Warm
Nurse station (1)	1.27	Slightly warm	-0.50	Neutral
Physician room (1)	1.10	Slightly warm	3.00	Hot
Physician room (2)	0.92	Slightly warm	2.00	Warm
Treatment room (1)	1.26	Slightly warm	0.00	Neutral
Nurse station (2)	1.23	Slightly warm	2.00	Warm
Physician room (3)	0.91	Slightly warm	0.00	Neutral
Nurse station (3)	1.28	Slightly warm	-0.50	Neutral
Nurse station (4)	1.30	Slightly warm	-1.00	Slightly cool
Nurse station (5)	1.13	Slightly warm	2.75	Hot
Physician room (4)	1.16	Slightly warm	1.50	Slightly warm
Nurse station (6)	1.18	Slightly warm	3.00	Hot
Treatment room (2)	1.04	Slightly warm	2.67	Hot

Treatment room (3)	0.76	Slightly warm	0.00	Neutral
Nurse station (7)	0.51	Slightly warm	1.00	Slightly warm

As can be seen from the table, the predicted thermal sensation by the standard was "Slightly warm" in all healthcare areas. Therefore, the PMV values suggested that all healthcare areas were thermally 'acceptable'. On the other hand, the results of the survey showed that only 53.33% of healthcare areas were thermally acceptable by the occupants. Overall, the prediction according to the standards did not match with the actual perception of occupants in 86.67% of the healthcare areas.

Furthermore, statistical significance of the difference between PMV and AMV values is investigated. First, the Kolmogorov-Smirnov normality tests and Levene's homogeneity test were conducted to determine the applicable statistical test for comparing the mean values of the PMV and AMV. The results of the tests are presented in Table 5. In addition, the histogram plots with normal curve for the PMV and AMV values are shown in Fig. 1.

Table 5. The results of the Kolmogorov-Smirnov and Levene's tests.

	Kolmogorov-Smirnov			**Levene's Test**	
	Statistic	df	p	F	p
PMV	0.186	15	0.174	47.074	0.000
AMV	0.201	15	0.106		

(a) (b)

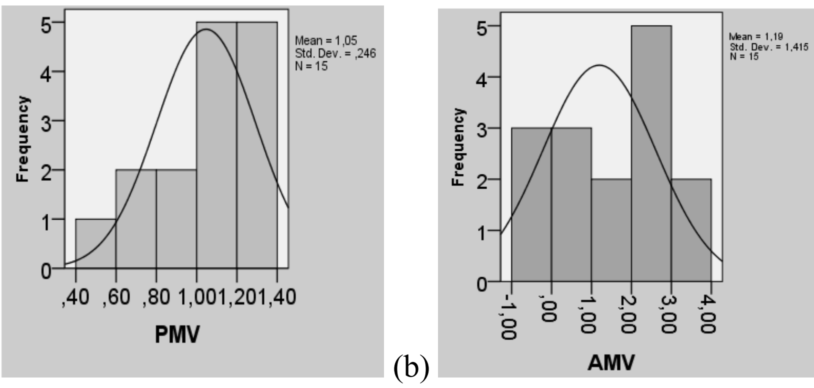

Figure 1: Histogram plot for the (a) PMV values; (b) AMV values.

The results of Kolmogorov-Smirnov test for the PMV and AMV values are p=0.174 (p>0.05) and p=0.106 (p>0.05), respectively. The results show that the values are normally distributed. The result of the Levene's test is p=0.000 (p<0.05), which indicates that the data set of PMV and AMV values are not homogenous. Second, t-test is conducted to understand the statistical significance between PMV and AMV values. Since the data set is normally distributed and is not homogenous, the mean difference is the result of the state where the variances are not equal. Table 6 shows that result of t-test.

Table 6. Results of t-test.

t	**df**	**Sig. (2-tailed)**	**Mean difference**
-0.399	14.849	0.696	-0.148

The result shows that the difference between the mean of AMV values and the mean of the PMV values is not statistically significant ($p = 0.696$; $p < 0.05$). In other words, the standards were not able to predict the actual thermal sensation of occupants.

Conclusions

In this study, indoor environmental conditions in a hospital building were investigated via objective and subjective measurements. Within this context, indoor environmental conditions were recorded to assess the compliance of indoor environmental conditions with ASHRAE Standard 55 (2017) and ISO 7730 (2005) Thermal Comfort Standards. The PMV indices were calculated to estimate occupants' thermal comfort suggested by the standards. The AMV indices were calculated to investigate the perceived thermal comfort of occupants. Then, the PMV and AMV indices were compared to understand the relationship between predicted and perceived thermal sensation of occupants. The main findings can be summarized as follows:

- The measured indoor air temperature values did not comply with the standards.
- The measured relative humidity values were within the recommended ranges specified in the standards.
- The measured air velocity values were below the maximum value specified in the ISO 7730 Standard (2005).
- 53.33% of the CO_2 measurements are below the maximum allowable level specified in the ASHRAE Standard 62.1 (2019).
- The difference between the mean values of PMV and AMV is not statistically significant.

The findings of this study show that the predefined comfort ranges do not ensure occupant thermal satisfaction. The limitation of this study is that the findings are based on one hospital building and point in time measurements. Future studies can incorporate several hospital buildings, surveying with more occupants and long-term measurements to validate the results of this study.

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Identifying Barriers to the Implementation of Sustainable Construction

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Abstract

In the last decades, industrialization and urbanization have led to an increasing demand in the construction industry. Subsequently, this demand caused many environmental problems, which are due to harmful emissions and wastes produced and released into the environment along with the use of natural resources and energy throughout the building life cycle. Adapting sustainable practices in the construction sector has potential in reducing negative environmental impacts, however; its implementation has not been successful yet due to numerous barriers. This study aims at identifying and prioritizing potential barriers to the transition of sustainable construction. Within this context, 7 barriers were identified via a thorough literature review and a survey is designed to prioritize these barriers to the transition of sustainable construction. A total of 10 professionals were interviewed and the responses were analyzed via Analytical Hierarchy Process (AHP) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) methods. The results show that the most influential barrier moving toward the sustainable construction practices is the difficulties in selecting sustainable construction materials whereas the least influential one is the design of the construction project.

Keywords: *AHP, construction industry, multi-criteria decision-making, sustainability, TOPSIS.*

Introduction

The construction industry has substantially grown over the recent decades, which resulted in a global rise in environmental concerns (Asman et al., 2019; Carvalho et al., 2019; Chen et al., 2019). Akhanova et al. (2020) indicates that the construction industry consumes 36% of ultimate energy use, a third of natural resources and 12% of fresh water in global. Besides, the construction industry contributes to 40% of solid waste production and 40% of CO_2 emissions (Akhanova et al., 2020). Recently, it is reported that sustainable construction holds the potential in mitigating the adverse effects of the industry and reducing harmful emissions (Yadegaridehkordi et al., 2020, Ahmadi et al., 2020; Mahmoud et al., 2019; McArthur & Powell, 2020). By definition, sustainable construction is "an industry that prevents the rapid depletion of resources, addresses the environmental and health problems caused by the buildings, reduces the impact of the industry on the environment and people, and enhances the quality of life and reduces its environmental footprint" (Durdyev et al., 2018). However, existing knowledge on sustainable construction is fragmented, limited and mostly theoretical.

Therefore, practitioners are hesitant to implement sustainable construction practices since the stages required for designing sustainable buildings are more complicated than that of in traditional buildings (Jalaei et al., 2020). In order to overcome these unseen barriers that hinder sustainable construction, the barriers need to be identified and prioritized so that correct actions can be taken by the stakeholders including policy-makers and manufactures.

This paper aims at identifying and prioritizing potential barriers to the transition of sustainable construction in Turkey. Seven barriers and 3 criteria were identified via literature review. Then, a survey was designed to understand the barriers. The analytical hierarchy process (AHP) and technique to order preference by similarity to ideal solution (TOPSIS) methods were used to prioritize the barriers. The following sections introduce the literature review, describe the methodology, present the AHP and TOPSIS methods, summarize results and present the discussion and conclusion.

Literature Review

Recently, mitigating harmful effects of the construction industry has become an important issue. Therefore, there is an increasing interest to understand the barriers to the transition of sustainable construction. Adabre et al. (2020) employed factor analysis and rank agreement analysis to classify 19 barriers to achieve sustainability in affordable housing in several countries (Adabre et al., 2020). The results show that 'high cost of serviced land', 'inadequate infrastructural development', 'income segregation', 'high interest rates' and 'lack of policies/weak enforcement of policies on land use planning systems for housing supply' are among the most common barriers. Akadiri (2015) investigated the barriers that effect the selection of sustainable materials in building projects in Nigeria. A survey study was conducted and the responses were analyzed via Predictive Analysis Software (PASW) (Akadiri, 2015). The results indicate that 'perception of extra cost being incurred', 'lack of sustainable material information' and 'lack of comprehensive tools and data to compare material alternatives' are among the top three critical barriers. Durdyev et al. (2018) identified hindering factors of adapting sustainable construction practices in Malaysia. A survey was conducted to construction professionals and the results were analyzed via partial least squares structural equation modeling (PLS-SEM). The results show that the most important barrier to sustainable construction in Malaysia is the 'lack of code and regulations' (Durdyev et al., 2018). Oke et al. (2019) investigated the drivers to the adoption of construction practices in Zambian. A survey study was conducted to the construction professionals and Mean Item Score (MIS) was used to analyze the results. The findings show that 'linking research to implementers' is the top driver among the others in the adoption of sustainable construction practices (Oke et al., 2019). The literature review shows that the barriers to sustainable construction are not consistent and show variation per country. Therefore, more research needs to be conducted to identify country specific barriers. Subsequently, this study investigates the barriers to the transition of sustainable construction in Turkey.

Methodology

In this study, three different criteria including social (C1), technical (C2) and legal (C3) were taken into account in the analysis. Next, seven barriers were identified based on a thorough literature review. Then, a questionnaire was designed and conducted to 10 civil engineers in order to identify and to prioritize potential barriers to the transition of sustainable construction. Finally, AHP and TOPSIS methods were employed to prioritize the barriers based on their relative importance. The barriers and their descriptions are presented in Table 3. It should be noted that the experts were requested to evaluate the barriers by using the 9-point scale, which is given in Table 1.

Table 1. Barriers and the descriptions.

Code	Barrier	Description
B1	Restrictions on the land selection	Contractors' main concern during the land selection is generally the maximum land use and profit. Therefore, they can overlook land options that might be more suitable for sustainable construction practices by having wind or solar energy potential.
B2	Design of the construction project	There may be mandatory practices enforced by the regulations (i.e. earthquake) and/or technical limitations of construction projects that can hinder sustainable construction practices.
B3	Difficulties in selecting sustainable construction materials	Practitioners, as customers, usually have their own tendencies and/or habits during material selection. Apart from that, there may be lack of sustainability information and/or sustainable product options that can motivate practitioners to change their behaviour as customers.
B4	High cost of sustainable construction materials/technologies/methods	Sustainable construction practices might require more advanced materials, technologies and methods which can have higher costs than traditional ones.
B5	Customer demands	Customers and/or contractors can prefer buildings built with traditional materials over those with sustainable materials.
B6	Lack of awareness among managers, engineers, employees and customers	Existing information about sustainability is fragmented and mostly conceptual. Apart from that, the uncertainty of benefits of sustainable construction demotivates the stakeholders to act, which in turn causes the lack of commitment by top managers to move toward sustainable construction.
B7	Lack of policies/guidelines	Sustainable construction practices require policies, legal frameworks, and supervision. The lack of policies results in low pressure to promote sustainable construction.

AHP Method

AHP, one of the multi-criteria decision-making methods, was developed by Saaty (1980). This method allows multiple criteria to be considered by decision-makers both quantitatively and qualitatively through pairwise comparisons and establishes a hierarchical relationship between criteria and alternatives in the system (Pamučar et al., 2018). There are three levels in AHP method. First, the model is structured hierarchically. Then, the importance of the criteria and the decision alternatives according to each criterion are compared and evaluated. In the last level, the order of decision alternatives is determined by making priority synthesis (Chaudhari et al., 2018).

The steps of the AHP method are as follows (Wolnowska & Konicki, 2019):

Step 1. In order to create the hierarchy of the identified problem, the main goal, the criteria that accomplish the main goal and alternative solutions are defined.

Step 2. In order to make the evaluation possible by the decision-makers, a pairwise matrix is created and that is carried out using a pairwise comparison scale, which ranges from 1 to 9. The pairwise comparison scale is shown in Table 1.

Table 1. Pairwise comparison scale (Saaty, 2008).

Scale	Ranking	Explanation
1	Equal importance	Two activities contribute to the objective equally
2	Weak or slight	
3	Moderate importance	One activity is slightly preferred over the other
4	Moderate plus	
5	Strong importance	One activity is strongly preferred over the other
6	Strong plus	
7	Very strong or demonstrated importance	One activity is very strongly preferred over the other
8	Very, very strong	
9	Extreme importance	One activity over another is of the highest preference order of confirmation

A pairwise comparison matrix is created in which A= $[a_{ij}]$ with the preference of experts using a relative Saaty's domination scale, which is shown in Table 1. The pairwise comparison matrix is given in Eq. 1.

$$A = \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ \frac{1}{a_{12}} & 1 & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \dots & 1 \end{bmatrix} \quad (1)$$

Step 3. In order to get Eigen value and Eigen vector, firstly, values in pairwise comparison matrix are normalized. After obtaining the normalized pairwise comparison matrix, the average of each line is calculated and the Eigen vector is obtained. Eigen matrix is also obtained by multiplying the pairwise comparison matrix with the Eigen vector.

Step 4. It should be checked whether the decision matrix created by experts is correct. Therefore, the consistency index (CI) of the pairwise comparison matrix is found by using Eq. 2. Then, consistency ratio (CR) is calculated by using Eq. 3.

$$CI = (\lambda_{max} - n)/(n\text{-}1) \quad (2)$$

$$CR = CI / RI \quad (3)$$

λ_{max}, which is the maximum Eigen value, is calculated by using Eq. 4.

$$\lambda_{max} = \frac{1}{n}\sum_{j}^{n} \alpha_j^* \tag{4}$$

The random index (RI) expression in the equation is a parameter and varies according to the number of elements in the matrix. These values are presented in Table 2.

Table 2. Random index values (Saaty, 2003).

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0,52	0,89	1,11	1,25	1,35	1,4	1,45	1,49

The consistency ratio should be less than 0.10 (CR <0.10). If it is large, the calculation is considered as inconsistent.

TOPSIS Method

TOPSIS, one of the multi-criteria decision-making methods, was developed by Hwang and Yoon (1981). The main purpose of this method is to determine the closest distance to the positive ideal solution and the farthest solution to the negative ideal solution between the alternatives with certain criteria (Ye et al., 2020). TOPSIS method consists of several steps (de Lima Silva et al., 2020):

Step 1. The decision matrix of the multi-criteria decision-making methods is created by defining criteria and alternatives. The decision matrix is defined as in Eq. 5 and is as follows:

$$D_{ij} = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \dots & \dots & \dots & \dots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix} \tag{5}$$

where the number of alternatives are represented as *m* and the number of criteria are represented as *n*.

Step 2. Normalization of the decision matrix should be carried out in order to correctly compare the criteria between themselves. To normalize the decision matrix (Equation 5), normalization criteria need to be calculated by using Eq. 6.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \qquad i = 1,2,\dots,m \text{ and } j= 1,2,\dots,n \tag{6}$$

Step 3. The normalized decision matrix, which is obtained via Equation 6, is multiplied by the weight values determined for each criterion. Thus, a weighted normalized matrix is obtained. The values in the weighted normalized matrix are obtained by using Eq. 7.

$$v_{ij} = w_j r_{ij} \qquad i = 1,\dots,m \text{ and } j = 1,\dots n \tag{7}$$

$$\sum_{j=1}^{n} w_j = 1. \qquad i = 1,\dots,m \text{ and } j = 1,\dots n \tag{8}$$

Step 4. The weighted normalized matrix values are used to create an ideal solution set. Positive ideal solution represents values that maximize the beneficial criteria and minimize the non-beneficial criteria. The positive ideal solution is given in Eq. 9.

$$A^{+} = (v_1^{+}, v_2^{+}, \ldots, v_n^{+} = \{(max v_{ij} \mid j \in I), (\min v_{ij} \mid j \in J)\} \quad i = 1,\ldots,m \text{ and } j = 1,\ldots n \tag{9}$$

Negative ideal solution is the values that maximize the cost criteria and minimize the benefit criteria. The negative ideal solution is given as

$$A^{-} = (v_1^{-}, v_2^{-}, \ldots, v_n^{-} = \{(min v_{ij} \mid j \in I), (\max v_{ij} \mid j \in J)\} \quad i = 1,\ldots,m \text{ and } j = 1,\ldots n \tag{10}$$

In the formulas shown above; *I* is represented benefit criteria and *J* is represented cost criteria.
Step 5. Using the Euclidian distance (S*) approaches, distances are calculated from the positive and negative ideal solution set of each alternative. The distance to the positive ideal solution for each alternative is calculated by Eq. 11 and the distance to the negative ideal solution is calculated by Eq. 12.

$$S_i^{*} = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^{*})^2} \quad i = 1,\ldots,m \text{ and } j = 1,\ldots n \tag{11}$$

$$S_i^{-} = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^{-})^2} \quad i = 1,\ldots,m \text{ and } j = 1,\ldots n \tag{12}$$

Step 6. The relative closeness (C*) to the positive ideal solution is calculated to rank each alternative. This value must be in the range of 0 to 1, and the sequence is made starting from the alternative closest to 1. The sequence is defined by using Eq. 13.

$$C_i^{*} = \frac{S_i^{-}}{S_i^{-} + S_i^{*}} \quad 0 \leq C_i^{*} \leq 1 \quad i = 1,\ldots,m \text{ and } j = 1,\ldots n \tag{13}$$

Results

AHP method was employed to obtain the weights of each criterion. The calculations were made by using the Microsoft Excel package program. The weights and pairwise comparison matrix are given in Table 4.

Table 2. Criteria weights and pairwise comparison matrix.

	Social	Technical	Legal	Weights
Social	1	5	1	0.46633
Technical	0.2	1	0.25	0.10067
Legal	1	4	1	0.43300

The consistency ratio of the pairwise comparison matrix was found to be 0.005. This result shows that the comparison matrix is consistent since the consistency ratio does not exceed the upper threshold of 0.1 (CR<0.1).

In the TOPSIS method, firstly, the decision matrix (Table 4) is created based on the responses of the experts. Next, the decision matrix is normalized by using Eq. 6. Then, the weighted normalized matrix is obtained by multiplying the normalized matrix by the weights of criteria. It should be noted that the criterion weights obtained via AHP method are used in the TOPSIS application. TOPSIS method is employed by using the Microsoft Excel package program.

Table 3. The decision matrix of TOPSIS method.

Code	Social	Technical	Legal
B1	7	7	7
B2	7	1	1
B3	9	5	9
B4	5	9	5
B5	7	9	7
B6	5	7	7
B7	9	7	5
Weights	0.46633	0.100673	0.432997

The weighted normalized matrix values are used to create positive and negative ideal solution sets, which are shown in Table 6.

Table 4. The set of positive and negative ideal solutions.

	Social	Technical	Legal
A^*	0.2215	0.0495	0.2333
A^-	0.1231	0.0055	0.0259

Euclidean distances are calculated from the positive and negative ideal solution sets identified for each barrier. The distances of each barrier to the positive and negative ideal solutions and the relative closeness to the positive ideal solution are shown in Table 7.

Table 5. The distance to the positive and negative ideal solutions and the relative closeness to the positive ideal solution.

Euclidean distances from the positive solutions set		Euclidean distances from the negative solutions set		Relative closeness to the positive solutions set	
S^*_1	0.0052	S^-_1	0.0277	C^*_1	0.8411
S^*_2	0.0474	S^-_2	0.0024	C^*_2	0.0487
S^*_3	0.0005	S^-_3	0.0532	C^*_3	0.9910
S^*_4	0.0204	S^-_4	0.0127	C^*_4	0.3830
S^*_5	0.0051	S^-_5	0.0285	C^*_5	0.8482
S^*_6	0.0125	S^-_6	0.0253	C^*_6	0.6691
S^*_7	0.0109	S^-_7	0.0215	C^*_7	0.6645

Finally, the barriers are ranked according to the relative closeness to the positive ideal solution. The ranking of the barriers is presented in Table 7.

Table 6. Ranking of the barriers.

Barrier Code	Relative Closeness (C*)	Ranking
B1	0.8411	3.
B2	0.0487	7.
B3	0.9910	1.
B4	0.3830	6.
B5	0.8482	2.
B6	0.6691	4.
B7	0.6645	5.

Discussions and Conclusion

In this study, two different multi-criteria decision-making methods, namely AHP and TOPSIS, were employed to prioritize potential barriers to the transition of sustainable construction. Seven barriers and 3 criteria were identified via literature review. AHP method was applied to obtain the weights of each criterion. The weights of criteria were calculated based on the responses of a questionnaire, which was conducted to 10 civil engineers. Then TOPSIS method was employed to obtain the ranking of the barriers.

In this study, the rank of the barriers in descending order are found as follows: Difficulties in selecting sustainable construction materials (B3); customer demands (B5); restrictions on the land selection (B1); lack of awareness among managers, engineers, employees and customers (B6); lack of policies/guidelines (B7); high cost of sustainable construction materials/technologies (B4); design of the construction project (B2). In addition, the most influential barrier moving toward the sustainable construction practices is found to be the difficulties in selecting sustainable construction materials. This result might be due to several reasons including the lack information provided for construction materials with respect to their sustainability, limited options for sustainable construction materials in the market and resistance and/or reluctance to change the behavior of practitioners as customers. Furthermore, the results show that the least influential barrier is the design of the construction project. This result might be due to the fact that the construction projects are designed according to the technical requirements, specifications and regulations. Thus, sustainability is not yet among the main concerns of engineers during the design phase. The results of this study will be beneficial to policy makers to understand the barriers to the transition of sustainable construction, and, thus, regulations and directives can be prepared to overcome these drawbacks.

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An Approach to Determine Exchange Information Requirements (EIR) for Metro Projects in Turkey

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Abstract

The paper represents a framework that can be followed while adopting Exchange Information Requirements for metro projects in Turkey. In contrast to the universal trend of implementing Building Information Model initially to superstructure projects, Turkey brought an obligation of BIM use for the first time in a metro project. Since 2014, metro projects tendered in Turkey, primarily in İstanbul, are BIM-mandated public projects. However, Employers have not yet developed organization-wide holistic standards to ensure delivered project will qualify their expectations. EIR define the requirements of the Employer regarding the content, delivery, and management of project related information including the roles and responsibilities of involved parties, applicable standards and milestones along the project lifecycle. It should clarify technical, commercial, and managerial aspects at different phases of a project. As each stakeholder is expected to be in full compliance with the document, EIR is fundamental for an Employer to ensure an efficient utilization of BIM methodology in accordance with a defined international BIM Standard, such as ISO19650. This paper aims to describe the aspects that should be included in EIR of metro projects in Turkey by analyzing similar EIR implementations around the world within the scope of international BIM Standard ISO 19650.

Keywords: *exchange information requirements (EIR), Building Information Modelling (BIM), metro projects.*

Introduction

Exchange Information Requirements (EIR) is a document specially tailored for an Employer to clarify their requirements and expectations from projects with Building Information Modelling (BIM) use. The document aims to set out the information to be delivered and the standards and processes to be adopted by all project stakeholders along the project lifecycle. EIR should be included in tender documentation, enabling design contractors to respond with their pre-contract BIM Execution Plan (BEP) where their proposal to meet client requirements is explained in detail. Pre-contract BEP aims to define how the specified information in EIR will be provided by demonstrating the tenderer's proficiency in delivery and management of information. PAS 1192-2:2013 states it should include the Project Implementation Program (PIP) setting out the capability, competence and experience of the tenderer, collaboration and information modelling objectives, project milestones, and the project delivery strategy. Comprehensive EIR is of vital importance for tenderers to develop appropriate and complete BEPs that include their clear plans for the whole construction process and also for the evaluation of tender responses, as it serves as a reference document to review tenderers' BEPs and award the contract (Wairi, 2018).

Clear definition of user's information needs prior to starting BIM processes explicitly enhances the outcomes of BIM implementation in any project. Furthermore, Ashworth et al. (2017) define a clear EIR as one of the fundamental principles of achieving BIM Level 2. The document covers technical, managerial, and commercial aspects of project delivery procedures. Technical aspects include software platforms, data exchange formats to be used, whereas managerial aspects refer to the standards, roles and responsibilities, coordination and collaboration processes. The latter, commercial aspects specify key issues such as BIM deliverables and competence assessment criteria.

In 2019, International Association of Public Transport (UITP) declared İstanbul as the lead city in the world that has the highest number of rail system construction projects at the same time by 17 ongoing projects (Alyanak, 2019). Although metro projects tendered in Turkey have been BIM-mandated public projects since 2014, Employers have not yet developed an EIR to standardize project delivery procedures. This paper aims to describe the aspects that should be included in EIR of metro projects in Turkey by analyzing similar EIR implementations around the world within the scope of international BIM Standard ISO 19650.

Research Motivation

The first metro project in Turkey that was designed using BIM technologies was initiated in 2015. The primary BIM-based metro project of İstanbul, which is being constructed in two parts by two different contractors, is expected to be in full service by 2021. As of June 2020, there are 16 metro projects with a total length of 71 kms being constructed in İstanbul, which are commissioned by 13 contractors and 8 design consultants. The goal is to build 49 km of additional metro lines by the end of 2023 (Istanbul Metropolitan Municipality, 2020).

Within the scope of the design studies of a metro project consisting of several stations, over 10.000 documents are produced and communicated between the project stakeholders. These documents are named according to diverse naming protocols, shared within different common data environment platforms in different data exchange formats.

In metro projects tendered in Turkey, different companies are usually in charge of design & construction of the project and operation & management of the built facilities. Consequently, the operating company often stays out of the initial procedures of the project such as planning and preliminary design resulting in incompatibility of project outcomes with their requirements. Their participation is essential for BIM Execution Plan to ensure the end product is compatible with their data requisition, internal procedures, and equipment and software preferences.

A major consequence of the absence of specified Employer requirements is to have projects with different modelling strategies. Each design consultant specifies the model structure and the level of detail that their models will have at different project phases in their BEP according to their internal standards. Models of uniform or at least comparable maturity level would be indispensable for future superposition of the city's metro lines into a federated master model.

In consideration of significant number of metro projects ongoing simultaneously in Turkey, the development of Exchange Information Requirements is of vital importance in maximizing the benefits of BIM implementation for all projects. Lack of EIR serving as a reference document disables design consultants from conceiving the appropriate BEP. There are many issues that could be standardized in accordance with Employer's requirements and implemented in each project's BEP such as document management procedures, model development strategies, data exchange formats, and software platforms in order to eliminate discrepancies between different projects.

Research Methodology

In order to determine the content of the Exchange Information Requirements for metro projects in Turkey, a literature review was conducted but a shortage of EIR-focused studies had been noticed. Most studies approach EIR from Facility Management (FM) point of view. Furthermore, specifications and guidelines mention the need for EIR but do not provide clear definitions of these requirements. ISO 19650, one of the most frequently used international standards for information management over the lifecycle of a built asset using BIM, describes a general framework for the content of the EIR. According to ISO 19650-1(BS EN ISO 19650-1:2018, 2018), the managerial and commercial aspects should define the standards of information and how they should be produced while technical aspects should specify detailed information needed to respond to project information requirements. Although there might be several appointments made for a project, the combined EIR serves as a comprehensive set of information requirements addressing all project information requirements (BSI, 2014). Apart from identifying some aspects that must be described in the EIR, such as metrics determining levels of information need, ISO19650 does not provide a detailed EIR content as each project is unique as per its requirements. Therefore, the standard can be considered as a starting point while preparing the EIR and a final checklist while revising the document.

Three sample EIRs that were included in procurement documents of three different projects were examined in order to establish possible EIR content for metro projects in Turkey. The first EIR, will be referred as Case 1 hereafter, is from design & build project of a corridor of Regional Rapid Transit System (RRTS) network in India. It covers detailed civil, architectural, and electro-mechanical (E&M) design & construction works of 7 elevated stations and detailed planning of proposed 5 underground stations within the corridor of 106.5 km total length. Case 2 is the only project within the sample projects excluding design works which includes construction of 9 elevated metro stations, an associated viaduct, and all associated works within 26.1 km-long project scope, also located in India. The latter one, Case 3 differs from the others with its scope and location, as it is from a bridge & causeway project, which is a sub-project of a mega project of 28.000 square kilometers site area, located in Saudi Arabia. It covers detailed design, procurement of materials, fabrication, transportation, installation and commissioning of 3 bridges connecting mainland to an island and associated causeways. The project being a unit of a group of projects brings additional features to this EIR. All three cases and their characteristics are tabulated in Table 1.

Table 1. Sample EIR Cases.

Case	Case 1	Case 2	Case 3
Scope	Design & Build	Build	Design & Build
Details	Civil, Architectural, and E&M works of 7 elevated stations, detailed planning of proposed 5 underground stations of RRTS network	Construction of 9 elevated metro stations, associated viaduct and all associated works	Civil works of 3 bridges and causeways
Length	106.5 km length	26.1 km length	N/S
Location	India	India	Saudi Arabia

Table 2 outlines the contents of all sample EIR documents. Green color represents aspects that are common in all cases while blue color refers to the ones that are discussed in two EIRs, black color demonstrates the aspects that are included in a single EIR and red color highlights unique features corresponding to characteristics of the project. All cases have an introductory section explaining the purpose of the document itself, BIM goals of the projects and other case specific subjects. Since Case 3 is a part of a mega project, there are sections defining the mega project characteristics and requirements such as the overall goal of BIM adoption, main project breakdown, Employer's BIM management organization to oversee information management of all projects. Although, each sub-project will have their own BIM Execution Plan (BEP), they will be in full compliance with the inclusive EIR.

All three cases have clear definitions of technical aspects such as BIM uses, LOD principles, coordinates, data exchange formats and software platforms. Case 3 have BIM uses that are specified as Employer mandated BIM uses which apply to all projects and also project specific BIM uses. LOD definitions and requirements are defined clearly for each project phase in all cases.

Applicable standards, roles and responsibilities, document naming convention, model structure, quality assurance processes, clash detection, and security & confidentiality are managerial aspects that are common in all cases. Case 1 and 3 have not specified model and coordination management issues such as model breakdown or clash detection rules explicitly, yet they have identified these issues to be defined in BEPs of the projects. As Case 2 refers to only the construction phase of the project unlike others, it has distinct definitions of development of construction, as-built, asset information models and clash detection procedures such as the content of the reports, sets to be used and clash classification system to be adopted. Case 1 specifies the details of Common Data Environment (CDE) to be detailed in BEP while Case 3 assigns the platform to be used and defines the review and coordination issue tracking procedures that will be followed.

Case 1 is the only EIR that discusses competence assessment and knowledge and skills requirements of design consultants and contractors while others only include BIM deliverables within commercial aspects.

Table 2. Contents of Sample EIR Cases.

<table>
<tr><th></th><th>Case 1</th><th>Case 2</th><th>Case 3</th></tr>
<tr><td>Introduction</td><td>-Purpose of Document
-BIM Goals / Objectives</td><td>-Purpose of Document
-BEP
-BIM Objectives
-Provisions of Modelling Services with Other Contractors
-Coordinated Model Including Works of All Contractors</td><td>-Purpose of Document
-Main Project BIM Goals
-Utilization of Project Information Model (PIM)
-Main Project Breakdown
-Employer's BIM management organization</td></tr>
<tr><td>Technical</td><td>-BIM Uses
-LOD Principles & Requirements
-Asset Information Requirements (AIR)
-Data Exchange Protocols
-Asset Information Model (AIM)
-Coordinates
-Model Production and Delivery Table (MPDT)
-2D Graphical Output
-Training
-Software Platforms
-System Performance</td><td>-Potential BIM Uses
-BIM Specification and LOD Definitions
-File Formats for Exchange and Submittal
-Asset Information Requirements (AIR)
-Coordinates
-Model Production and Delivery Table (MPDT)
-Software Platforms
-System Performance
-Hardware</td><td>-Employer Mandated BIM Uses
-Project Specific BIM Uses Requirements
-LOI Need-Standard and Approach
-File Formats
-Coordinates
-Software Platforms
-Survey Strategy</td></tr>
<tr><td>Managerial</td><td>-Applicable Standards
-Roles and Responsibilities
-Document Naming Protocol
-Security
-Process Mapping
-Common Data Environment (CDE)
-Design & Services Coordination
-Geometric Quality Assurance & Quality Control
-Data Segregation
-BIM Validation Prior To Model Sharing
-Exclusions in Model</td><td>-Applicable Standards
-Roles and responsibilities
- File Naming and Folder Naming Convention
-Limitation and constraints on Data Entries in Model
-Integration with Maintenance Management System
-Model Delivery
-Ownership and Rights to BIM Deliverables (Construction Model/As-Built Model/Asset Information Model)
-BIM Modelling Requirements
-Modelling Guidelines for BIM Elements
-Model Quality Assurance
-Clash Detection Management
-Clash Detection Reports</td><td>-Applicable Standards
-Roles & Responsibilities
-Key Information Management Employer Contacts
-Model Delivery
-Model Breakdown
-Model, File And Object Naming Convention
-Model Ownership
-Model Requirements
-Common Data Environment
-CDE Procedure Guideline
-BIM360 Design Workflow Submissions
-Employer CDE Procedure
-Security & Confidentiality
-Model Review Workshop
-Coordination Issue Tracking
-Clash Detection & Avoidance
-Viewing And Navigating The Federated Model
-Quality Assurance Processes</td></tr>
<tr><td>Commercial</td><td>-Competence
-Knowledge and Skill Requirements</td><td>-BIM Deliverables</td><td>-BIM Deliverables</td></tr>
</table>

EIR Development for Metro Projects in Turkey

All three cases of EIR were included in the procurement documents of respective projects that were shared with the prospective design consultants or contractors. Considering the significant amount of ongoing metro projects in Turkey, it is quite possible that an Employer has several tenders progressing at the same time. In order to avoid any confusion, it would be beneficial for EIR to have an introduction section that includes the project information, associated projects, purpose of the document, BIM objectives and Employer's BIM management organization and contact list, if applicable.

As EIR serves as the reference document throughout the project lifecycle, the content, delivery, and management of project-related information should be clearly identified within technical, managerial and commercial requirements.

Technical, Managerial, and Commercial Requirements

In order to optimize BIM implementation in the project, EIR should clearly define Employer targeted BIM uses. Case 1 specifies BIM uses per preliminary design, definitive design, construction documentation, pre-construction, construction, and project handover phases with associated responsible party such as Design Consultant or Contractor and including file exchange formats while Case 2 briefly summarizes potential BIM uses. For a metro project Employer who deals with several projects, BIM uses definition of Case 3 which includes both mandated and project specific uses would be recommended, since mandatory BIM uses such as Design Authoring and 3D Coordination would be required in all projects, while project specific BIM uses such as Lightning Analysis or Disaster Planning would be required depending on the project characteristics.

Levels of detail expected from models at different project phases should be explained in detail to ensure that the prospective consultants/contractors fully comprehend the context of modelling studies involved in the project. Expressing clear and strict LOD definitions within EIR would enable Employer to have models from different projects that are comparable in terms of detail and could be combined in a federated master model.

Case 1 identifies software platforms that Employer uses and their input formats, emphasizing that the consultants/contractors need to ensure their respective software platforms can deliver output in the given format. Similarly, Case 2 specifies the requirements that software solutions should satisfy such as being IFC certified, while Case 3 directly recommends software applications and versions oriented for specific tasks such as 3D coordination or construction simulation. Recommendation of software solutions of Employer's preference would be beneficial for standardization of outputs from different projects. EIR should also specify submission file formats besides the native file such as .ifc, .3dpdf, and COBie asset data, if requested. Furthermore, in order to ensure all stakeholders could access and use information from models, system performance precautions such as maximum file size should be defined.

Another technical aspect that should be defined in EIR is related to the restrictions required to maintain accurate coordinates. In order to ensure models' integration with GIS based applications, International Terrestrial Reference System (ITRF) to be used and required modelling practices such as using "shared coordinates" system should be defined.

EIR must provide a list of applicable BIM standards and guidelines within managerial aspects that are required to be adopted by consultants/contractors in order to establish consistent collaboration and information delivery procedures. Roles and responsibilities which are discussed in all three cases, have critical role in ensuring consultant/contractor is aware of what is expected from their BIM team and enabling them to build the appropriate team. For instance, Case 3 requires BIM Staffing Plan that identifies responsible people per discipline, section or phase of the project together with their duration and extent of BIM experience, and description of prior BIM projects.

All phases of a metro project, including operation and maintenance, are important for the overall life cycle of the built assets. As mentioned earlier, Employer being in charge of design and construction works but not being the operator of the facility is a common fact for metro projects in Turkey. Identifying Computer-Aided Facilities Management (CAFM) systems that will be used and their data requirements within EIR would be quite beneficial in enhancing end user integration to BIM processes of earlier phases of the project. Case 2 can be taken as an example as it specifies equipment data necessary for operation and maintenance (O&M) that must be defined for elements of Asset Information Model such as model number, installation date, item tracking number, references to O&M manuals, warranty data, etc.

To ensure the model information remains consistent and intact, EIR should define model division strategy, model and object naming procedures, and model quality assurance criteria. Data segregation refers to division of models by zones and disciplines to facilitate discipline specific deliverables, inter-disciplinary collaboration and operational efficiency in large scale projects. Although it depends on the scale of the project, Employer can set the general framework of model division strategy to be adopted in all projects. All projects having the same model and object naming convention would also be beneficial for document management standardization. Model coordination, quality control, and clash detection processes are remaining model – based managerial aspects that should be defined in EIR. Requirements such as maximum file size, clearing the file from unnecessary objects, views and schedules, regulating work sets can be specified to maintain file integrity and increase efficiency. Clash detection processes which will be described in detail in BEP should be discussed in EIR to give an insight to prospective consultant/contractor on expected coordination studies. As Case 2 is a project that only covers construction works, it provides detailed clash detection procedures to be followed in order to eliminate conflicts that might appear on site. It even provides lists of clashes to be reported, such as conduits and cable trays that clash through floor slabs.

Common Data Environment is a key aspect of any project that involves BIM use. Case 3 explains Employer's approach to information management through CDE in detail, involving a list of CDE platforms that Employer uses at different phases of the project. If the platform to be used has already been assigned, submission and review workflows, utilization of the features of the platform such as coordination issue tracking could be described for determination of information management procedures.

Being included in procurement documents, EIR serves as an informative document for tenderers that gives insight on the scope of BIM processes within the project. As in Case 2 and 3, EIR should provide a list of BIM deliverables within commercial requirements such as improved design review process using AR/VR technology, construction sequencing & simulation, integration with GIS platform, building systems analysis, energy analysis, lightning analysis, disaster planning or any other specific requirements. In order to ensure successful execution of BIM processes and procedures, BIM specific competence assessment could be defined in EIR as in Case 1.

Conclusion

EIR plays an essential role in a BIM based project as it provides clear definitions of Employer's needs, information delivery procedures, and BIM related processes at the very beginning of the project. Wairi (2018) states an effective EIR can improve productivity in terms of budget and duration, the quality of the built facility and enable effective management and operation of the built asset at lower cost through contribution to output information obtained by Employer at the end of the project.

Despite the significant number of ongoing metro projects in Turkey, which are all BIM-mandated projects, Employers have not yet developed an EIR to ensure end user's information requirements are clearly defined at procurement phase. This study aimed to determine what should be included in EIR for metro projects in Turkey. First, research motivation had been identified as the characteristics and differing outputs of metro projects in Turkey due to lack of standardization with the aim of establishing the necessities of EIR development. Then a literature review had been conducted and limited number of studies have been found focusing on creating EIR except some templates and a general framework provided by international standard ISO 19650. Therefore, EIR documents from three infrastructure projects from India and Saudi Arabia that have different scopes and contexts have been analyzed to determine possible contents of EIR for metro projects in Turkey. As ISO 19650 describes EIR contents within three main headings of technical, managerial, and commercial requirements, sample EIR cases were examined and compared based on these requirement categories. Common aspects that were included in all cases and case specific requirements were discussed to provide a framework for the aspects that should be included in EIR of metro projects in Turkey.

The differences between the scopes of sample EIRs verified that project characteristics define the content of the EIR. One EIR includes comprehensive discussions about an aspect, whereas the other contents with a brief description and refers to the topic as to be detailed in BEP such as CDE description in Case 1 and 3. While Case 1 briefly mentions CDE and directs to BEP for details, Case 3 specifies the platform to be used, review and coordination issue tracking procedures to be followed within the platform as they had already been determined within the organization. Another example is the explicit definition of clash detection procedures by Case 2, which is the only EIR that focuses only on the construction phase of the project, such as the clash classification system and report contents while others leave these issues to be defined in BEPs of their projects. Therefore, Employer should draw the boundaries of EIR and BEP by clear definitions of BEP content depending on project requirements.

Considering an Employer has several metro projects in İstanbul, for development of a comprehensive EIR that aims to standardize BIM related processes for all projects, Case 3 is the most suitable EIR to be taken as a reference as it includes both Employer mandated and project specific requirements. Upcoming studies for the corresponding EIR development should include customization of the needs specific to local conditions and interpretation of references within the context of local practices. Future works could also include interviews with Employers of metro projects and end users of built facilities to emphasize industry needs, problems encountered due to lack of EIR and further elaboration of EIR contents.

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Internet of Things (IoT) Applications in Construction Industry: A Construction Project Management Perspective

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Abstract

The labor intensive and fragmented nature of the construction industry requires tedious repetitive tasks to be performed at construction sites for monitoring and controlling construction projects. Efficient use of time and resources are key to increase productivity and decrease costs, which will then increase profit margins of construction companies in return. Not only the construction phase that requires focus in this manner, but also the other phases of project life-cycle such as planning, design, and operations/facility management deserve better handling to achieve project goals. Internet of things (IoT) proposes an approach that provides connectivity between things within a network by using emerging technologies. Leveraging the use of IoT might produce reliable, real-time, and accessible data for potential applications in order to improve the quality and productivity of activities in the construction industry while eliminating the fragmentation problems and reducing the discontinuities between tasks. In this study, application areas and potential benefits of IoT implementations in the construction industry that can transform its poor current practice into a better vision will be discussed. Barriers and possible challenges of adopting IoT applications would be mentioned, as well. A review of the literature is made to discuss the application areas of IoT specifically in construction project management domain including site monitoring, task management, asset tracking and monitoring, and safety monitoring, with their intended objectives and the technologies used in these associated applications.

Keywords: *construction informatics, construction project management, information and communication technology, internet of things.*

Introduction

Recent advances in the development of state-of-the-art emerging technologies provide widespread and relatively much more accessible solutions to engineering problems, nowadays. Decreasing costs of technology-based implementations and availability of extensive wireless networking technologies increase the availability of potential digital transformation applications in different fields of private industry. This transformation also has a significant impact in the research and application domain of the construction industry which led to valuable studies and implementations of technological solutions.

The labor intensive and fragmented nature of the construction industry (Pheng et al., 2016) requires tedious repetitive tasks to be performed at construction sites for monitoring and controlling construction projects. Efficient use of time and resources are also key to productivity improvement and cost reduction, which will increase profit margins of construction companies in return. It is not just the construction phase that requires focus in this manner, other phases of project life-cycle such as planning, design, and operations/facility management also deserve better handling to achieve project goals.

Internet of things (IoT) proposes an approach that provides connectivity between things within a network by using emerging technologies that are affordable. Use of these technologies such as wireless sensor networks, cloud computing applications, computer vision applications at construction sites might provide accurate information to interested parties when required and hence overcome the fragmentation issue. By the integration of IoT implementations into processes undertaken at construction sites, promising outcomes such as reliable, real-time, and accessible data might be produced for potential applications in order to improve the quality and productivity of activities in the construction industry.

The number of IoT applications at construction sites are still at its infancy and might require much effort to exploit the potentials. The aim of this study is to give examples and discuss the application areas and potential benefits of IoT implementations in the construction industry that can transform its poor current practice into a better vision. The barriers and possible challenges of adopting IoT applications will also be mentioned in general terms. In the upcoming section, a background information is given including the definition of IoT, explanation of its architecture, and its enabling technologies. In another section, potential application areas of IoT in construction project management domain will be discussed. Finally, important remarks with benefits of IoT applications in construction project management will be made in the conclusions section.

Background Research on IoT

Internet of things (IoT) is a phenomenon that proposes an approach for connecting everything in order to provide communication throughout an established network. IoT is defined as an integrated framework which is enabling cross-platform innovative applications to share information through connected sensors and actuators (Gubbi et al., 2013) where sensors abstract data from the physical layer and wireless networks provide connection between things. Advances in the technology domain has greatly simplified the abstraction of digital data from real world entities in the physical layer with using reachable sensors and wireless networking infrastructures that provide reliable real-time data processing capabilities. IoT aims to connect anything from any place at any time within an integrated framework to allow high level applications for end-users from any profession by utilizing sensing, analytics, and visualization tools.

In order to provide a further understanding about the structure of IoT applications, a generic architecture for IoT is provided in Figure 1 which is composed of five layers. The very first layer at the bottom corresponds to *perception layer* where sensing instruments are used to abstract data from the physical world. The perception of different phenomena can be digitalized in this layer such as reading temperature, humidity, detecting proximity, and measuring acceleration. In the second *network layer*, a seamless transmission of the digital data abstracted from the previous layer is sent via wireless technologies like WiFi, ZigBee, Bluetooth, etc. to the next one. Third layer is *middleware layer* where the processing and storage functions are done in accordance with their type and service requirements. In the fourth layer of this architecture, which is the *application layer*, the end-user is served with the applications that use the derived data from the first layer in order to provide meaningful information which may further ease the life of end-users. The last *business layer* is an optional one that is used when the corresponding IoT implementation is serving for business holders. The 'information' obtained from the abstracted data is visualized at the dashboards in this layer for feeding companies with intended output in accordance with their business models.

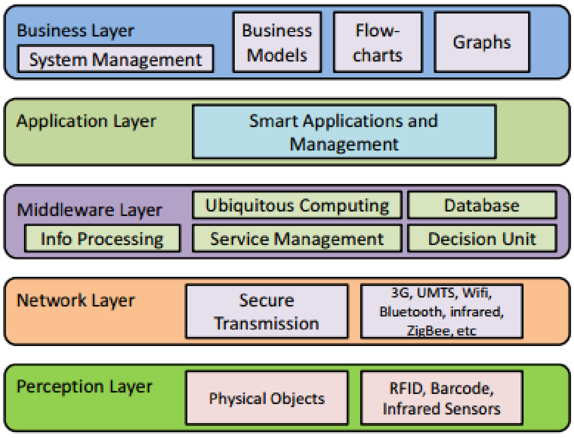

Figure 1: Generic IoT architecture (Khan et al, 2012).

The above figure represents a generic architecture according to the needs of the system that is required to be implemented. Customization of the IoT architecture in accordance with the intended use is also possible and the layering can be changed correspondingly. For different architectures with comparisons the reader is kindly referred to Al-Fuqaha et al. (2015).

There are several enabling technologies that are used in the implementation of IoT applications which enable seamless flow through above stated layers in the architecture. These can be radio frequency identification (RFID) to tag and track entities, wireless sensor networks (WSN) which presents an infrastructure for the intended implementation, and other relevant components such as sensors, communication units, processing units, etc., cloud computing (CC) services and platforms, and tools for visualization of the generated output such as mobile devices, tablets, etc. A more comprehensive illustration of these technologies can be seen in Figure 2.

Using these technologies and the architecture above, IoT solutions can be applied to different areas. Some of these applications can be exemplified as smart/intelligent buildings/cities, smart transportation and logistics (Vermesan & Friess, 2014), patient monitoring, monitoring eating disorders, and in-door navigation system for blind and visually impaired people (Al-Fuqaha et al., 2015).

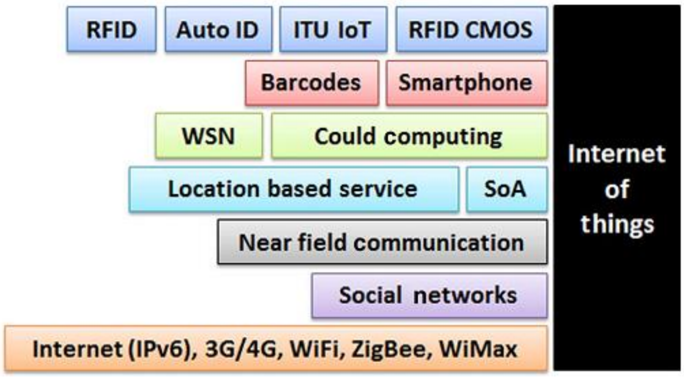

Figure 2: Relevant technologies for IoT implementations (Xu et al., 2014).

It should be noted that flawless implementation of the IoT applications are not possible yet. Moreover, there are also barriers and challenging issues in realizing these applications. While some of these challenges might be reliability, scalability, interoperability, mobility and performance issues (Al-Fuqaha et al., 2015), most prevalent ones are privacy and security of processes and data, while there are potential threats and system vulnerabilities to these risks (Čolaković & Hadžialić, 2018). For a deeper understanding of security and privacy issues and their solutions readers are kindly referred to (Lin et al., 2017).

Potential Application Areas of IoT in Construction Project Management

IoT has a potential to transform our working habitat into smart environments which can bring efficiency and productivity to our processes, and economic benefits to our projects, as well. Utilization of the cutting-edge/emerging technologies at construction sites would enable increase in construction performance and productivity, efficient use of resources, transparency in processes, better communication and coordination with a collaborative workspace, and so on. Specifically, adoption of IoT applications in construction industry can augment project management functions such as safety management, progress monitoring, time and resources management, and quality assurance at construction sites.

Traceability of resources at construction sites and reliable status reporting become much easier while we are having fast booming advancements in the development of technology side that can provide real-time wireless connectivity and communication. Decreasing costs of these emerging technologies may provide higher implementation rates at construction sites, thus, it might mean an increase in the capability of real-time tracking and monitoring of construction activities and decrease in the costs of corresponding tasks at construction sites.

In traditional way, resources are being surveyed and records are collected at construction sites manually with doing periodical visits by responsible site personnel. For example, safety monitoring at construction sites is done through site surveys with manual visual inspection to detect unsafe behavior of workers and anomaly situations at construction sites. Instead, these efforts might be eliminated with the adoption of IoT applications that can produce reliable and real-time information at construction sites. Potential benefits of IoT applications can be exploited in construction project management domain by searching effective use cases. Some of these applications have been exemplified in the table below (Table 1. Potential IoT implementation examples in construction management.

Table 1. Potential IoT implementation examples in construction management.

Management Area	IoT implementation example	Author
Progress Monitoring / Task Management	Automated visual management of construction activities; Automation of routine tasks like surveying and daily record keeping by utilizing sensor networks and computer vision techniques	Kim et al. (2013)
Resources Management	Implementing virtual asset and inventory management systems	Zhong et al. (2017)
Resources Management / Time Management / Progress Monitoring	Tracking equipment at the site to infer efficient operating hours of the asset and to track related activities	Li et al. (2018)
Quality Management	Tracking of equipment to do predictive maintenance analysis	Yuan et al. (2016)
Safety Management	Reliable and real-time safety monitoring of workers	Mneymneh et al. (2019); Wuet al. (2019); Kanan et al. (2018); Kim et al. (2017)

Considering these application areas, several examples from literature regarding the implementations of IoT at construction project management domain are reviewed and these will be given in the remaining part of this section. These studies are a part of the management activities that are conducted at construction sites and selected based on their overall potential impact and contribution to construction project management domain, subjectively.

One important area of IoT implementation in construction project management domain is site monitoring and task management by the use of reliable and real-time information sharing through utilization of enabling technologies of IoT. Kim et al. (2013) utilized mobile computing technology for on-site construction management in order to offer effectiveness in related tasks. The system they developed uses smartphones and peripheral technology such as wireless communication, database systems, and augmented reality (AR) to enhance and augment task management, site monitoring, and real-time information sharing at construction sites. The developed system allows managers to assign roles to their personnel and allocate tasks through the application on mobile devices.

These tasks can be pinned and visualized on digital maps using AR (see Figure 3) to couple the workers to be assigned for the intended tasks and check their status. The system also allows sharing the project information such as drawings among participants collaboratively in real-time. With the developed system, users can access a database for site images that are captured from the CCTV cameras at site and stored for professionals to monitor the current status of the site using their mobile devices.

Figure 3: On-site construction management task visualization (Kim et al. 2013).

Another area of implementation is tracking of assets and resources by leveraging IoT applications at construction sites in order to provide effective and efficient management. Zhong et al. (2017) investigated the use of IoT in prefabrication industry through production, logistics, and assembly phases of prefabricated items integrating BIM into the technology used for this study. In order to enhance the traceability and visibility to have a real-time capturing of the current project status, all corresponding resources for the activities held are tagged by RFID tags. The developed system includes an integration of IoT and building information modeling (BIM) platforms to achieve the intended objective and provide end users with the real-time information throughout the processes being handled.

With the use of this developed system, the supervision of prefabrication works from planning to assembly can be improved since the flow of critical information related to the products and processes are captured and shared throughout all phases. This, of course, can assist managers during their decision-making processes regarding the operations since they will be able to have much better control during monitoring of the project outputs in terms of cost, schedule, and quality.

In another study, Li et al. (2018) proposed a similar IoT enabled BIM based system that allows real-time visibility and traceability of prefabricated assembly products on construction sites facilitating RFID technology for tagging and cloud computing for uploading and sharing information. The functional flow of the proposed study starts with *staff registration* to introduce them to the system, then this follows *order management* module to make necessary confirmations and modifications on orders, *assembly confirmation and quality checking* module to check delivery details of precast components by on-site foreman, *real-time progress monitoring* module to monitor the resource usage of the processes, progress visualization module to visualize and share the progress on a BIM model imported to the web based platform of the system, and finally, *error alert* module that enables the users of the system to see whether the component is assembled into its right position by checking the actual assembled global positioning system (GPS) coordinates and the planned place. An overview of the workflow of proposed system can be seen in Figure 4.

Figure 4: Overview of the proposed workflow (Li et al., 2018).

Another useful study that can be given as an example to asset monitoring is conducted by Yuan et al. (2016) which proposes a solution that is developed to monitor the condition and performance of temporary structures at construction sites using cyber-physical systems. The developed system integrated several sensors (i.e., load cell, accelerometer, switch sensor, displacement sensor) into a scaffolding structure to measure and collect data from the physical structure and to send this information about the visualization of the current status on a virtual model which can be monitored by mobile devices. The system communicates with end user through cloud services where the user can get notifications about the conditions and warning situations of the monitored temporary structure. The sensor implemented physical structure can be seen in Figure 5.

One of the major application areas for IoT implementations in construction project management domain is safety management of projects through the utilization of wireless sensor networks, wearable devices, and computer vision techniques. There are abundant opportunities to overcome safety related management issues at construction sites such as by identification and detection of hazardous situations and places, tracking of resources to prevent accidents and preventing entry to unauthorized site zones, etc.

One of the main concerns in safety management practice is to provide compliance with the safety regulations at construction sites. An example for this can be given as hardhat use of the workers. Researchers like Mneymneh et al. (2019) and Wu et al. (2019) have studied computer vision techniques for creating an intelligent monitoring system that detects and identifies whether personnel at construction sites wears their hardhats. An example application is shown in Figure 6.

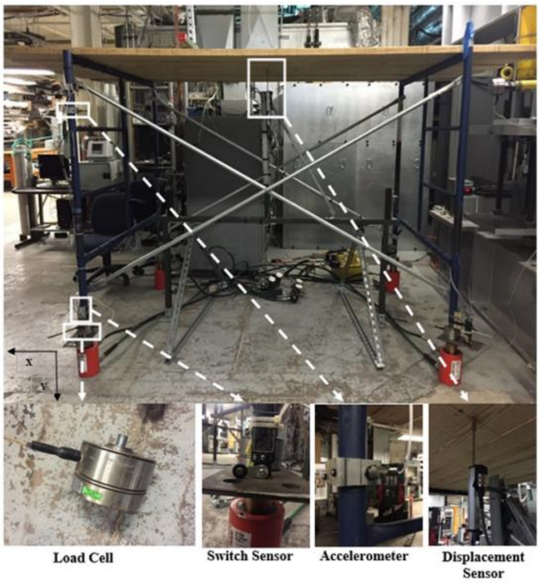

Figure 5: Sensors deployed on physical structure (Yuan et al., 2016).

Figure 6: Test examples from hardhat detection (Mneymneh et al., 2019).

Another important safety related issue that requires more attention is being struck by objects, equipment and vehicles at construction sites. To overcome such an issue, Kanan et al. (2018) designed a solution that utilizes IoT in order to monitor the locations of resources and then alarms in real-time when hazardous situations occur. In the proposed solution RFID sensors and antennas are used to detect the proximity of the resources to each other and the overall system is connected to a backend platform that sends real-time notification when an alarm occurs. It can be seen in Figure 7 that the system is designed to generate warnings when the proximity threshold is exceeded.

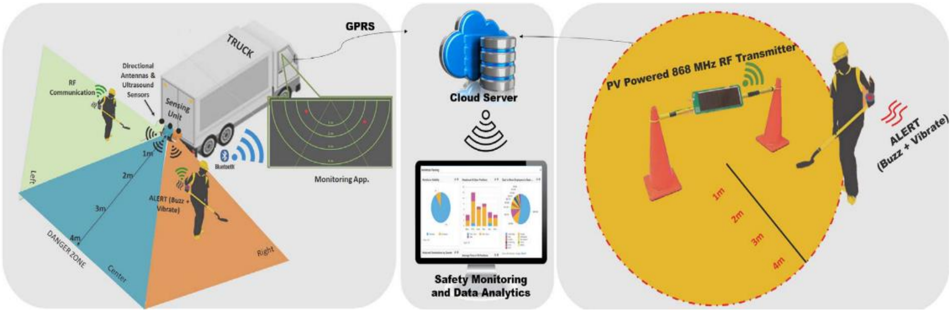

Figure 7: Proposed proximity detection and warning architecture (Kanan et al., 2018).

A research conducted by Kim et al. (2017) proposed a method that uses vision based hazard avoidance system. The developed solution works on the image captured at construction sites to identify hazardous situations and transfers it to the wearable device (i.e., Google Glass) that is being used by the personnel at site. The captured images are processed instantaneously and several safety parameters such as hazard distance and safety level information are calculated to be shared with the wearable device. Conceptually, this information is being shown by AR technology at the wearable glass of the end user. The overall flow of the proposed system is shown in Figure 8, as well.

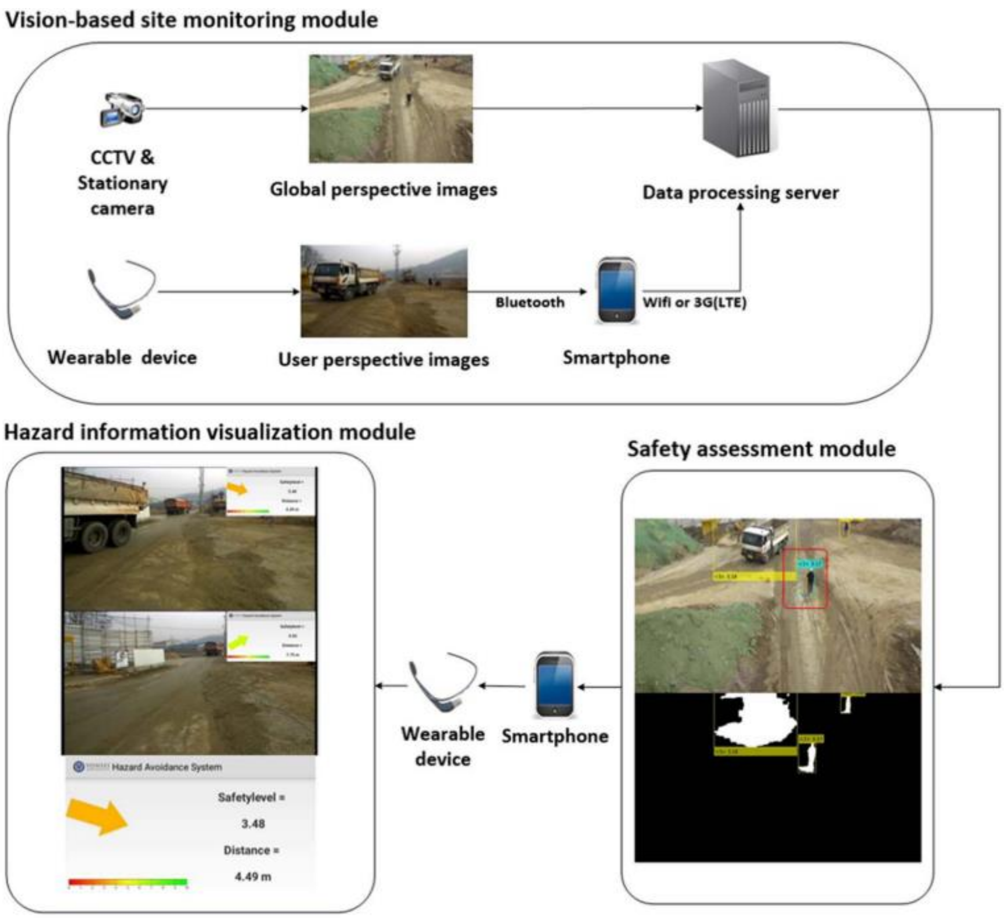

Figure 8: Vision based hazard avoidance system architecture (Kim et al., 2017).

Discussion and Conclusion

Advances in technological development and reduced costs of related solutions have caused IoT applications spread everywhere. The IoT vision that aims at connecting things at anywhere at any time would help the industry increase the efficient use of resources by allowing real-time monitoring and visualization, and at the same time generating reliable information from the executed processes. The construction industry has an equal opportunity with other industries to benefit from the potential advantages of IoT vision.

As stated in the examples above, IoT can lead to many promising applications in the field of construction project management. As it connects resources at construction sites and provides real-time data through implemented networks, the construction business might get benefit from it by automating its processes using the output of these applications. Generated data can be used for the monitoring of activities and reporting their statuses on management dashboards that can contain *key performance indicators* and critical information about the jobs undertaken at the sites. These applications can also be integrated into systems that feed real-time and reliable information for *business intelligence* tools used to develop more realistic business models. The use of these systems might maintain sustainability in actions and applications, and thus can create competitive advantage in the marketplace for construction companies.

A review of IoT has been made by giving its definition, exemplifying architecture types, defining related technologies with general use cases, and also, typical barriers and challenges are presented. After giving a background information about IoT, potential use cases and application areas in construction industry are shared with the reader. Proposing several example areas of implementation for construction industry, implementation examples from the literature examined in the field of construction project management are presented. Examples of IoT implementations including site monitoring, task management, asset tracking and monitoring, and safety monitoring applications are given along with their intended objectives and technologies used.

IoT is regarded as a disruptive technology that is expected to have a very huge impact with its applications among all industries and in our social lives. However, several limitations such as applicability of sensor networks to the construction areas, adoption of the new technology and acceptance level from the workers' side should be considered regarding the implementations of IOT applications in the construction industry. In this study, a better understanding of IoT phenomenon and potential application areas has been tried to be provided. The application areas and studies have been selected subjectively and are not limited to what is presented here. The construction industry can take advantage of what IoT has to offer to this world. It is gaining importance day-by-day and with emerging technologies it might create many other opportunities for the construction industry in the near future.

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Sustainable Construction Practices - A comparative Assessment of Requirements in Certification Systems in Europe, Russia, Turkey and the U.S.

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Abstract

Due to a great amount of energy consumption, adverse impact on the environment, and ineffective use of resources in construction industry; the idea of sustainable construction is recognized in all over the world. Leadership in Energy and Environmental Design (LEED) is one of the most widely used green building certification systems. Energy and Atmosphere category contributes to the maximum possible points in the LEED certification system at most. In this research, LEED certified buildings in Europe, Russia, Turkey and the U.S. were compared in terms of Energy and Atmosphere. For the overall understanding of sustainable construction practices, buildings in Russia and Turkey were compared according to all main categories. The findings suggest that buildings in Russia have a significant lack of ensuring On-site Renewable Energy credit category, compared to Europe, Turkey and the U.S. Apart from Turkey, which is at worst in terms of Green Power credit category, all three region have achieved less points in On-site Renewable Energy. In terms of all main credit category comparison, the findings indicate that the need for Material and Resource, and Energy and Atmosphere are of paramount significance in both Russia and Turkey.

Keywords: *energy and atmosphere, energy consumption, green buildings, LEED, sustainable construction.*

Introduction

The buildings are blamed to be responsible for nearly 40% of all energy consumption in the world (Gurgun et al. 2016). Besides, building sector accounts for nearly 30% of the share of CO_2 emissions (Sabapathy et al. 2010). Since buildings consume a significant amount of energy as well as having adverse impact on environment, green building certification systems are becoming more common in construction industry in all around the world (Gurgun & Arditi 2018). Buildings are credited according to their sustainable development attributes related to transportation, material use and demolition, indoor environmental quality, energy consumption, and water efficiency in such certification systems.

Many countries have developed their standards as a certification system such as LEED in the United States; BREEAM in the United Kingdom; Minergie in Switzerland; CASBEE in Japan. However, since LEED system is the most frequently used certification system in most of the countries (Gurgun 2017), this study covers only LEED certified buildings.

The Leadership in Energy and Environmental Design (LEED) has been widely used as a green building certification system over the last two decades in all over the world (Gurgun & Arditi 2018). Several authors analyzed LEED certified buildings to explore best design strategies. Ma and Cheng, for instance analyzed 1000 LEED-NC v3 certified buildings to explore achievement of individual credits. Sullivan and Oates examined 53 LEED certified buildings in v2.0, 2.1 and 2.2 to specify achieved credit patterns. Cheng and Ma analyzed 1381 LEED certified buildings to identify the interrelationships between credits. However, the literature is lack of comparative studies based on country.

Buildings may achieve four different certificates in LEED as: Certified (40-49 credits), Silver (50-59 credits), Gold (60-79 credits), and Platinum (80+ credits). The maximum score that can be achieved as the sum of all credits achieved from different categories is 110 in LEED. There are different versions of LEED developed after its first introduce. In addition, there are different categories and prerequisites for new construction, core and shell, schools, retail, data centers, warehouse and distribution centers, hospitality, and healthcare facilities. The comparison of LEED v3 and LEED v4 for main credit categories in terms of new construction is shown in Table 1.

Table 1. Comparison of credits categories in LEED new construction v3 and v4.

LEED v3	ID	Max Credit	LEED v4	ID	Max Credit
Sustainable Sites	SS	26	Sustainable Sites	SS	10
Water Efficiency	WE	10	Water Efficiency	WE	11
Energy and Atmosphere	EA	35	Energy and Atmosphere	EA	33
Material and Resources	MR	14	Material and Resources	MR	13
Indoor Environmental Quality	IEQ	15	Indoor Environmental Quality	IEQ	16
Innovation	INN	6	Innovation	INN	6
Regional Priority Credits	RPC	4	Regional Priority Credits	RPC	4
			Location and Transportation	LT	16
			Integrative Process	IP	1

Energy and atmosphere (EA) is the category that buildings can gain at most credits in both v3 and v4. Therefore EA category was concentrated on deeply in this study. The prerequisites for LEED v3 and v4 new construction rating system are shown in Table 2. Main difference between versions is that, one prerequisite namely “Building-level energy metering” was added at v4. Table 3 indicates the differences of the credits in energy and atmosphere category for new construction projects.

Despite its standard, the rate of the achievement for particular credits varies according to country. Therefore this study attempts to compare achieved credits in the energy and atmosphere category in Europe, Russia, Turkey, and the U.S. The achieved credits of buildings in Russia and Turkey for all categories were also compared.

Table 2. Prerequisites in LEED v3 and v4 new construction rating system.

Version	ID	Prerequisites
LEED v3	EAp1	Fundamental commissioning of building energy systems
	EAp2	Minimum energy performance
	EAp3	Fundamental refrigerant management
LEED v4	EAp1	Fundamental Commissioning and Verification
	EAp2	Minimum Energy Performance
	EAp3	Building-Level Energy Metering
	EAp4	Fundamental Refrigerant Management

Table 3. Energy and atmosphere credit comparisons of v3 and v4 new construction.

ID	Credits in v3	Max	Credits in v4	Max
EA	Energy and Atmosphere (Overall)	35	Energy and Atmosphere (Overall)	33
EA1	Optimized Energy Performance	19	Optimize Energy Performance	18
EA2	On-site Renewable Energy	7	Renewable Energy Production	3
EA3	Enhanced Commissioning	2	Enhanced Commissioning	6
EA4	Enhanced Refrigerant Management	2	Enhanced Refrigerant Management	1
EA5	Measurement and Verification	3	Advanced Energy Metering	1
EA6	Green Power	2	Green Power and Carbon Offsets	2
EA7	Demand Response	0	Demand Response	2

Methodology

This study compares the LEED certified buildings in Europe, Russia, Turkey and the U.S. according to the data from USGBC (2019) with respect to energy and atmosphere credit category. In addition, the LEED certified buildings in Russia and Turkey were also compared with respect to all credit category. According to USGBC (2019), 38 buildings in Russia were awarded with LEED certification. Those which are still in progress were not included in this study for any country. Since there were only 13 buildings that were awarded with LEED v3 new construction, while there was no new construction in v4, all versions and all project types were included in this research just for the Russian case.

Results

The number of buildings according to LEED version, as well as maximum possible credit scores for main credit category, and energy and atmosphere category are illustrated in Table 4. The comparison of the all credit categories between Turkey and Russia, in terms of certified, silver, gold and platinum awarded green buildings is shown in Table 5. The findings indicate that most of the projects were awarded with gold certification level both in Turkey and Russia. In terms of average achievements, awarded projects in Turkey are better with respect to sustainable sites, material and resources, and innovation; while that of Russia are better in terms of water efficacy, energy and atmosphere, indoor environmental quality, and regional priority credits.

Table 4. Awarded LEED versions by Russian green buildings.

Features	LEED-NC 2.2	LEED-CI v3	LEED-NC v3	LEED-EB:OM v3	LEED-CS v3	LEED v4 BD+C: WDC	LEED v4 O+M: EB	LEED v4 BD+C: DC
Number of Buildings	1	8	13	2	11	1	1	1
Main Categories								
SS	14	21	26	26	28	10	10	10
WE	5	11	10	14	10	11	12	11
EA	17	37	35	35	37	33	38	33
MR	13	14	14	10	13	13	8	13
IEQ	15	17	15	15	12	16	17	16
INN	5	6	6	6	6	6	6	6
RPC	0	4	4	4	4	4	4	4
LT	0	0	0	0	0	16	15	1
IPC	0	0	0	2	0	1	0	16
Energy and Atmosphere								
EA1	10	22	19	18	21	18	20	18
EA2	3	0	7	6	4	3	5	3
EA3	1	5	2	6	2	6	7	6
EA4	1	0	2	1	2	1	1	1
EA5	1	5	3	3	6	1	2	1
EA6	1	5	2	1	2	2	0	2
EA7	0	0	0	0	0	2	3	2

Table 5. Achieved credit comparison of Turkey and Russia in terms of all categories.

Country	Reference	Category	ID	Platinum	Gold	Silver	Certified	Total Average
Turkey	Bayhan and Gurgun (2016)	Number of Buildings		11	82	20	9	122
		Average Achievement	SS	88%	77%	73%	59%	76%
			WE	89%	80%	66%	52%	77%
			EA	50%	45%	36%	22%	44%
			MR	50%	39%	33%	35%	39%
			IEQ	76%	51%	30%	33%	49%
			INN	91%	78%	65%	54%	76%
			RPC	98%	91%	76%	67%	88%
Russia	USGBC (2019)	Number of Buildings		2	24	11	1	38
		Average Achievement	SS	76%	72%	58%	73%	68%
			WE	91%	90%	85%	40%	87%
			EA	78%	50%	41%	31%	48%
			MR	46%	25%	18%	36%	24%
			IEQ	69%	60%	38%	47%	54%
			INN	92%	70%	58%	0%	66%
			RPC	100%	98%	82%	75%	93%
			LT	50%	100%	63%		71%
			IPC	100%		33%		50%

Table 6 shows the comparison between, Europe, Turkey, U.S. and Russia in terms of energy and atmosphere credits. The results indicate that most of the projects were awarded silver certification level in Europe and the U.S., unlike Turkey and Russia. The achievement level is at most in enhanced refrigerant management (EA4) for LEED certified projects in Europe, Turkey, and Russia, while that of enhanced commissioning (EA3) in the U.S. In overall, the buildings in Europe have achieved more credits with respect to energy and atmosphere (EA) with the average of 49%, compared to other 3 regions. According to individual credits, buildings in Europe, Turkey, and the U.S. were at best in terms of EA1/EA2, EA4/EA5, EA3/EA6, respectively. There was no credit category that buildings in Russia gained more than any other 3 regions. Even achievement of on-site renewable energy (EA2) credits by Russian construction companies were 9%, indicating huge gap to be filled.

Table 6. Achieved credit comparisons of Europe, Turkey, United States, and Russia in terms of energy and atmosphere.

Region	Certification level	Number of building	Achievement (Percentage)							
			EA	EA1	EA2	EA3	EA4	EA5	EA6	EA7
Europe* (Gurgun et al., 2016)	Platinum (>80)	37	81%	93%	56%	68%	92%	74%	64%	–
	Gold (60-79)	37	50%	64%	7%	50%	81%	56%	30%	–
	Silver (50-59)	105	40%	50%	8%	38%	65%	43%	24%	–
	Certified (40-49)	10	27%	36%	7%	10%	70%	10%	10%	–
	Overall	189	49%	60%	17%	45%	74%	50%	32%	–
Turkey* (Gurgun, 2017)	Platinum (>80)	7	73%	81%	57%	70%	85%	100%	15%	–
	Gold (60-79)	51	43%	44%	13%	45%	90%	87%	20%	–
	Silver (50-59)	13	27%	33%	1%	0%	85%	47%	0%	–
	Certified (40-49)	7	25%	25%	53%	0%	15%	3%	0%	–
	Overall	78	41%	44%	19%	36%	82%	74%	14%	–
U.S.* (Gurgun & Arditi, 2018)	Platinum (>80)	129	85%	94%	80%	74%	59%	66%	78%	–
	Gold (60-79)	624	51%	62%	26%	61%	55%	36%	51%	–
	Silver (50-59)	747	35%	41%	9%	55%	51%	28%	44%	–
	Certified (40-49)	–	–	–	–	–	–	–	–	–
	Overall	1500	46%	54%	22%	59%	53%	35%	50%	–
Russia** (USGBC, 2019)	Platinum (>80)	2	78%	85%	50%	50%	100%	100%	0%	100%
	Gold (60-79)	24	50%	58%	4%	42%	89%	75%	17%	0%
	Silver (50-59)	11	41%	51%	8%	36%	75%	31%	18%	0%
	Certified (40-49)	1	31%	42%	14%	0%	0%	0%	0%	0%
	Overall	38	48%	57%	9%	39%	87%	62%	16%	33%

* Credits for only New Construction with LEED v3
** Credits for all type of projects

Conclusion

This study aimed at analyzing the differences in LEED-NC v3 and v4, as well as comparing the achievement of the credits between Russia and Turkey in terms of all main credit categories, and that of between Russia, Turkey, Europe and the U.S., in terms of EA credits, since in LEED the maximum credits can be achieved in this credit category. The Findings indicate that achievements in credit categories changes significantly depending on the level of certification as well as country or region. Overall, buildings in Russia have gained fewer credits in material and resources, and energy and atmosphere, similar to the buildings in Turkey. Comparison between Turkey, Europe, the U.S., and Russia shows that LEED certified buildings were gained just a few credits in on-site renewable energy category. This study can be used by researchers and practitioners who aim to be awarded LEED certification by improving the poor practices taken in the corresponding regions. For further studies, credits in categories other than energy and atmosphere can be evaluated for an overall understanding of sustainable construction practices.

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The Adoption of Multidimensional Exploration Methodology to the Design-Driven Innovation and Production Practices in AEC Industry

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Abstract

The new horizon for research & development in AEC is directed through an interdisciplinary design-thinking approach. The design paradigms are not only as they were about form and function but now also about efficiency, sustainability, productivity, desirability, feasibility, and viability in current day. As a result of this approach, the term design innovation approves oneself. Correspondingly, emerging technologies such as robotic fabrication & construction tools, self-fabrication & assembly, information and communication technologies, computer science and related software technologies, enable the designers and engineers to push the edges of their creativity, productivity and sensitivity upon global issues. The emergence of those new technologies is defined as digitalism, and both academy and industry have almost totally adapted to this digital-design thinking approach. Consequently, the smooth communication between machines, makers and designers dominates the progression in architecture, science, technology and engineering. However, because of this shift, a research gap has emerged between new academic research and classical industrial production as theory and practice do not overlap anymore. For the adoption of this emergent holistic design-thinking approaches; a new learning methodology has been introduced in academia, under the title of 'Multidimensional Exploration Methodology'.

Keywords: *design driven innovation, digital design-thinking, fabrication & construction tools, interdisciplinary approach, production, prototyping. sustainable development.*

Introduction

In this paper, an adaptation of the *Multidimensional Exploration Methodology* in education to professional practices in the Architecture – Engineering – Construction (AEC) industry is explained. The alternation from digital design-thinking education through design-driven innovation and related production practices is also discussed. The aim of this work is to fill the gap between academy and industry by the usage of this methodology, generating design driven innovations that could potentially expedite the progression on the way of sustainable development and environmental conscious design.

Thanks to the Fourth Industrial Revolution (Schwab, 2017), the technologies for data collection have become more eligible and accessible on the last decade. Multitude of sensors are now cheap and available for personal use. Moreover, the user's daily life has adapted to the usage of intelligent embedded systems, smart phone applications, and cameras now surveil the built environment. Since the usage of smartphones has dictated nearly every action of quotidian life, and the personal dataflow is stored in big data, the information of these actions can be accessible and exists for further usage. As a consequence, and even not obvious, people live in a big data cloud. As the term Interactive Architecture indicates, it *"includes contributions from the worlds of architecture, industrial design, computer programming, engineering, and physical computing"* (Fox & Kemp, 2009). By the collaboration of several disciplines with a contemporary understanding, adapting the architecture to the conscience modern worlds' necessities and user's expectations is now the underlaying design thinking process behind the project. *"The concept of embedded intelligence in buildings is not new; rather what makes it currently possible are cheap digital sensors, access to computer power to handle big streams of data, and the development of software specifically developed for on-going operations and maintenance of buildings"* (Kensek, 2014). Since the technologies of sensing and data collection became eligible and accessible, the design research that corresponds to digital data collection also has augmented. Additionally, by the deepening of accuracy in data, the research quality also shows significant increase. On the other hand, the design of the built environment is almost totally adapted to the Digital-Design Thinking (Oxman, 2006) and related production methodologies. Recently the digital tools for design, modeling and visualization have been extremely advanced and easy to use, empowering the designers for data-led, environmentally responsible decision-making. The built environment also has become smarter by the help of IOT and data gathering devices. As a result, there is a continuous development in smart home technology that translates subsequently into smart cities development. Correspondingly, the built environment is being regenerated by the users and society, rather than by only designers. The new technologies for construction and design, take reference from the real-time information and are able to create reactive environments with live interactions.

Multidimensional Exploration Methodology

The *Multidimensional Exploration Methodology* is a theory that the authors are currently working upon to develop further. *"Academic knowledge always needs to take earlier knowledge into consideration, and to build upon a similar epistemology… From an academic perspective, this plurality in discourses within designedly ways of thinking is not a sign of weakness but rather a sign of maturity"* (Johansson-Sköldberg, Woodilla, & Çetinkaya, 2013). The method is based on three classical learning methods as *Cognitive Learning Theory* (Greenwald, 1968); (Bloom & Krathwohl, 1984), *Kolb's' Experiential Learning Methodology* (Kolb, 1984) ; (Kolb, Boyatzis, & Mainemelis, 1999) and Design Science Research Methodology (Van Aken, 2005); (Henver, March, Park, & Ram, 2004). The main objective of the new hybrid learning method is to rebuild the cognitive activities of the learner aligned with the new generation architectural design requirements. This method has 4 main phases:

- Objectives' Identification
- Perform Risk Analysis
- Develop and Test
- Review and Evaluate.

In Figure 1, the spiral graph that describes the methodology can be seen. The spiral model is crucial on this method because of the inclusion of risk analyzed learning loops, creating a self-evaluation and exploration process until cognitive activities are transformed into new knowledge. Moreover, thanks to the spiral different phases, the knowledge is not learned from a unique source, yet, thanks to the experiential learning techniques, the learner generates it as is progresses down the design path.

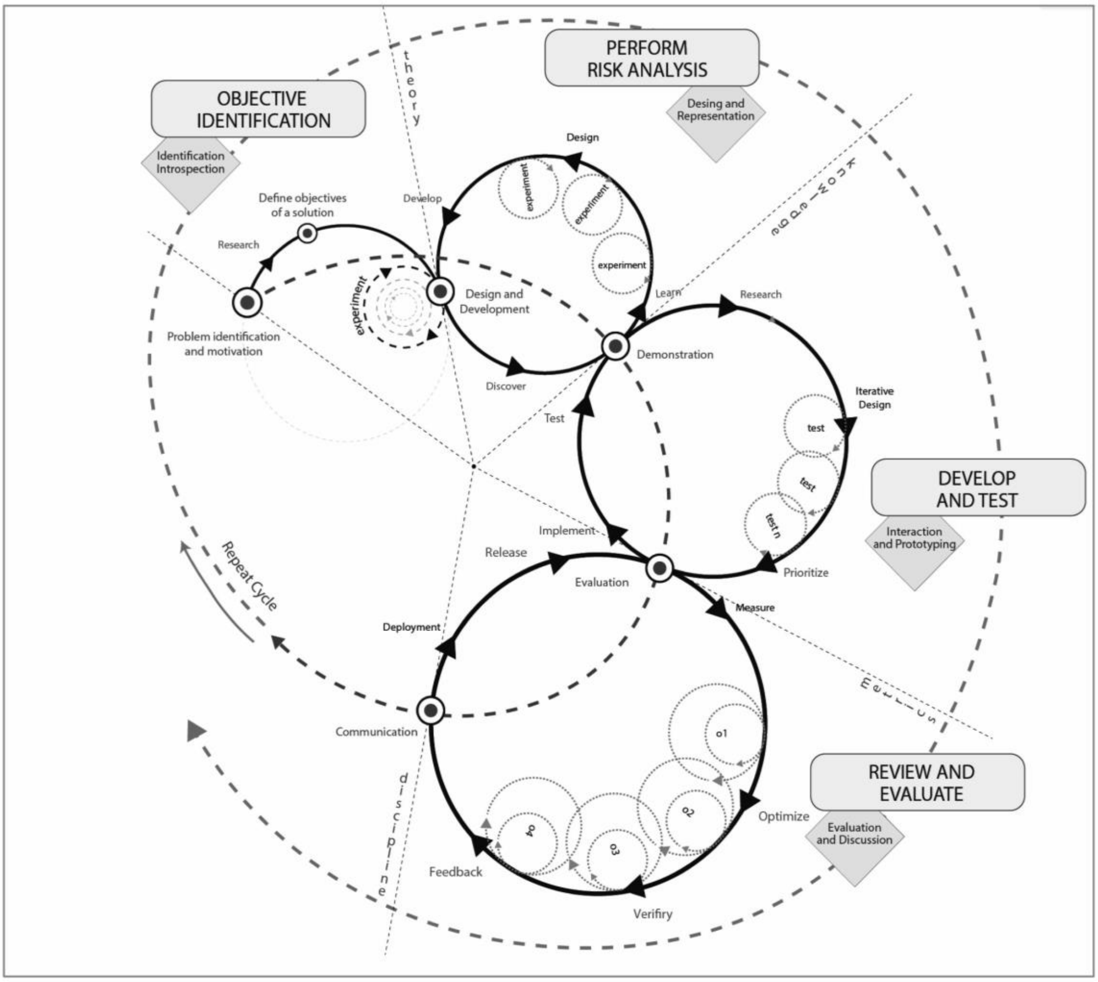

Figure 1: Multidimensional Exploration Methodology Spiral Graph Expanded

Even though the *Multidimensional Exploration Methodology* is proposed and applied only to academic learning and research practices, it has a great potential to be adapted to professional, industrial and planning practices, such as in industrialization, production and construction.

Multidimensional Exploration Method: From Academy to Industry

The alignment with the aforementioned new architectural design understanding takes the reference from cognitive background of the young professionals. Architecture, engineering and construction students learn the new contexts and up-to-date methods during the last part of their university education. As a result of this translation of knowledge from university to industry, the re-generation of the cognition upon the requirements of built environment depends on the learnt facts. During the learning period in academy, the student develops skills and generates knowledge by the exploration method, which becomes an intrinsic part of their knowhow and experience. In Figure 2, the shift of applied phases from academic research to industrial practice is described. The transition of the generated knowledge from academy (research) to practice (development), could be applied according to the list shown below:

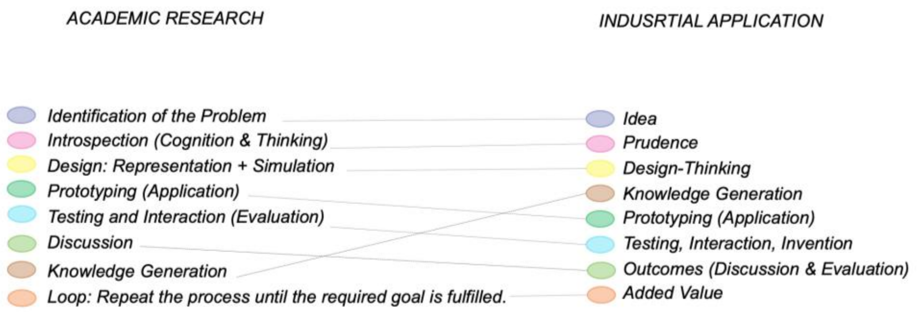

Figure 2: The shift of applied phases from academic research to industrial development.

Since usually in the academic research the outcomes of the project are mostly theoretical, generally no real application is required. Theory to application needs to be covered in the holistic 'research and development' with prototyping (production) practice. In the industry, the research and development tend to be inseparable, as the development can be based on real testing. By the *Multidimensional Exploration Method*, prototyping is included as one of learning phases, as it adds a substantial contribution to the generation of knowledge through *learning by doing* principles, as well as it is used as a tool for upgrading the value of the research projects.

Transferring this learning and workflow method to the professional practice is done via the same principles. The spiral model adds more sub-steps and check points to the development scheme (See Figure 4). In academic research, the student uses his current skills, previous knowledge and cognition to develop new skills and generate aligned knowledge. In industry, the young professional uses the regenerated cognition and knowledge to develop prudent and innovative products and systems aligned with a much more specific goal that has place in the market.

Design-Driven Innovation

Design and innovation processes have been competing throughout the history (Roy & Riedel, 1998). Even today, it stands as an important topic in design industry. However, the term design-innovation corresponds to a new paradigm, by proposing a hybrid of design and innovation. This holistic design approach contains design with added values, authentic ideas, actual technologies, sustainable development that develop innovative outcomes. *"The focus is on how the design process can be organized and managed towards product and service innovations on corporate and community (users) levels"* (Gerlitz, 2015).

The term Digital-Design Thinking includes significant use of new digital paradigms in design and representation practices (Oxman, 2006). Consequently, the design-driven innovation covers up both the design innovation aligned with current digitalized trends, where the term digitalism (Negroponte, 1995) also applies. After the arise of Industry 4.0, innovative projects are produced via digital-design thinking and design-innovation altogether. Regarding the design and innovation processes, the aforementioned holistic design approach is a key to combine the generated knowledge by research and development in academic world. On the other hand, the current technologies used in the industry can benefit immensely from it. Integrating design thinking models in which strategy building, innovation, and design management become one unified process, has various advantages (Acklin, 2010).

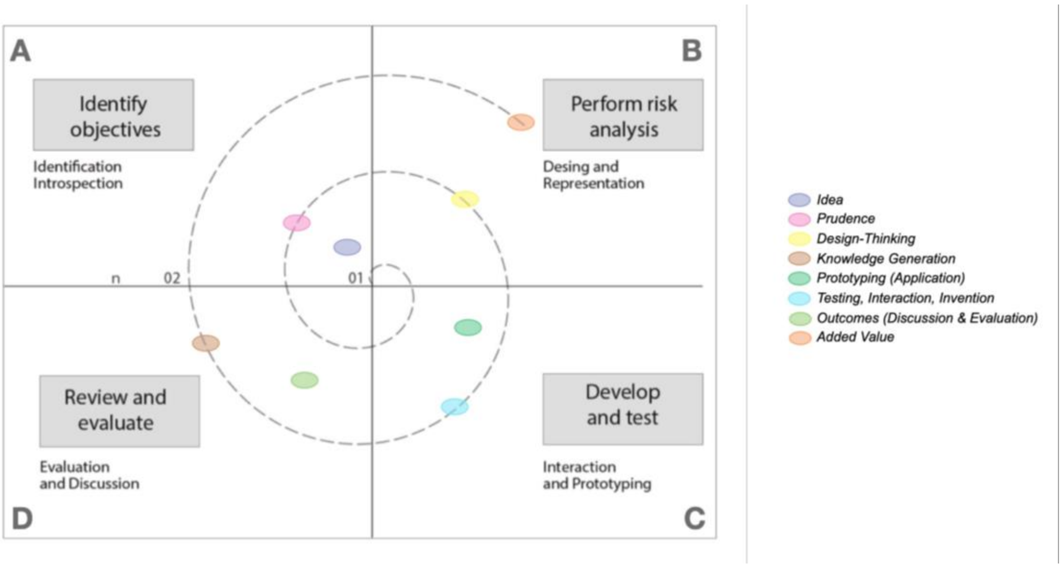

Figure 3: Multidimensional exploration methodology spiral graph with design driven innovation approach steps.

In Figure 3, the diagram shows the overlapping of the *Multidimensional Exploration Methodology* spiral method and the Innovative Industrial practice steps. This diagram can be read as a visual reference of the transition from the academic research and development to the Design-Driven Innovation in professional AEC field.

Figure 4 shows the four poles of the Design-Driven Innovation Compass as;

- Discovery
- Development
- Innovation
- Investigation

In between of the four main axis, the young practitioner's work should flow through the phases that are adapted from the learning methodology. Starting from the inspiration and the initial idea (1st cycle – Discovery to Investigation), the facts should be discussed and evaluated by prudence. Later on, the design thinking and the applicability should be processed. On this phase (2nd cycle – Investigation to Development), digital-design thinking approach should be concerned. Moreover, while the practitioner is designing the project, the learning method is actively used and the person generates new knowledge upon previous research and development examples from academic environment. On the following phase (3rd phase – Development to Innovation), the main contribution is done by testing, prototyping and application of new technologies. The tests should continue until the required results are achieved. On the last phase (4th phase – Innovation to another Discovery), the spiral loop continues with reviewing and evaluating the outcomes, and documentation of added values. On the last phase, the economic and technologic outcomes are visible, regarding to the feasibility and the originality of the project. Loops happen fast and evaluation loops within loops exist. While the four main poles define the principal contributions of design-driven innovation processes, the sub-steps determine the applications and detailing. The sub-steps also follow each other in a spiral fashion, until the required results are obtained with the following order: *inspiration* with the initial steps, generates the idea with the scope of *cognition* in the 1st phase. Afterwards on the 2nd phase, during the investigation, by *knowledge flows*, *collaboration* between disciplines and *co-creation* occurs. During the 3rd phase, as a result of the previous phases, the development of the project by prototypes and testing happens, and might result as concrete *invention* that was envisioned on phase 1 and 2. On 4th phase, if the invention is successful and worthwhile pursuing, other interest can be further achieved and the project could be developed further as bigger scaled *productions*.

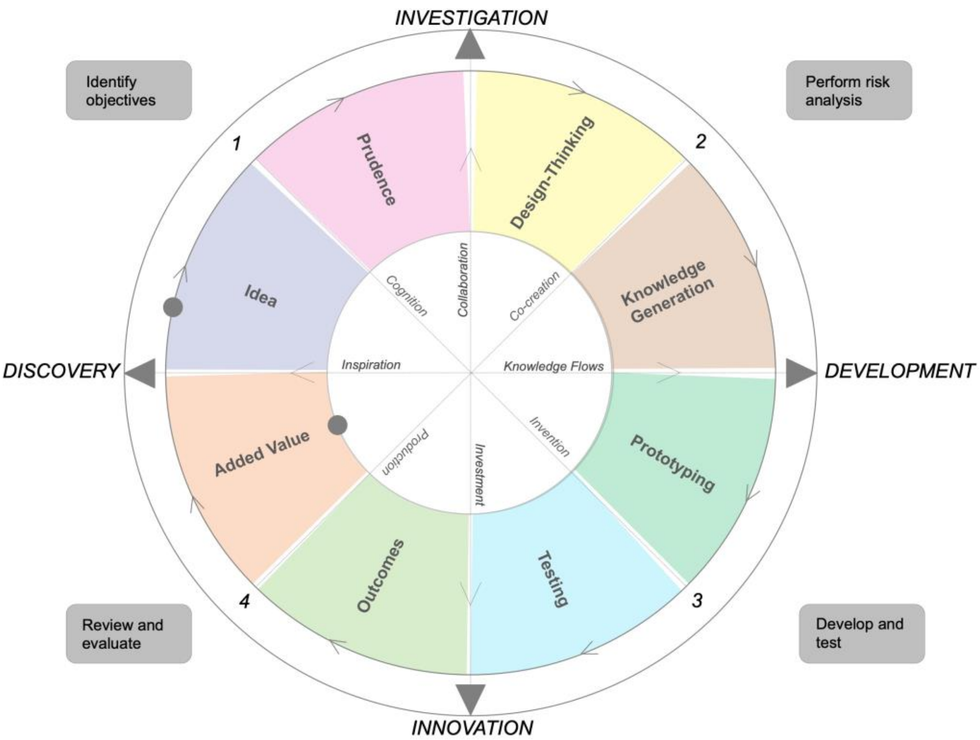

Figure 4: The Design-Driven Innovation Compass

Discussion

Academic research and development are essential for the industry. Especially in current day where AEC based companies in hybrid technologies and investment on interdisciplinary approaches do not have time to focus on long term goals. The basis of innovation knowhow comes from the academy, even that the development, results and outcomes are specific to industry. In this paper, the focus is on the knowledge generated in academia and transferred and developed in professional practice, as is understood that R+D tends to happen naturally in other industries apart from Architecture. Adapting the *Multidimensional Exploration Method* essentials to production practice directs the professionals to achieve design-driven innovation in their projects with totally unexpected results. The importance of interdisciplinary approaches by this research and development method is to achieve compatibility between knowledge fields and build bridges between them. Hybrid projects, learning from other disciplines and using co-creation as a design approach is highly encouraged in design-driven innovation as a process to increase interest, utility and complexity. Further vision of AEC industry has various enthusing prospectus. From theory to fabrication, construction and production, emergence of new technologies, software, devices and tools develop extremely fast. Digital-design thinking is essential for current practices, as well as design-driven innovation where staying connected and up-to-date is essential and crucial.

New Design and Production Practices in AEC Industry

Regarding the importance of actual software and workflows, productive and efficient visualization and documentation technologies have emerged in relation with the digitalism in AEC industry. As a matter of fact, digital-design thinking and the design-driven innovation are enhanced because they have found proper applications and projects to thrive.

For instance, by the prevalence of the usage of BIM, the understanding of the modeling tools swiped from just being a visualization medium to an information smart file that can be built upon reality and accuracy. Architects and engineers use BIM to model as they construct the exact building in real world, as new technologies and concepts such as the ‘digital twin’ (Grieves & Vickers, 2017) appear. The anticipated benefit of BIM is to be able to hold the material information, geographic and location data and even pursue energetic analysis (Eastman, Telicholz, Sacks, & Liston, 2011). Besides all these possibilities, the benefits of BIM are limited to the design and construction areas to be used by the technical agents, and not yet adapted to the post-construction phase for occupant’s appropriation. To take the benefit from the existing passive data of the building and to combine the passive data with the real-time ambient and environmental data as well as the personal data, a step further in design and development is needed. BIM is a good example of digitalization in architecture and a holistic digital-design thinking approach, which also leads the practitioner to take pseudo design innovation decisions. Moreover, regarding to the interdisciplinary approach and interoperability of BIM; Industry Foundation Class (IFC) is a term that is a standardized, digital description of the built asset industry. It is an open, international standard ISO 16739-1:2018, and promotes vendor-neutral, or agnostic, and usable capabilities across a wide range of hardware devices, software platforms, and interfaces for many different use cases (buildingSMART, 2019). One of the key aspects of BIM, which is interoperability, requires a fluid workflow between professions, offices. Even though BIM is a methodology to follow, each designer chooses to dominate one software, and specializes using that software as the main BIM tool. Working with files of different formats and the need to exchange information quickly and accurately, regarding to the burden of BIM. To face this type of problems on exchanging the information between software, the transfer of information which are both geometric and non-geometric; are carried out with the help of a common extension of IFC (e-Zigurat, 2019). The Industry Foundation Classes is fundamental for BIM practice, and mostly when it comes to *openBIM*, which aims to allow the compatibility of flows.

On the other hand, Lean Construction is good example for the design-driven innovation. The term stands for a “way to design production systems to minimize waste of materials, time, and effort in order to generate the maximum possible amount of value" focusing on the whole life-cycle of the building. This approach tries to manage and improve construction processes with minimum cost and maximum value by considering customer needs (Koskela, Howell, Ballard & Tommelein, 2002). Therefore, thanks to digital technologies and the regeneration of the cognition of the practitioner in academy, leads the future of built environment through the sustainable development.

Companies within the AEC and architecture production related sectors tend to struggle when trying to adapt to new methodologies and technologies, as architecture has always been a slow paced and traditional field. Disruptive innovators and young professionals that can apply *Multidimensional Exploration Methods* in a regular basis have the power to bring new life into the field and push boundaries forward (Gausa, 2014). New digital fabrication technologies have brought together design, research and fabrication (Gershenfeld, 2005), closing the gap between what can and cannot be done in architecture offices and construction sites. New material developments also advance the knowledge further (Oxman, Ortiz, Gramazio & Kohler, 2015), where they can be thought and understood as proper digital materials, where matter can be encoded and located only where is needed.

Production software that uses BIM principles start to also close the gap between the designers’ table and the industry; in example, Tekla (Trimble Solutions Corporation, 2020); offer the possibilities to embed data and user behavioral patterns into design and construction elements, in a deeper way than just adding information to the model and use as a visualization tool. Translating reality into parametric based modelling (Schumacher, 2008) is the preferred tool to be used by the sector. By all indicators, the future of design and production in AEC, incorporates data and parameters in the built environment, likewise, leading design and engineering companies started to adapt the required changes to their application and production methods.

Applied research projects in the material and automatization field can be a good example to illustrate how prototypes and proof of concepts from academic projects can be transferred and developed even further to suit architectural applications. 3D printing technologies for architecture using concrete and other cement-based materials, studied in a project by Dini on 2005 (Sher, 2019); differ and add value in scale to first additive manufacturing concepts.

Moreover, the project results documented by the patent for the world’s first 3D printer (Masters, 1979) prove that, the research with positive applied results within forty years’ time-span. The development is shown by Apis Cor’s research and development project (Apis Cor, 2020) as; *“The two-story government agency building in Dubai is reportedly the largest ever 3D printed”* (Zeiba, 2019). This generates new technological niches within the AEC sector. Usage of robotics in different stages of construction have proven positive to enhance human possibilities and what can be done with traditional materials when advanced technologies are used (Gramazio & Kohler, 2008). New systems and elements that have the possibility to self-assembly (Menges & Tibbits, 2012) prove that new ways of thinking, designing and even understanding the build environment are possible and efficient. New technologies such a VR-AR (Fologram, 2018) demonstrate that human cognition and skill can be augmented by the use of technology, closing the gap between skilled on-site labor and digital BIM coordination models.

AEC companies need to adapt quickly to the new paradigm shift that is already happening in the academic sector, which inevitably will force the whole AEC industry to shift into innovative approaches to projects to stay competitive in their market niche.

Conclusion

From academy to industry or from production practices back to research and development, there needs to exist a constant two-way connection. By this paper, we would like to expand the *Multidimensional Exploration Methodology*, from learning environments to industrial production practices, and vice-versa.

During their specific careers, the students should be trained by not only theoretical knowledge but also by a sustainable thinking and learning methodologies, which would guide them through design-driven innovation in later professional practice, much more connected to reality and matter. By this method, the learner digests the requirements of the actual built environment as well as the forthcoming necessities of global concerns, concepts that are needed in the current world. On the other hand, the designer, could apply this learning methods to generate knowledge within companies and industrial applications, professional fabrication, construction and production practices, and following the *Design-Driven Innovation Compass* techniques the projects would lead to outcomes in sustainable, innovative and efficient development.

The interdisciplinary approach between research fields should be considered for design-driven innovation. Actual design innovation is based on knowledge flows and the re-generated cognition of the new generation designers and engineers work in collaboration and gain inputs from several disciplines.

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Integrated Project Delivery in AEC Sector: A Systematic Literature Review

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Abstract

Considering decreasing profit ratios, low productivity ratios, lack of collaboration, increasing complexity and global competition in construction sector; there is a need for new approaches in order to improve construction projects' life cycles around the world. To improve construction projects' life cycle and project delivery systems, some new approaches and contract types such as integrated project delivery (IPD), lean management, partnering and smart contracts have been developed. IPD, developed in order to overcome the problems in existing project delivery systems, has been increasingly adopted in some developed countries. This study aims to review and classify previous studies, and determine potential research areas related to integrated project delivery (IPD). This study is a three-step systematic literature review consisting of bibliometric search, scientometric analysis and qualitative discussion. Findings of this research point out that there is insufficient number of research related to integrated project delivery. An important conclusion of this study is that there is a need for more researches related to integrated approaches to understand impacts on construction projects' life cycles.

Keywords: *bibliometric search, integrated contracts, integrated project delivery, IPD, project management, scientometric analysis, systematic literature review.*

Introduction

Researchers and professionals in construction sector have been seeking solutions for encountered problems in the industry. As a result of this seeking, some new approaches such as lean management and some new technologies like building information modeling (BIM) have come into use in construction sector. However, there are still inadequacies in integrating new technologies and approaches into contract types, decreasing wastes, improving cooperation and increasing productivity. Integrated project delivery (IPD) is a promising method to overcome these problems resulting from traditional project delivery systems.

The American Institute of Architects (2007) defines IPD as "*a project delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication, and construction*". IPD offers some advantages such as increased collaboration, early involvement among stakeholders, qualified scope documents, decreased conflicts, improved cost and time management. IPD has been increasingly adopted in some developed countries, and it has already achieved improvements in some construction projects (Khemlani, 2009; Matthews & Howell, 2005). On the other hand, there are still limited practices of IPD around the world, and there are some barriers to implementation. IPD implementation has several challenges including legal barriers, adversarial relations, resistance to change, lack of owner willingness and lack of awareness (Li & Ma, 2017).

Researches related to IPD are not very old; however, partially similar approaches such as partnering, alliancing and multi-party contracts have been studied previously. Considering benefits of integrated project delivery, a new project delivery method, it is an encouraging field to research. There are important publications and case studies around the world, and some organizations have issued standard forms for integrated project delivery contracts. On the other hand, studies and practices are not adequate and extensive in most of the countries including Turkey. Considering needs and problems in AEC sector, an integrated project delivery approach, including BIM, lean and sustainability perspectives, could be a good project management understanding. Therefore, this study aims to review and classify studies, and determine potential research areas related to integrated project delivery.

Research Method

This study is a three-step systematic literature review consisting of bibliometric search, scientometric analysis and qualitative discussion. Workflow of the systematic literature review is illustrated in Fig. 1.

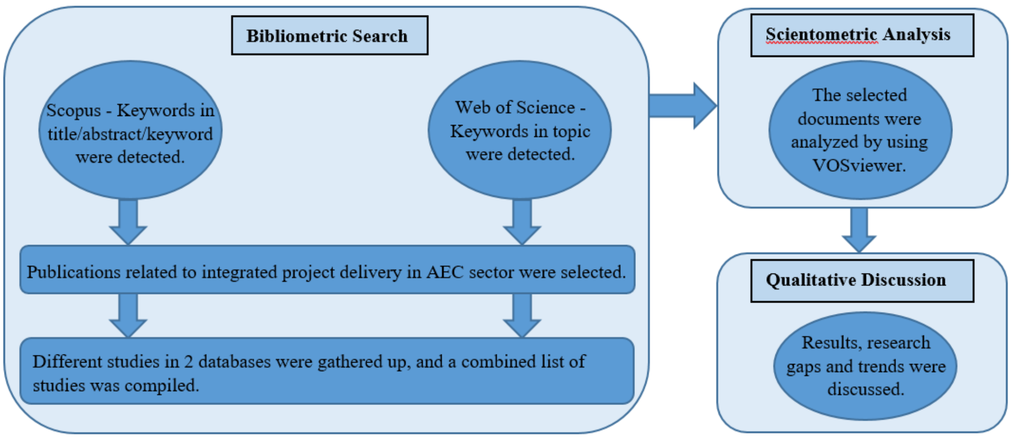

Figure 1: Workflow of the systematic literature review.

Bibliometric Search

The first step of the systematic literature review was the bibliometric search. A systematic search of IPD studies was performed in two comprehensive databases, namely, Scopus and Web of Science (WoS). These databases contain high amount of publications, including scientific journals, books and conference proceedings, and both databases are scientifically trustworthy.

Considering that using exact wording could result in missing some relevant documents, different wording was used in query string in order to find all related publications. Initially, identified keywords were searched in title/abstract/keyword fields, and 15.413 and 242.799 studies were detected in Scopus and Web of Science databases, respectively (Fig. 2 – Search Numbers 1 and 2). Then, subject area was limited to related areas, and 5.610 and 13.205 studies were found in Scopus and Web of Science databases, respectively (Fig. 2 – Search Numbers 3 and 4).

Search Nu.	Database	Query String	Affiliation Country	Num. of Results	Search Date
1	Scopus	TITLE-ABS-KEY ("integrated project delivery" OR "integrated contract" OR "integrated contracts" OR "IPD" OR "multi-party contract" OR "multi party contract" OR "alliance contract" OR "partnering")	All	15.413	18-Jul-20
2	WoS	TS=(integrated project delivery OR integrated contract OR integrated contracts OR IPD OR multi-party contract OR multi party contract OR alliance contract OR partnering)	All	242.799	19-Jul-20
3	Scopus	TITLE-ABS-KEY ("integrated project delivery" OR "integrated contract" OR "integrated contracts" OR "IPD" OR "multi-party contract" OR "multi party contract" OR "alliance contract" OR "partnering") AND (LIMIT-TO (SUBJAREA , "ENGI") OR LIMIT-TO (SUBJAREA , "BUSI") OR LIMIT-TO (SUBJAREA , "MULT") OR LIMIT-TO (SUBJAREA , "Undefined"))	All	5.610	18-Jul-20
4	WoS	TS=(integrated project delivery OR integrated contract OR integrated contracts OR IPD OR multi-party contract OR multi party contract OR alliance contract OR partnering) Refined by: WEB OF SCIENCE CATEGORIES: (MANAGEMENT OR ENGINEERING MULTIDISCIPLINARY OR ARCHITECTURE OR ENGINEERING CIVIL) Timespan: All years. Indexes: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI.	All	13.205	22-Jul-20
5	WoS	TS=(integrated project delivery OR integrated contract OR integrated contracts OR IPD OR multi-party contract OR multi party contract OR alliance contract OR partnering) AND SU=(Architecture OR Construction & Building Technology OR Engineering) Refined by: WEB OF SCIENCE CATEGORIES: (ENGINEERING CIVIL OR ENGINEERING MULTIDISCIPLINARY OR ARCHITECTURE OR GREEN SUSTAINABLE SCIENCE TECHNOLOGY) AND RESEARCH AREAS: (ENGINEERING OR ARCHITECTURE OR CONSTRUCTION BUILDING TECHNOLOGY) AND DOCUMENT TYPES: (ARTICLE OR REVIEW OR PROCEEDINGS PAPER OR BOOK CHAPTER OR BOOK REVIEW) Timespan: All years. Indexes: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI.	All	4.571	22-Jul-20
6	Scopus	AFFILCOUNTRY ("Turkey" OR "Turkia" OR "Turkiye" OR "Türkiye") AND TITLE-ABS-KEY ("integrated project delivery" OR "integrated contract" OR "integrated contracts" OR "IPD" OR "multi-party contract" OR "multi party contract" OR "alliance contract" OR "partnering") AND (LIMIT-TO (SUBJAREA , "ENGI") OR LIMIT-TO (SUBJAREA , "BUSI") OR LIMIT-TO (SUBJAREA , "MULT") OR LIMIT-TO (SUBJAREA , "Undefined"))	Turkey	15	20-Jul-20
7	WoS	TS=(integrated project delivery OR integrated contract OR integrated contracts OR IPD OR multi-party contract OR multi party contract OR alliance contract OR partnering) AND SU=(Architecture OR Construction & Building Technology OR Engineering) Refined by: WEB OF SCIENCE CATEGORIES: (ENGINEERING CIVIL OR ENGINEERING MULTIDISCIPLINARY OR ARCHITECTURE OR GREEN SUSTAINABLE SCIENCE TECHNOLOGY) AND RESEARCH AREAS: (ENGINEERING OR ARCHITECTURE OR CONSTRUCTION BUILDING TECHNOLOGY) AND DOCUMENT TYPES: (ARTICLE OR REVIEW OR PROCEEDINGS PAPER OR BOOK CHAPTER OR BOOK REVIEW) AND COUNTRIES/REGIONS: (TURKEY) Timespan: All years. Indexes: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI.	Turkey	42	22-Jul-20

Figure 2: Detailed information about searches.

Results obtained from WoS database were more comprehensive and include results obtained from Scopus database. Therefore, 13.205 results obtained from WoS database (Fig. 2 – Search Number 4) were refined by categories, research areas and document types, and finally 4.571 studies were selected for further analysis (Figure 2 – Search Number 5). Then, contribution of Turkey to IPD literature was analyzed by filtering publications by the researchers whose affiliation belongs to Turkey, and 15 and 42 studies were detected in Scopus and Web of Science databases, respectively (Fig. 2 – Search Numbers 6 and 7).

Scientometric Analysis

The second step of the review was scientometric analysis, and the selected studies were analysed by using VOSviewer (version 1.6.11) software. VOSviewer is a common science mapping tool used for creating maps based on network data and visualizing maps (Van Eck & Waltman, 2019).

Qualitative Discussion

In the third step of the review, research results, current research gaps and future research trends were discussed.

Results

4.571 global publications, detected in WoS database, were firstly classified according to their publication years. Fig. 3 shows the distribution of publications according to publication years. It is shown that there is an increase in the number of publications in recent years.

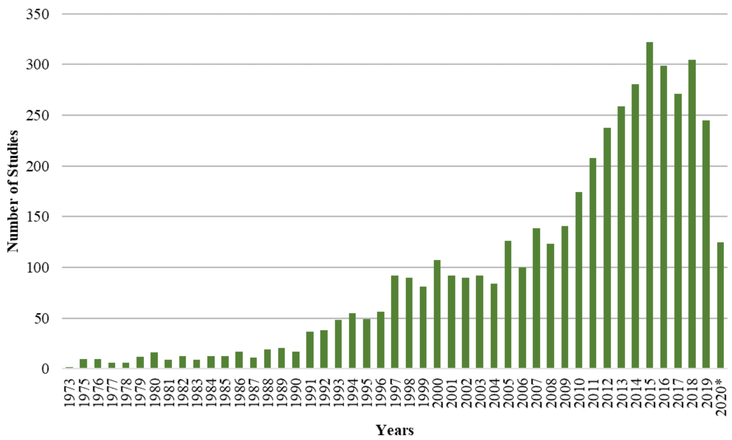

Figure 3: The distribution of publications according to publication years. *: Documents published until 22 July 2020 were included.

In addition to yearly distribution, researches were also classified according to their types as shown in Fig. 4.

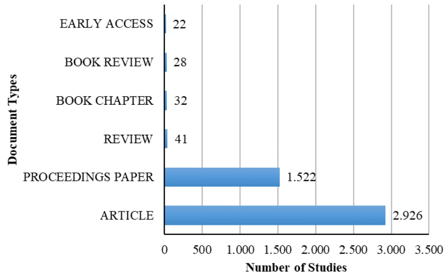

Figure 4: The distribution of publications according to document types.

Moreover, the distribution of studies published globally in the areas of engineering, architecture and construction building technology is given in Fig. 5. As it is shown Turkey achieves the global average; however, it is not adequate considering promising ways of IPD.

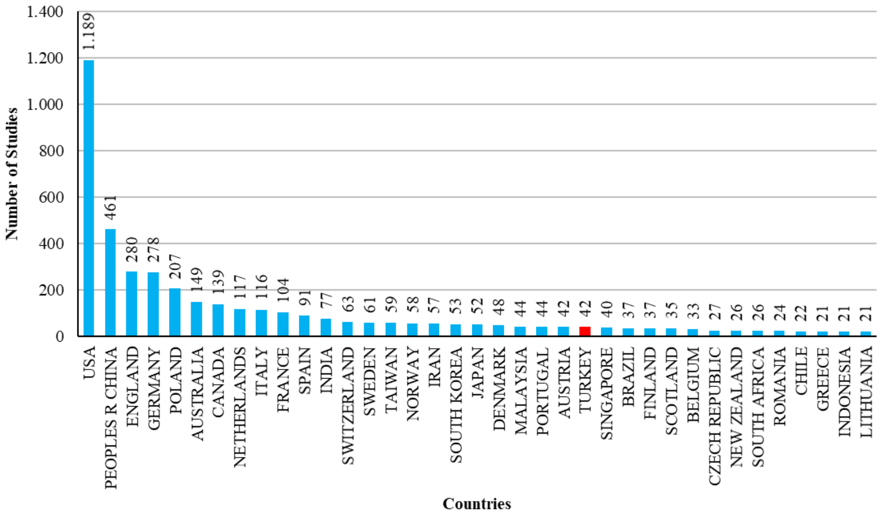

Figure 5: The distribution of studies according to countries. *: Countries, in which less than 20 studies were published, were not included in the figure.

According to the Search Number 7 in Fig. 2, integrated project delivery and IPD related topics are new fields in Turkey, and researchers have started to investigate these topics in recent years (as shown in Fig. 6). In addition, Figure 6 shows the most productive authors in Turkey according to the number of studies they have in IPD and IPD related fields.

Authors	Number of Studies
DIKMEN I	8
OZORHON B	8
BIRGONUL MT	7
ARAYICI Y	2
ERAY E	2
POLAT G	2

Publication Years	Number of Studies
2018	4
2017	5
2016	2
2015	5
2014	3
2013	4
2012	4
2011	4
2010	2
2009	6
2008	2
2007	1
	42

Figure 6: Detailed information about studies in Turkey. *: Authors who have 1 publication related with IPD topics were not included in the figure.

Scholars and Collaborations

Co-authorship analysis was conducted by using VOSviewer to determine the researchers studied IPD and their collaborations with other researchers. In this analysis, minimum number of documents and minimum citation numbers of an author were selected as 3 and 0, respectively. As a result, 207 of 11.105 scholars meet the requirement, and they are visualized in Fig. 7. Node and font sizes in Figure 7 are proportional to the number of publications, and Davey, P. is the most productive IPD researcher with 38 documents. Link thickness in Fig. 7 refers to the number of publications co-authored, and Chan, Albert, P.C. has the strongest linkage.

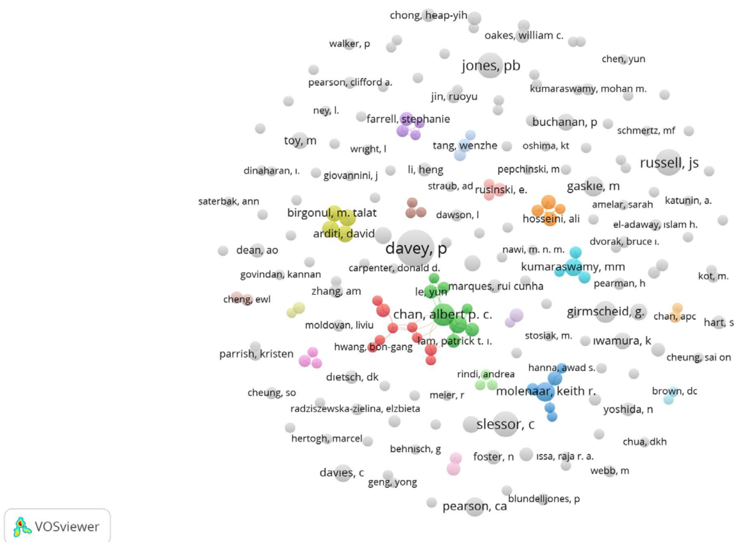

Figure 7: Co-authorship analysis in VOSviewer.

Keywords Analysis

Keyword co-occurrence analysis was conducted by using VOSviewer to describe research topics and visualize core contents. Fractional counting methodology was used in the analysis, because Van Eck and Waltman (2014), developers of VOSviewer, suggested using the fractional counting methodology instead of the ordinary full counting methodology. In this analysis, minimum number of occurrences of a keyword was selected as 3. As a result, 580 of 9290 keywords keywords meet the requirement, and frequently used keywords are visualized in Figure 8. Node and font sizes in Figure 8 are proportional to the usage frequency of keywords, and most frequently used keywords are "sustainability", "construction", "partnering", "project management", "BIM", and "collaboration". In addition, keywords are grouped based on frequency of together usage, and these groups, called clusters in VOSviewer, are colored differently. In this analysis, 580 keywords are grouped under 37 clusters which show main study areas of IPD scholars.

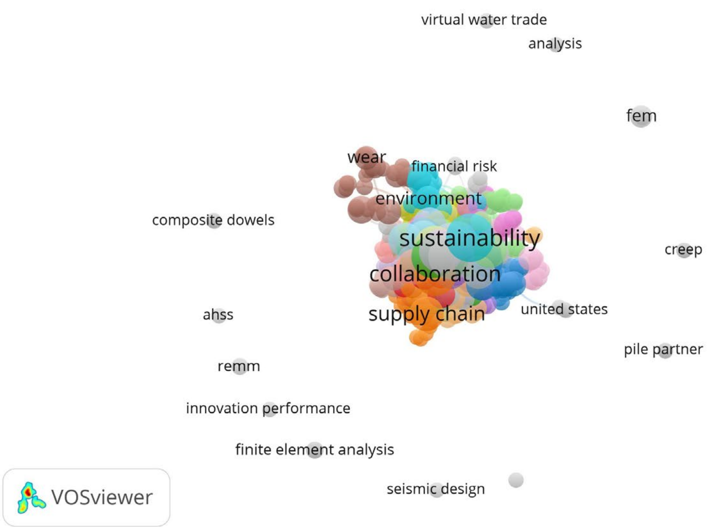

Figure 8: Co-occurrence analysis in VOSviewer.

Qualitative Discussion

According to the conducted keyword co-occurrence analysis explained in the previous section, it could be concluded that there is a lack of studies directly related with integrated project delivery. Integrated project delivery as a new approach is mentioned in some of the detected studies; however, most of the detected studies have focused on issues related with sustainability, partnering, BIM or collaboration.

In addition, after reviewing abstracts, titles and keywords of the studies; it is found that there is a big gap in implementation and case studies of IPD. Considering that IPD is a very promising method, future research trends could be extensive studies and real cases regarding IPD approach which is assembling BIM, lean and sustainability perspectives.

On the other hand, Turkey, as a developing country, has been constructing mega projects, and AEC is one of the leading sectors. Moreover, BIM utilization, green building certification and lean management have become popular in Turkey. Considering opportunities and problems in Turkish AEC sector, an integrated project delivery approach, including BIM, lean and sustainability perspectives, could be a good project management understanding.

Conclusion

IPD is a promising method to overcome encountered problems in traditional project delivery methods. IPD offers some crucial advantages; but there are limited practices around the world, and there are some barriers to implementation. This study applied a three-step systematic literature review to determine the current situation of IPD research. Findings show that IPD researches, case studies and implementations are insufficient, and there is a need for further studies which are combining new approaches such as lean, smart contract, IPD and BIM. IPD approach can attract practitioners' attention in AEC sector in case well documented studies are published and advantages are explained precisely.

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A Scientometric Analysis of Public–Private Partnerships: A Literature Review

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Abstract

Since the late 1990's, governments in both developed and developing countries have been increasingly involved in implementing PPP policies to reduce their infrastructure deficits. The attractiveness of the PPPs wasn't only based on the financial shortages of governments, but also on the allocation of risks between partners. However, there are a number of barriers influencing the implementation of PPPs in developing countries. The purpose of this paper is to identify the barriers in implementing PPPs in the developing countries. Although a considerable amount of literature has been published on PPP problems, there seems to be a lack of systematic review of what they have already provided. As such, the study presented in this paper maps and analyses the state of existing publications on PPP research with a scientometric approach. In order to achieve the objectives of the review, we categorize the papers to the issue raised and provide a summary of specific insights. It is hoped that the resulting accumulated knowledge will provide insights for directing further PPP research.

Keywords: *public-private partnership (PPP), PPP's classification, PPP's issues.*

Introduction

A Public Private Partnership is a cooperation established between public authorities and the private sector to finance, construct, renovate, operate, maintenance. A Public Private Partnership concept; is a cooperation established between the public authorities and the private sector in order to provide financing, construction, renovation, operation, maintenance, i.e., the entire process involving the project (Green Paper, 2019).

The European Union commission focuses on the four basic features of PPP. First of all, since the projects are created with this model are long term, they require long term cooperation between the government or public institutions and private sector partners. Secondly, since the projects are carried out with many shareholders and many subcontractors, the financial problem of the project will include the same complexity. The third feature, the public institution or the government is to control the project stages by the 3 main (time, cost, and quality) components of the management triangle. The forth and the final feature is; to achieve risk management efficiently between public organization and private sector and to transfer all the risks that the private sector partner can undertake (Green Paper, 2019). It is seen that these four features are the keys when we get to the bottom of the problems of the projects that are created with PPP model in Turkey and worldwide.

In this study, the main problems that are stated worldwide will be classified according to the research areas through the academic studies conducted. In Turkey, it is aimed to identify the problems that may be encountered and to be a source for future studies to use public-private cooperation projects more efficiently. Many researchers in different countries have intensively reviewed the concept of PPP and its applications. A number of professionals and scholars have reported on the state of PPP practice in many developed and developing countries. Looking at the case of Turkey as a developing country, it is possible to find a large number of articles on the Turkish experience.

Methodology and Data Sources

Research on PPP projects is not expected to conclude the debate on this matter. A better understanding of risk in PPP projects can significantly assist in designing containment measures to deal with their likely impact on the projects. To achieve this objective, a research plan was established to identify the risks related to PPP projects by literature review.

This study applies a bibliometric review approach to examine the characteristics of PPP studies through multiple methods. In this study, the software VOSviewer was used to analyze basic statistical information in the data source, covering outputs and frequencies of citations in terms of countries, institutes, sources, and authors.

No such research has been carried out in Turkey before, and it is aimed to present this study as a source for future projects and scientific studies.

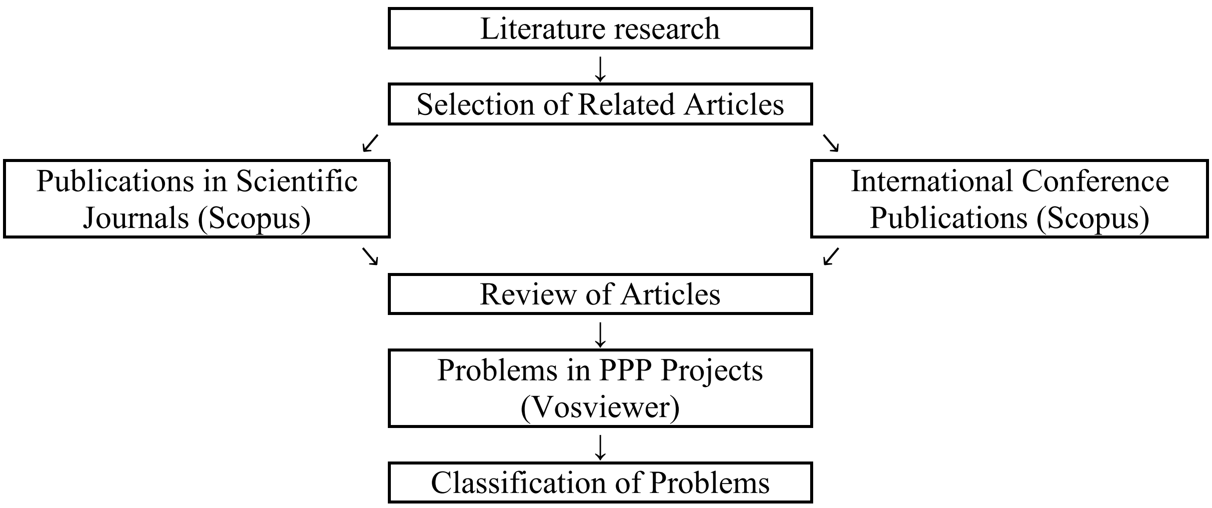

Figure 1: The literature review process.

The main aim of this study, carried out in 2019, is to identify the problems in PPP projects in Turkey. As a first step, systematic exploration of PPP publications was carried out in two scientifically reputable databases, namely Scopus and web of Science (WOS) core databases. The access strategy used in this study is "PPP" or "PFI" or "public-private partnership" or

"P3". More than 1717 articles, originally published between 1986 and 2019 (until 8 June 2019) were examined. The research area was narrowed to identify the problems encountered in public-private partnership projects after these studies were categorized worldwide. A scientometric analysis was performed by adding the phrase "problem" to the studies in order to create the collapsed workspace.

Scientometric Analysis of Publications

A comprehensive literature review of articles on Public-Private Partnership (PPP, P3) and private finance initiatives (PFI) was conducted in this section using bibliometric analysis. Scientometric Analysis; Analysis of the work done on this construction model according to its subjects has enabled the work to be carried out more efficiently. As an example, China, one of the countries that have done a lot of work on PPP, has created a resource with the studies of its authors in order to classify the problems experienced. With the distribution analysis by years, which is another study class, the popularity of this model in the world can be determined, and analyzes can be made about how it will show distribution in the following years and what measures should be taken regarding the model that is in an increasing trend.

From the publication of the first article, according to the Scopus (2019) database, by 1986, fewer than 50 articles had been published. After 2000, however, the literature on PPPs expanded significantly, especially in the last decade, with a stronger rhythm of growth. The analysis of the studies were collected in 3 main titles: authors, countries, distribution by year.

Country-Institute Analysis

The United States is at the top of the list with 308 studies, among 72 countries where researchers have published studies on the PPP theme. With 274 studies, China is in the 2nd place and England with 211 studies is in the 3rd place in the list, respectively. Australia ranked fourth, published 85 studies, after which countries such as Canada, Germany, Hong Kong, Malaysia, and Russia complete the list. Turkey due to the small number of studies, especially in the international arena is not located in the top 10 on this list.

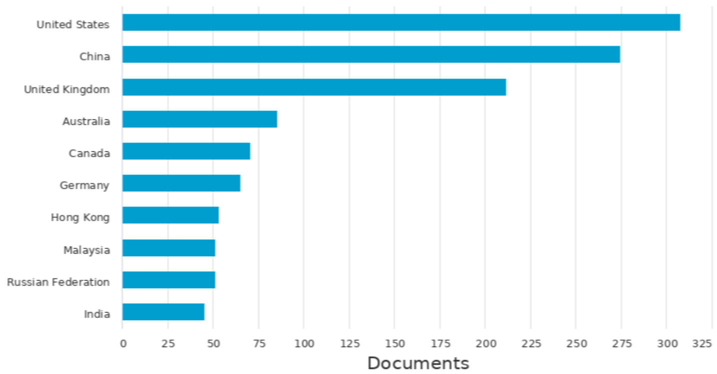

Figure 2: Distribution by countries.

Distribution by Years

The results show an increasing number of studies for PPP, P3, and PFI abbreviations as a result of increased interest (Fig. 3). Although the history of this production model dates back to the construction of the Suez Canal in 1859, the real leap and awareness are based on the last 15 years. Since 2002, growth has been almost exponential, and despite the slight decline in the number of studies confirmed in 2018, it will likely increase in the next 15 years, especially given the number of projects developed in the past 15 years. The systematic review of this study includes studies published until the beginning of June 2019, the number of studies published that year seems relatively low.

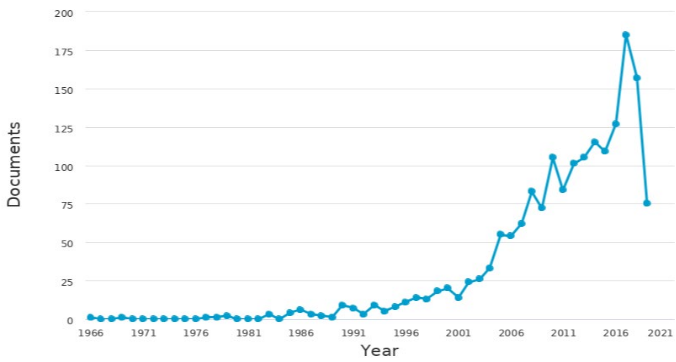

Figure 3: Distribution of PPP studies by years.

Author Analysis

In this part of the studies carried out via Scopus, an evaluation has been made on the productivity of academicians. Figure 4 Distribution of studies conducted in the world, Fig.5 shows the distribution of the authors of the limited studies carried out in Turkey. In this construction model, Albert P.C., working at the Hong Kong Polytechnic University, which published 16 studies among the authors, ranked first. In the second place, Peter E.D. from Curtin University with 10 studies. Love is followed by Jun Fang from the Wuhan University of Technology with 9 studies. These names are followed by names such as J. Smith, S. Wang, X. Zhang, A. Akintoye, respectively (Fig. 4). In Turkey, R. Akbıyıklı, E.C. Names such as Akçay are academics who contribute to this model of construction through one study (Fig. 5).

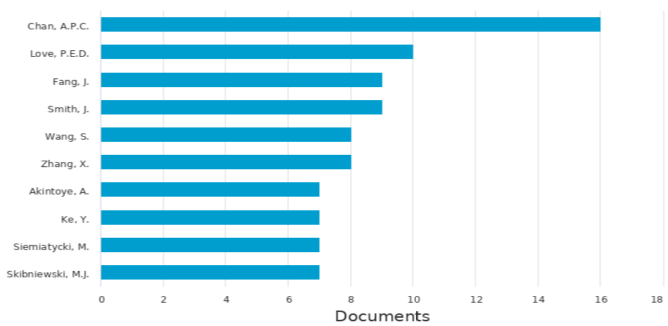

Figure 4: Distribution by authors worldwide.

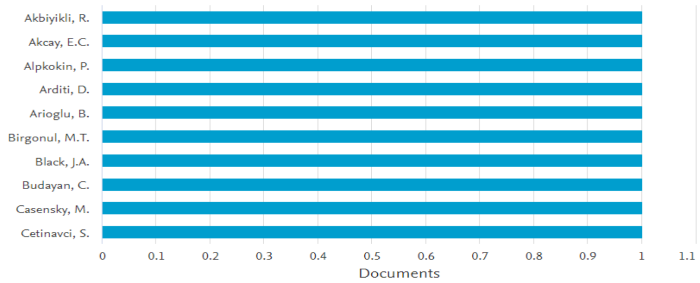

Figure 5: According to the authors' distribution in Turkey.

Research Topics and Temporal Evolution

In the projects carried out with the PPP model, keyword analysis were carried out through the VOSviewer program to identify the main research topics of the problems encountered worldwide. In the analysis process, widely used keywords that can be collected under the title of "public-private partnership" in the world were standardized (PPP, PFI, P3). Analysis results are shown in Fig. 6.

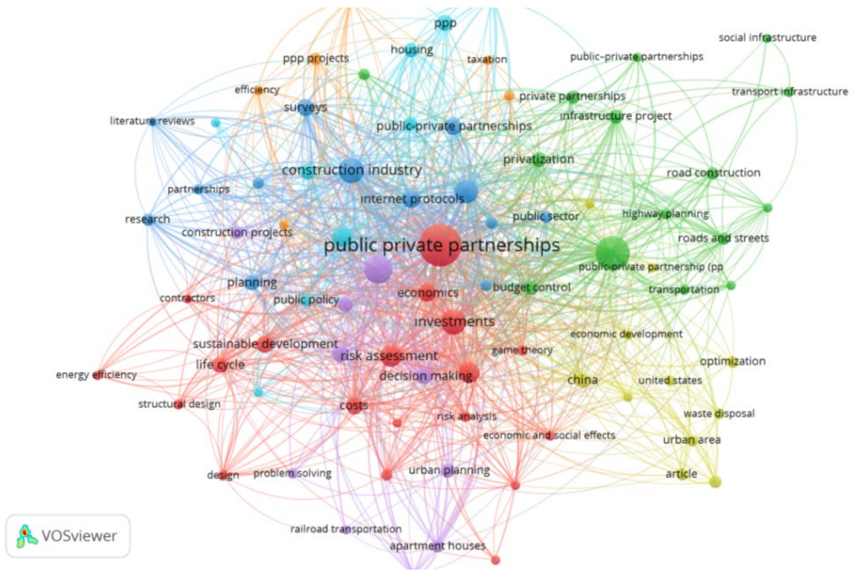

Figure 6: Visualization of problems in PPP projects on keywords.

In Fig. 8, the node and font sizes show how often each keyword is used, and the link thickness shows how often the linked keywords are used together. In public-private partnership, terms are much more intertwined than other studies. The reason for this is that the problems expressed by the terms cannot be considered independently. If the studies are analyzed according to the research areas; the class represented by red color contains many items under the title of the economy. Economic problems are the leading problems that will arise in this project delivery model by developed countries or developing countries in order to keep up with the globalizing world and catch up with the ever-developing technology. The importance of this research area can be understood from its proximity to the phrase "public-private partnership" in the center. In this study area; problems such as investment, cost, risk analysis, risk assessment, economic and social impact come to the fore.

In this construction model, political factors come into play as one of the partners is a public institution. Keywords used in research for this area; It is in the form of "privatization", "public policies", "taxation" and "social infrastructure". Another area of research is the planning phase, which covers the process prior to the realization of the projects. The keywords used for this are; "Structural design", "road planning", "design" and "urban planning".

Transportation projects constitute the majority of the projects realized with the public-private cooperation model. The keywords used in research related to transportation are; "Road construction", "transportation infrastructure," railway transportation" and "infrastructure projects". In the types of research related to this subject, "surveys" and "literature research" come to the fore. The public-private partnership model has many sub-branches. It is common and also the most widely used of these models in Turkey; Built-Operate-Transfer and Build-Lease-Transfer. “The United Kingdom”, which is considered as the originating country of these models and especially known as the founder of the build-lease-transfer model, and “China”, which has carried out various research on the subject in literature research, are two countries that come to the fore as research areas.

Major Issues in PPP Projects

Following the bibliometric analysis and science mapping, the papers have been categorized by problems in PPPs to provide suggestions for near-future research trends in PPP themes.

Risk Assessment

One of the main problems in projects carried out with public-private partnerships is risk assessment. Considering that PPP projects are carried out with long-term contracts, it is inevitable to realize a good risk management process. The first step of a defined and predictable risk analysis for the construction of the PPP is usually to prepare a comprehensive list of all project-related risks. Such a list is known as a risk record. The risks in this list to be created vary depending on the country where the project is implemented, the nature of the project, and the related assets and services. However, some risks are common to many PPP projects. These are usually divided into risk categories associated with a specific function (such as construction, operations, or financing) or a specific project phase (such as termination). It is often useful to consider the importance of risk when allocating risk (WB, 2006).

As a result of the process of identifying, analyzing, evaluating, correcting, and monitoring risks, it offers many advantages such as the selection of better strategic goals related to the targets, enabling the more realistic demonstration of talents through achievable goals and targets (Columbia, 2005). Based on these advantages, it would be wrong to draw a conclusion that all risks have been transferred by the government to the private sector. When acting with the philosophy of transferring the risk to the party that can best meet the risk, both parties will benefit from this process positively. For example; governments are required to take on demand risks, including guarantees given to include the private sector in projects implemented with this model. When the guarantees are given are realized without a good feasibility study and without any public interest; governments suffer huge financial losses.

Project Finance

Although PPP projects are thought to be carried out through two main shareholders, they involve many shareholders in the system. Investors and lenders are the most important ones in the economic field and the ones that will finance the project. Besides financing of shareholders capital (usually around 10-15%), many financing instruments such as bonds and bills, bank loans, and structured debt are used in financing PPP projects. One of the most important elements in PPP contracts is the creditworthiness of the projects. As a requirement of project financing, shareholder responsibilities are limited to their capital in debt repayments, and debt payments are made by fund flows from undertakings in charge. For this reason, financial institutions want to provide credit to the project in terms of the creditworthiness of those who will ultimately pay the service (administration/government or service users) (Emek, 2010). The involvement of the public partner in the project also increases the creditworthiness mentioned and provides a trusted environment to the partners who will provide project finance.

Demand Forecast

Demand forecasting is the most important issue that governments must work before the contract to attract a private sector partner to the project. Once the claim estimate is determined, a guaranteed price is determined by governments or public bodies. This guaranteed price is a toll for bridges, it is a usage fee for airports. These determined state guarantees come to the forefront as the most important factor in regard to the success or failure of many projects. For example, the UK has given up the implementation of some projects with the PPP model due to the damage caused by the state guarantees to the national economy. As another exemplary country, Brazil has created special funds to meet state guarantees.

Government guarantee is a form of government intervention that is the reason for responding to the failure of markets to best distribute risks. Government guarantee is a way for governments to encourage the private sector to participate in PPP programs or projects. State guarantee is the most important material used to build trust in the PPP market and demonstrate state commitment. When designing guarantees, it is necessary to consider efficiency by addressing the scope and duration of the guarantee. The reasonable state guarantee structure is vital to the success of the PPP project. However, if the state guarantee is precarious or inappropriately provided, or if it exceeds the capacity of the state, the PPP projects will fail (Xu et al., 2014). A failed PPP project can prevent investors from investing in similar projects or the same area, and ultimately, the government suffers further losses in economic and social development.

Economic and Social Effect

The priority of the states that want to raise the welfare and economic levels of their peoples with the social state approach should be to prioritize the satisfaction of the most important shareholders, namely the people when designing these projects. According to Do Ba Khang, the criteria for measuring project success should focus on three factors:

- Effectiveness of the implementation process (time, cost, technical goals, and business relationship)
- Product and service quality of PPP projects
- Partner Pleasure (Khang, 2008).

This satisfaction is; It is only possible with a positive reflection of the economic factor, which is the most important factor of implementation, on the public. There are many shareholders in the projects realized with this model. But one of the most important shareholders that governments should focus on should be the people and their satisfaction should be prioritized. At the contract stage of the practices realized with the PPP model, the transition fees should be made especially for highways and bridges considering the welfare level of the public. It cannot be said that success has been achieved in such projects without the satisfaction of the public.

Conclusions

PPP, especially in developed and developing countries, shows an upward trend in the last 15 years as shown in Figure 3. This model reached the country after 1980 in Turkey and approached the pick level in the 2010s. This requires a much better understanding of the model and a much reliable implementation. The efficient implementation of this model depends on a very good preliminary study and the reference of countries that have successfully implemented this model.

This paper aims to be a resource for future studies by classifying academic studies on PPP. This classification was performed by applying bibliometric and scientometric analyzes. The public-private partnership model includes complex and long-term contracts. This model also requires and includes much more stakeholders than other project building models. These features of the model make the process of achieving the targeted success much more forcible. It is required to be performed a very rigorous study from the beginning of the process of the feasibility and decision phase of the model by time the private sector assigns the projects to the government. Although the data obtained in this study focus on risk assessment, project finance, and demand forecasting, there are many sub-headings in addition to these two elements.

As Turkey is a developing country, to keep the balance between economic constraints with new investments is one of the difficulties facing Turkey. Therefore, the importance of the PPP model is increasing one more time. For developed or developing countries considering the projects realized as successful, it is necessary to focus on the specified problems by giving importance to feasibility studies.

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Cost and Time Overrun Management with Particular Reference to Underground Metro Lines

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Abstract

Cost and time overruns on infrastructure projects are globally attractive. In the international literature, research on infrastructure projects in different geographical environments outstand. Among infrastructure projects, urban metro line investments are notable. Over the past decade, Istanbul has invested in huge metro projects wherein time and cost overruns are commonly observed. The reasons that give rise to such overruns attract much attention in practice and research. This paper contributes to these studies by specifically undertaking the three completed metro lines in Istanbul. Firstly, on three metro lines cost and time overruns are numerically analyzed. Secondly, the paper examines as to how such monetary increases and time extensions have emerged and managed by the contracting parties. Consequently, the discussions provide useful insights for effective contract management with special reference to work and time increase within underground metro projects.

Keywords: *underground metro project, cost overrun, time overrun.*

Introduction

The age of mega projects is being experienced and scales of projects are getting larger day by day (Flyvbjerg, 2007). In parallel with this growth, project goals, duration, cost, and risk exposure have increased dramatically over time (Chapman, 2016). Althoug risk, particularly economic risk, is becoming increasingly a public policy and management concern, there are only a few studies in literature on the economic risks assessment and management of urban rail system projects. (Flyvbjerg, 2007).

Since there are only a few studies in literature and risk assessment and management process is not carried out for all phases of the project, significant cost overruns are emerging in urban rail system projects (Flyvbjerg, 2007). In this context, Morris (1990) states that the key factors which are causes of cost and time overruns are poor planning and implementation, insufficient project financing, bureaucracy, and lack of coordination between stakeholders.

In this paper, the work undertakes the cost and time overrun of underground metro projects in Istanbul. There are six metro lines with a total length of 115,39 kilometers currently under operation in the city and in 2019, around 500 million passengers were transported via these lines. In addition to that, a total of 227 kilometers of rail systems are planned to be constructed in the city by the end of 2024. Considering the size of the metro projects planned to be constructed, it is seen that past planning and implementation experiences have great importance in terms of efficient use of public resources.

For the purposes described above, the scope is narrowed down to the M1 (Yenikapı – Ataturk Airport -Kirazlı Metro Line), M4 (Kadıköy-Kartal-Tavşantepe Metro Line) and M5 (Uskudar-Umraniye-Cekmekoy Metro Line), whose share in the Istanbul metro network is about 60%.

Following the Section 2 and 3 for methodology and data, Section 4 discusses these three metro lines by selected parameters contained in the literature and selected for the purpose of discussing the project planning and management performances. Finally, Section 5 concludes the paper by highlighting the findings and suggesting the future research.

Methodology

Many studies have witnessed substantial cost and time overruns and discussed the reasons as to why optimistic estimations have been undertaken and what has caused the costs deviating from originally intended (Flyvbjerg et al., 2002; Flyvbjerg, 2007; Flyvbjerg, 2011; Cantarelli et al., 2013; Locatelli et al., 2017).

Flyvbjerg et al. (2002) discuss about the concepts of "Actual Cost" and "Estimated Cost" in order to analyze the management performance and cost overruns of projects were examined through the concepts discussed through dozens of case studies. Besides, Siemiatycki (2016) examined this study and stated that, considering past studies, this statistical study with such a powerful data set and instruments could yield very clear results.

The methodology here is primarily to undertake an analysis from the main perspective of "Project Management Performance" by employing planning and implemantation performance through emerged cost and time overruns. Here, the time overrun of each project has been determined by considering the contract duration in the tender phase and the project completion time.

However, unlike the studies in the literature, project contract prices were used instead of the estimated cost since the data on the estimated costs of the projects could not be accessed. Actual cost, which emerged after cost overrun, was compared with this contract price to measure planning and implementation performance. Each instrument is discussed individually for three metro projects.

Data

The whole data is collected from the Istanbul Metropolitan Municipality where authors were assigned in Department of Rail Systems. Within this scope, all projects and correspondance about three metro line in the Istanbul Metropolitan Municipality data base were reviewed. In addition, a semi-structured survey was held with technical experts, municipal officials and other professionals who has been working on planning and implementation of urban rail systems for many years.

Project Management Performance

Istanbul is the largest agglomeration and economic center of Turkey (almost 16 million population). The public transport system is mainly composed of different types of buses and minibuses, namely road type of public transport but rail network is consistently developing since the 2000s and onwards (Canitez et al., 2018).

Considering all public transportation systems in the city, the average daily number of passengers who use public transportation was around 15 million in 2019 and the share of rail systems in this number is approximately 19%. When the number of passengers carried by the Tram, Funicular, Cable Car and Commuter Rail Lines operating in the city is deducted from this share, it is seen that the share of six metro lines currently under operation is 10.9%.

This ratio means that approximately 500 million passengers are transported in 2019 by metro. The share of each metro line within the Istanbul Metro Network is shown in Table 1.

Table 1. Annual number of passengers and share of each metro line in the Istanbul Metro Network (*https://www.metro.istanbul/yolcuhizmetleri/yolcuistatistikleri*).

LINE CODE	LINE NAME	LENGTH	TOTAL NUMBER OF PASSENGERS IN 2019	SHARE IN THE ISTANBUL METRO NETWORK
M1	Yenikapı-Ataturk Airport-Kirazlı	26,80 km	149.474.313	30,17%
M2	Yenikapı-Hacıosman	23,49 km	161.021.092	32,50%
M3	Basakşehir-Kirazlı	15,60 km	23.673.379	4,78%
M4	Kadıköy-Kartal -Tavsantepe	26,20 km	88.622.395	17,89%
M5	Uskudar–Umraniye-Cekmeköy	20,00 km	66.521.391	13,43%
M6	Levent-Hisarüstü	3,30 km	6.070.993	1,23%
TOTAL	**-**	**115,39 km**	**495.383.563**	**100%**

Among the lines in the table, the cost and time overruns for Aksaray – Ataturk Airport phase of M1 line, Kadıköy-Kartal phase of M4 line and Uskudar-Cekmekoy section of M5 line are investigated. The reason for choosing these phasses for analysis is that all data related to these projects can be accessed, the projects have been currently under operation and the cost and time have been emerged clearly.

The tenders were held in different currencies such as Turkish Lira (TL), Swiss Francs (CHF), US Dollar (USD) and Euro. General information about the projects and cost and time overrun values are given in the table. Table 2.

Table 2. Cost and time overrun in three metro projects.

LINE CODE	PROJECT NAME	LENGTH	CONTRACT PRICE	COST OVERRUN	TOTAL CONTRACT VALUE	COST OVERRUN (%)	STARTING DATE	CONTRACT DURATION (DAYS)	EXTENSION OF TIME (DAYS)	COMPLETION DATE	ACTUAL PROJECT DURATION (DAYS)
M1	Aksaray-Yenibosna Phase (Civil and E&M Works)	12,20 km	640.766.720,00 CHF	447.960.013,95 CHF	1.088.726.733,95 CHF	69,91%	22.05.1986	1620	1761	25.08.1995	3382
	Yenibosna - Ataturk Airport Phase (Civil Works)	2 km	3.154.296.440.000,00 TL	1.110.943.210.00 0,00 TL	4.265.239.650.000,00 TL	35,22%	9.12.1999	365	222	18.07.2001	587
	Yenibosna - Ataturk Airport Phase (E&M Works)		2.210.321.730.000 TL + 5.170.055 USD	424.381770000 TL + 992.650,56 USD	2.634.703,50 TL + 6.162.705,56 USD	19,20%	7.09.2001	360	57	20.12.2002	469
M4	Kadıköy-Kartal Metro Phase	21,17 km	751.256.042,50 EURO	150.100.957,29 EURO	901.356.999,79 EURO	19,98%	21.03.2008	900	709	17.08.2012	1610
M5	Uskudar – Umraniye – Cekmekoy Metro Line	20 km	563.899.995,32 EURO	112.721.046,64 EURO	676.621.041,96 EURO	19,99%	20.03.2012	1140	1266	21.10.2018	2406

The reasons of these increases in the costs and time of the projects are explained in the following sections.

M1 Metro Line

The tender for the first phase (Aksaray – Yenibosna) of the M1 metro line (Figure 1) was held in 1989 for around 640 Million CHF. The main purpose in the planning of the line was to connect the historical and touristic peninsula of Istanbul to the Coach Station and Ataturk Airport. Construction works on the line, the contract duration of which was 1620 days, began on May 22, 1986.

The Aksaray – Otogar (Coach Station) section, which constitutes the 8.6 km part of the Aksaray-Yenibosna phase of the metro line, was opened on December 24, 1989.

Following these opening, Otogar (Coach Station) – Yenibosna section was revised. As part of this revision, the route of the this section, which passes from the north of the first ring road, one of the main highway axes of Istanbul, to reach Ataturk Airport, has been changed to passing from the south of the first ring road. The main reason for this change was the fact that the number of passengers would be higher in the south of the first ring road.

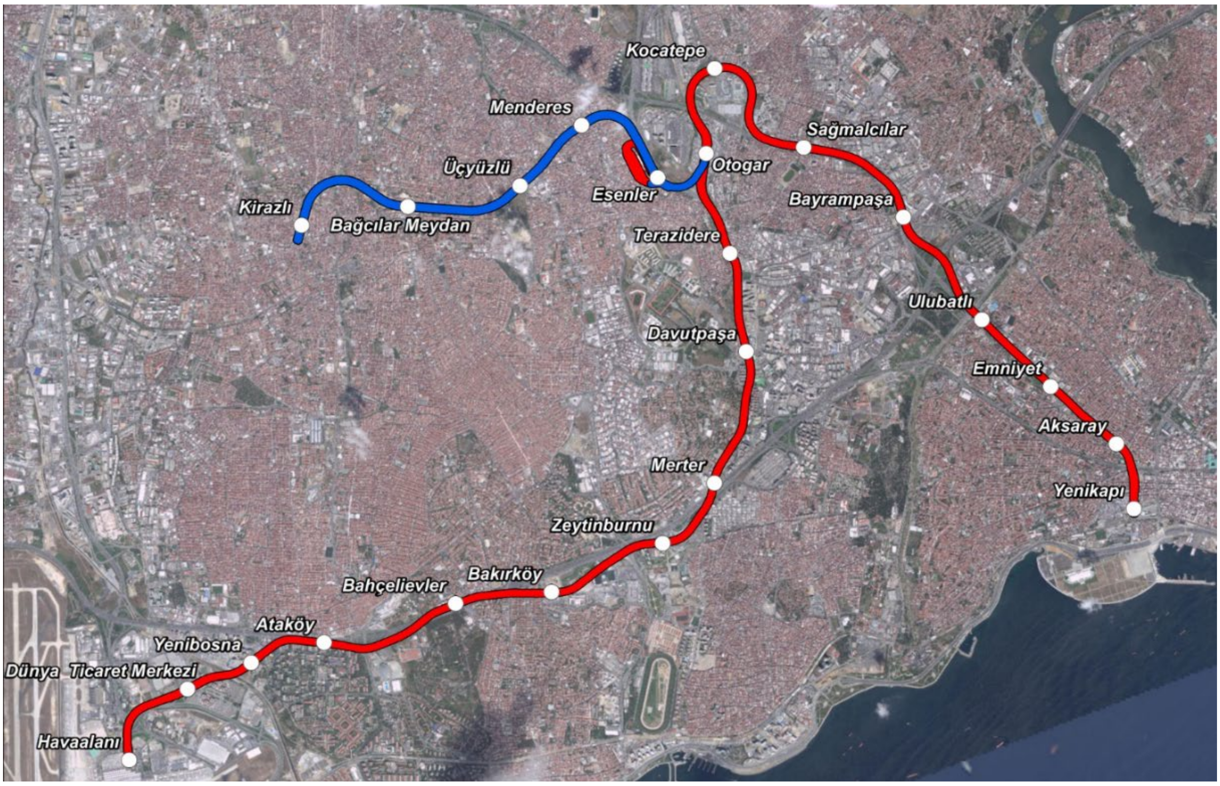

Figure 1: General view of M1 (Yenikapı – Ataturk Airport Metro Line).

With the effect of this revision, the design process had been restarted. Aksaray - Yenibosna phase of the project was opened on August 25, 1995 with total contract value of around 1 Billion CHF due to the resulting design revision and quantity increases.

The tender for civil woks of the second phase (Yenibosna – Ataturk Airport) of the M1 metro line was held in 1999 for 3.154.296.440.000,00 TL. The contract duration of project was 365 days and works began on December 9, 1999.

Two years after the civil works started, the E&M works tender of Yenibosna - Airport phase was held for 2.210.321.730.000 TL + 5.170.055 USD. The contract duration of project was 360 days works began on September 7, 2001.

Due to the design revisions, construction site site handover problems and quantitiy increases, Yenibosna – Ataturk Airport phase of the project was opened on December 20, 2002 with total contract value of 4.265.239.650.000,00 TL for civil works and 2.634.703,50 TL + 6.162.705,56 USD for E&M works.

Total Contract Value and Actual Project Duration of Aksaray – Yenibosna and Yenibosna – Ataturk Havalimanı phases of the M1 (Yenikapı - Ataturk Airport) Metro line is summarized in Table 3.

Table 3. Total contract value and actual project duration of Aksaray–Ataturk Airport phase.

PROJECT PHASE	CONTRACT PRICE	TOTAL CONTRACT VALUE	CONTRACT DURATION	ACTUAL PROJECT DURATION
Aksaray-Yenibosna Phase	640.766.720,00 CHF	1.088.726.733,95 CHF	1620 days	3382 days
Yenibosna - Ataturk Airportı Phase (Civil Work)	3.154.296.440.000,00 TL	4.265.239.650.000,00 TL	365 days	587 days
Yenibosna - Ataturk Airport Arası (E&M Works)	2.210.321.730.000 TL + 5.170.055 USD	2.634.703,50 TL + 6.162.705,56 USD	360 days	469 days

M4 Metro Line

The tender for the first phase (Kadıköy - Kartal) of the M4 metro line (Figure 2), which is the first metro line in the İstanbul's Anatolian Side, was held in 2008 for around 750 Million EURO.

The contract duration was 900 days and works started on March 23, 2008. The line was integrated with the Marmaray line crossing the Bosphorus. Besides, it was aimed to connect the high-density residential areas in the East of the Anatolian Side to the Bosphorus shores, which are the commercial and historical center of the city and located in the west of İstanbul's Anatolian Side.

During the planning phase of the Kadıköy - Kartal - Tavsantepe Line, a depot and maintenance area was planned to be constructed near by the Tavşantepe Station of the line. Also, it is planned that this depot and maintenance area construction will be carried out in parallel with the tender of the second phase of the line (Kartal - Tavsantepe) and depot area works would be completed before opening.

In the later stages of the construction, it was observed that the tender for Kartal - Tavsantepe section, the second phase of the line, would be delayed. For this reason, in order to connect the line between Kadıköy and Kartal to the depot area, TBMs continued to be driven after passing the Kartal Station and tunnel construction works between Kartal Station and Warehouse Area were included in the scope of the contract.

However, after a while, it was seen that estimated cost of depot and maintenance area, which is planned to construct near by Tavşantepe Station, is extremely high due to expropriation cost and the design and tender process of the this area was canceled. Therefore, construction of a temporary depot and maintenance area, which is fully underground and close to Maltepe Station, was included to the scope of the work and TBMs continuing the excavation between Kartal and Tavsantepe were stopped and dismantled.

With minor design changes and quantity increases that occurred in addition to the two major changes listed above, Kadıköy – Kartal phase of the project was opened on August 17, 2012 with total contract value of around 900 Million EURO.

Figure 2: General view of M4 (Kadıköy – Kartal - Tavşantepe Metro Line).

M5 Metro Line

The tender for M5 metro line (Figure 3), which is the second metro line in the İstanbul's Anatolian Side, was held in 2011 for around 560 Million EURO. The contract duration of project was 1140 days and works began on March 20, 2012.

The reasons that emerged in the later stages of the project and led to cost and time oveerun are listed below:

- because of the quantity increases that emerged during the implementation phase of the work as the Uskudar –Umraniye - Cekmekoy Metro Project is fully underground,
- changes in construction methodology of Altunizade Station which was designed as a level-crossing structure but was constructed as an underground station due to the lack of permission from the relevant institutions,
- extension of the line length due to the change in location of the Uskudar switch tunnel
- changes in construction methodology of councorse level of Necip Fazıl Station due to its environmental impacts,
- project revisions to design upper level of the Cekmekoy Station as a car park and additional works that emerges in the Depot and Maintenance area.

With these major design changes and quantity increases, Uskudar – Yamanevler section of the line was opened on December15, 2017 and Yamanevler – Cekmekoy section of line was opened on October 21, 2018 with the total contract value of arounf 670 Million EURO.

Figure 3: General view of M5 (Uskudar–Umraniye–Cekmekoy Metro Line).

Discussions

In order to measure the planning and implementation performance of projects, cost and time overrun values for analyzed parts of three metro lines given above are used through data obtained from the Istanbul Metropolitan Municipality Department of Rail System data base and interviews.

Cost overrun ratio for Aksaray – Yenibosna Phase of M1 Line is calculated as 69,19% while the ratio is 35,22% for civil works and 19,20% for E&M works of Yenibosna – Ataturk Airport phase. Besides, extension of time for Aksaray – Yenibosna Phase of M1 Line is determined as 1761 days while the value is 222 days for civil works and 57 days for E&M works of Yenibosna–Ataturk Airport phase.

In Kadıköy – Kartal phase of M4 Line, cost overrun ratio is calculated as 19,98% while extension of time is 709 days. For the M5 Line (Uskudar – Umraniye – Cekmekoy Metro Line), cost overrun ratio is found as 19,99% and time extension is computed as 1266 days.
When the construction process of the three metro lines is examined, it is seen that the main factor causing cost and time overrun is the including additional works to project scope at the implementation stage, which are not taken into account in planning phase. Cost and time overruns emerging due to design changes resulting from these additions work as well as increases in quantities have caused projects to be completed higher cost and duration than considered in tender phase.

Conclusion

In this study, the cost and time overruns of three metro lines constructed in Istanbul in a 30-year period are evaluated. After reviewing literature, Istanbul Metropolitan Municipality data base and helding a semi-structured survey with technical experts, municipal officials and other professionals on cost and time overrun of three metro lines, it could be concluded that design changes could be evaluate as major cause for cost and time overrun. This situation is thought to be the result of insufficient planning stage, the rapid and unplanned growth of the city and the rapid change in public transportation demand.

In addition, it has been determined that quantity increases, and site handover delays are other reasons affecting the cost and time overrun.

In future studies, it is thought that with robuster data sets including different case studies and the statistical analyzes to be carried out for evaluating the root causes via factors such as planning, implementation, geographical conditions, financing and line length will yield extremely good results for the efficient use of public resources in urban rail system investments.

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Recent Developments in Utilization of Glass as Aggregate in Concrete Industry: Effects on Sustainable Construction

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Abstract

Sustainable development in the construction industry aims to improve the quality of life. It covers environmental, economic and social dimensions, as well as the concept of management, responsible management of the resources that are used in construction, and especially concrete production. Preserving natural resources is an important responsibility for the whole world. Significant improvements in the use of alternative materials are being done in construction to limit the impact of CO_2 emissions due to construction. It is very important to use available resources wisely and efficiently to maintain ecological balance. Glass is one of it in recent years. It is widely used in our lives with products such as glass, glass plates, bottles, glassware and vacuum tubes. Glass is an ideal material for recycling. Using recycled glass helps save energy. Increasing glass recycling awareness accelerates inspections related to the use of waste glass in different forms in various fields. One of its important contributions is in the construction area where waste glass is reused for concrete production. This study mentions the sustainable usage of recycled glass as aggregate replacement in concrete.

Keywords: *aggregate, CO_2 emission, construction industry, sustainability, waste glass.*

Introduction

Sustainable construction is defined in different ways as; "the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from siting to design, construction, operation, maintenance, renovation and deconstruction", but more comprehensively, sustainability can be considered from three dimension of planet, people and profit across the entire construction supply chain. Key concepts include the protection of the natural environment, choice of non-toxic materials, reduction and reuse of resources, waste minimization, and the use of life-cycle cost analysis. Sustainable construction mainly aims to reduce the negative environmental impacts generated by construction industry. In order to decrease CO_2 emissions and to preserve the natural resources, a great effort has been noted over the last decades to utilize industrial waste, by-product or recycled materials in construction industry. If a material is fully sustainable, then embodied and operational energy must be low.

The construction materials which need globally per year is approximately 13,000 tons only for the sustainable construction industry; and the amount of limestone, clay material and sand in these materials is about 80%. One of the main reasons of the polluted environment is the industrial waste material. With time pollution has affected our environment gradually as a result of waste generated from industries. Therefore, there has been a growing interest to recycle the waste materials. The main reason of recycling is to conserve energy, help the environment, reduce pollution, slow global warming and lower waste products in landfills. Through recycling, less materials are placed in the landfills, and there is more room in the landfills for non-biodegradable garbage materials.

Concrete, consisting primarily of cement, water and aggregates, is the most used construction material all over the world and plays an important role in the growth of infrastructure and industrial sectors. Cement manufacturing industry is one of the CO_2 producing sources that is caused global warming. However, using the waste materials and by-products as cement replacement materials become an attractive alternative because it helps to reduce the cost of concrete and cement manufacturing, also has numerous indirect benefits such as saving energy, reducing landfill cost and protecting the environment from possible pollution effects.

Civil engineers are always searching about waste materials that can be used as a mixing ingredient in cements in order to reduce its cost and to improve its quality. There are several studies related with the utilization of waste materials in construction. Every year, a large amount of waste is produced and most of these waste is not recyclable. (Sakalkale et al., 2014).

Concrete is the most used man-made building material and its demand is increasing day by day. Conventional concrete aggregate consists of sand (fine aggregate) and various sizes and gravel or stone shapes (coarse aggregate). Since, using natural resources harm the environment, using waste glass as aggregate replacement will make the concrete manufacturing industry more sustainable. Increase in the use of glass products in recent years caused an increase in the waste glass amount. As United Nations mentioned, about 7 % of the yearly disposed solid waste materials are glass, which has an adverse impact on the environment. There is great potential for using waste glass in the concrete construction industry. When the waste glasses are reused in the production of concrete products, the production cost of concrete will decrease (Topcu and Canbaz, 2004). And also cause environmentally sustainable construction by using less natural resources (Malik et al., 2013).

A study by Afshinnia and Rangaraju (2016) stated that although there has been increasing effort to recycle glass waste in recent times, over 50% of collected waste glass in some parts of the world is still being disposed of in landfills. For instance, in the United States, 11,480 thousand tonnes of waste glass was generated in 2014 and only 26% was recycled, with the remainder being landfilled (U.S. EPA, 2014).

The use of recycled materials such as broken glass in place of coarse aggregate in concrete has presented itself as an innovative idea with multiple advantages. First, it has economic benefits. This refers to the reduction in the overall construction cost, including the cost of required transport and mix design requirements (Luz and Ribeiro, 2007). Second is its compatibility with other materials; the waste materials used must not have an adverse reaction with other materials in the mixture (Smith and Hashemi, 2011). Third is the concrete properties. The ability of waste glass to take part in the alkali-aggregate reaction (Ganiron Jr, 2014).

Glass

Glass is a hard and fragile material prepared by melting sand with sodium carbonate and lime ($CaCO_3$) and cooling rapidly. It can be found in many forms and it is hundred percent recyclable material with high performance. Glass is one of man's most innovative inventions. The unique properties of glass made it applicable in various industries, including windows in buildings and cars, or bottles for beverages. The life of glass is short. Therefore, it needs to be recycled often to prevent environmental disasters from its compilation. The use of glass in construction industry has provided an innovative and environmental friendly avenue for glass disposal. The quantity of waste glass continuous to grow rapidly. Industrialization and improved living standards are some of the contributors to the growing waste glass quantity.

Uses of Recycled Waste Glass

The waste glass utilization in concrete can be in 3 forms; cement replacement, coarse aggregate replacement and fine aggregate. Advantages of waste glass usage are:

- Cuts waste disposal costs, which are likely to rise due to landfill tax.
- Conserves the environment by saving a significant amount of primary raw materials each year.
- Improve the life of our landfill sites, helping to preserve the countryside.
- Saves a considerable amount of energy and reduces the amount of CO_2, NO_x and other air pollutants from the manufacturer of cement clinker when ground glass powder used as a cement replacement.
- Increase public awareness of the problem of waste and benefits of recycling.
- Offers many alternative uses for recycled glass based products, without compromising on either cost or quality (Sudharsan et al., 2018).

A study by Shayan and Xu (2006) observed that glass powder could be used as a substitute for aggregate or cement in concrete up to 30% without any negative long-term effects on the concrete. In addition, field trial application of waste glass in concrete slab led to the recommendation of the use of combined glass aggregate and powder to produce 40 MPa concrete mixtures (Shayan and Xu, 2006).

Topcu and Canbaz (2004) reported a decreasing tendency in the mechanical properties of concrete mixtures containing waste glass content as coarse aggregate replacement as the glass content increases. Results obtained by Olofinnade et al. (2017a) show a similar decreasing tendency for compressive and tensile strengths. However, it was found that 25% waste glass could be incorporated as a coarse aggregate replacement in concrete to improve the compressive strength of the concrete. Park, Lee, and Kim (2004) reported that the strength properties of concrete containing waste glass as fine aggregate exhibited a decreasing tendency with increasing waste glass content. A study by Olofinnade, Ndambuki, Ede, and Olukanni (2016b) recommended the use of combined fine and coarse glass aggregate by up to 25% content in concrete (Oluwarotimi et al., 2018).

In addition, Ismail and Al-Hashmi (2009) opined that the observed low strength in glass concrete could be attributed to the weak adhesive bond between glass aggregate and the cement paste. Previous works have also reported the use of waste glass in finely powdery form as a partial substitute for Portland cement in concrete. From previous studies, it was reported that ground glass possesses pozzolanic capability at particle sizes below 100 μm, and its addition to concrete. (Oluwarotimi et al., 2018)

The development of an appropriate production technology should recognize the differences between glass and natural aggregates. For example, the basically zero water absorption of glass improves the mix rheology and calls for quite different mix designs, including the choice of admixtures, which also depends on whether a dry or wet technology is used.

Since plain Glass Concrete is quite brittle, just like conventional concrete, it is advantageous to reinforce glass concrete products with either randomly distributed short fibers or, in the case of thin sheets or panels, with fibermesh or textile reinforcement. (Meyer et al., 2001)

Many studies concluded that the use of crushed waste glass creates a good abrasion resistance and lower shrinkage in dry conditions in comparison to plain concrete. In addition, concrete with waste glass has lower water absorption compared to plain concrete (Anna, 2013). The use of glass as aggregate affects the mechanical properties of concrete. Explaining further that the low adhesion and bond strength between the cement paste and glass aggregate in combination with the relatively smooth glass surfaces alters the mechanical properties as stated in Meyer et al. (2001).

Topcu and Canbaz (2004) stated that concrete mechanical properties are reduced when glass wastes are used and Park et al. (2004) also concluded that using waste glass as fine aggregate replacement in concrete mixture reduces the slump value. Indicating that as the replacement level increases, the mechanical properties decreases.

Using waste glass as partial replacement of fine aggregate was reported by Shehata et al. (1996). The mechanical properties of concrete showed an increase in modulus of rupture due to improvement in the interfacial bonding between cement paste and aggregate and the glass aggregate also plays the role of cracks arrestors, stopping cracks from advancing. Shayan (2002) reported that the maximum percentage by weight of normal aggregate that could be replaced by glass for both coarse and fine aggregate is 50% in both structural and non-structural applications. Using suitable pozzolanic materials minimize the negative effect of ASR.

Serniabat et al. (2014) used waste glass as coarse aggregate in concrete at different 9 proportions. The glass is crushed at 5 mm-20 mm size, using ordinary Portland cement type 1 with fine sand less than 0.5 mm, coarse aggregate was replaced at 0, 10, 20, 30, 40, 50, 60, 70, and 80%. They observed a maximum compressive strength of 26.8 MPa at a balance ratio of glass beads.

Gerges et al. (2018) used recycled green waste bottles to replace coarse aggregate at 33, 50, 66 and 100% replacement ratios. Their experiment concluded that 33% was the appropriate percentage replacement to maintain concrete properties. They concluded that the use of glass in concrete has significant influence on both fresh and hardened properties of concrete.

Kereyou and Ibrahim (2014) used windows waste glass as substitute in concrete coarse aggregate. The replacement of coarse aggregate was at 0, 20, 25, and 30% replacement ratios. They studied the fresh and hardened properties of the specimen at 28 days. They concluded that there are optimal economic effects at 25% coarse aggregate replacement.

The study of Al-Bawi et al. (2017) used recycled waste glass as a partial replacement of aggregate in self compacting concrete. The specimen was tested at different weight percentages of 0, 20, 40, 60, 80 and 100%. Water to binder ratio of 0.35, total binder content of 570 kg/m^3, and constant slump flow of 700 ± 30 was used. The specimens were tested at age 28 days. They concluded that the waste glass content decreased the brittle nature of the concrete compared to the reference concrete.

Effects of Waste Glass on Properties of Concrete

The use of waste glass to replace the aggregate in concrete affects the properties of concrete. The physical properties of waste glass are approximately the same with sand, hence it is used as an aggregate. Sand has 0.36% absorption and specific gravity of 2.19 whereas waste glass has 2.71% and 2.57, respectively. Their density values are very similar with 1672 and 1688 kg/m^3 for sand and waste glass, respectively. Effect of waste glass on fresh and hardened mortars are given below summarized from different researches.

Slump Test: The research conducted in Topcu and Canbaz (2004) revealed that the rise in waste glass in the concrete mixture decreased the slump value by about 0.2% due to poor geometry of waste glass and it also reduced the workability by about 1.5% in the study carried out by Andrić et al. (2017) where a 0.45 water cement ratio was used with waste glass as aggregate in concrete.

Compressive Strength Test: Most studies have shown that that compressive strength decreases as the amount of waste glass increases (de Castro and de Brito, 2013; Topcu and Canbaz, 2004). The analysis of Serniabat et al. (2014) on 9 different mixtures of waste glass in concrete crushed at 5mm-20mm demonstrates a maximum compressive strength of 38891 psi (268.14 MPa). Additionally, the findings of Al-Zubaid et al. (2017) indicate that 13% waste glass replacement has the highest compressive strength after 7, 14, and 28 days. However, the compressive strength increased by about 28.7 % after 7 days at 10 % glass replacement and there were no increase in compressive strength after 28 days as investigated by Ganiron Jr. (2014).

In contrast, some findings have shown that the compressive strength of concrete is also influenced by the size of waste aggregate. This is attributed to the pozzolanic properties of waste glass used .It was found that concrete compressive strength has improved by Ildir et al. (2010) from 30-35 MPa when the size of the aggregate is at 80 μm.

Flexural Strength Test: Results from several studies shows that as waste glass quantity increases, the flexural strength of concrete decreases due to reduction in adhesive strength of glass particles due to the reduction in adhesive strength of glass particles (Jani and Hogland, 2014 ; Topcu and Canbaz, 2004). Contrary to most research, a rise in flexural strength by 20 % was observed when waste glass and sheet glass powder were used as fine aggregate in concrete according to Batayneh et al. (2007), and Mageswari and Vidivelli (2010) respectively. The study of Al-Zubaid et al. (2017) also shows that the flexural strength of concrete containing waste glass increased compared to the conventional concrete where 13% partial replacement proved to have the highest flexural strength at 7, 14, and 18 days due to the increase in the amount of ($CaCO_3$) in the concrete.

Splitting Tensile Strength Test: Utilizing waste glass as an aggregate in concrete produces variation in results with regards to its effects on tensile strength. Results of several research indicate that as the amount of waste glass increases, the tensile strength of concrete decreases by 10 % in the study of (Topcu et al., 2014) and by 37 % in the research performed by Park et al. (2004) due to its amorphous structure.

Furthermore, several results have found that there has been a rise in tensile strength of concrete by 20% in the study of Mageswari and Vidivelli (2010) and by 25% in the Tan and Du (2013) research due to an increase in the percentage of waste glass .Thus they concluded that as the percentage of waste glass increases, the tensile strength of the specimen increases. Similar findings were observed by Al-Zubaid et al. (2017) but the splitting tensile strength decreased at 15% partial replacement compared to its gradual increase at 11 and 13%.

Water Absorption Capacity Test: The study of Taha and Nounu (2008) stated that, using waste glass reduced the water absorption capacity of concrete and restrict the movement of micro-cracks and moisture migration.

Alkali-Silica Reaction (ASR) in Waste Glass Concrete: Glass and sand are concentrated with silica, but behave very differently. This is due to the properties of silica in sand because the structure is regular crystalline, which makes it stable and resistant to chemical influence. Glass on the other hand is in amorphous form which is not stable. This observation has been the topic of intensive research.

The use of glass powder in concrete has shown promising results in mitigating ASR in concrete where the use of glass in concrete as 20% and 30% replacement of aggregate by Afshinnia and Rangaraju (2015) and as 10, 20, 30, and 40% replacement by Ammash et al. (2017) showed effective results in mitigating ASR in specimens. The same results was also observed by Zheng (Zheng, 2016).

There are a number of measures to avoid ASR or its damaging effects for instance : grinding the glass to pass at least U.S. standard mesh size #50;adding mineral admixtures that can effectively suppress the reaction; making the glass alkali-resistant, for example, by coating it with zirconium (a solution chosen by the glass fiber industry, but impractical for post-consumer waste glass); modifying the glass chemistry, if that is an option, e.g. for specialty glasses; sealing the concrete to protect it from moisture, either on a micro- or component level, because ASR needs three factors to thrive: alkali, silica, and moisture; using a low-alkali cement, which is likely to be less effective, unless alkalis from the environment can be kept away; developing special ASR-resistant cements, some of which are already being offered commercially (Meyer et al., 2001).

Conclusions

For many years, the recycling and waste management industry has been dealing with the problem of identifying or developing reliable markets for mixed color broken glass. To date, there are only low-value applications that do not use the physical and other natural properties of glass. Recent research has made it possible to use this metal in concrete, either in commodity products, as much as one goal, or in value-added products that fully use the physical and aesthetic properties of concrete (Meyer et al., 2001).

Saving the world is a global issue and many stakeholders are looking for ways to limit energy use and reduce its impact on the environment, research has observed that glass is a sustainable building component. The general mechanical characteristic strength of concrete, which recycles waste glass in older ages, was better than conventional concrete. Building construction is a convenient and profitable environment for using recycled waste glass. Waste glasses are preferred because total dependent cement is not sustainable due to high CO_2 emissions.

However, engineering standards need to be a guide for the application of recycled waste glass in construction. This control measure has the potential to make the use of recycled material more expensive than natural aggregates. The construction industry is involved in making profits, ensuring long-term durability of structures, and also has corporate social responsibility to protect the environment, so re-evaluation to reduce the use of cement and natural aggregates in their activities due to environmental impacts. It is in their interest to find ways to incorporate the use of recycled glass without any detrimental effect on industrial profits and structural durability. Efforts to push waste glass into the structure require continuous research and development. Research on cost analysis should be done to confirm or reject the economic concerns of using waste glass in construction. Glass wastes used for construction will help reduce the volume of waste glass going to landfill and will also represent the potential to reduce the amount of natural aggregate required for construction. Processing waste glass and moving it to the desired building construction resources may require higher energy consumption and also increase emissions. This action loses its purpose of using recycled waste glass, so it is anticipated that a life cycle analysis will evaluate the impact of recycled waste glass on the building and reports will be produced to assist the adoption of recycled waste glass in the construction industry. Then, to change the perspective of recycled waste glass as a component in building construction, stakeholders can offer rewards to the construction industry by highlighting the great potential of using recycled waste glass in the construction industry through the government. The government should also enact legislation that encourages and encourages the use of recycled materials in construction. Mix ratios, glass shape and its size, and type of processing the waste glass should be defined (Ogundairo et al., 2019).

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Effects of Apartment Buyers' Demographic Characteristics on the Success of the Transaction between Buyer and Developer

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Abstract

The number of new residential projects has been increasing over the years because of population growth and urban transformations. The organizational arrangement of these projects takes several forms including government-subsidized residential projects, commercial developments, and turn-key projects. Most apartment buyers and developers prefer commercially developed projects because they provide flexible payment options for buyers and easy financing for developers whose cash flow is sustained by the periodic payments made by buyers. Even though some projects start and are completed on schedule, within budget, and in good quality, it is observed that many apartment buyers face the situation where the purchased apartment unit does not satisfy their basic requirements because of extensive delays, cost overruns, and/or quality-related problems. In this paper, the effects of the demographic characteristics of apartment buyers on the success of the transaction between the buyer and the developer is investigated. The correlations between buyers' demographic characteristics and their perceived success of the transaction are evaluated. One of the results of this study is the significant relationship between the contract price and the success of the transaction. It was also found that the success of the transactions that involved payment by instalment is higher.

Keywords: *housing projects, build-sell system, transaction success.*

Introduction

The construction industry is important both for the welfare of the people and the economy of the country. The construction industry is vital for the economic development of a country because the physical development of infrastructure such as roads, bridges, coastal structures, power plants, and buildings is a measure of economic growth (Alzahrani & Emsley, 2013). Indeed, a growing economy progresses in parallel with the development of a country's physical infrastructure, such as the country's industrial areas, residential units, and transportation network (Tabish & Jha, 2011). Significant studies in this industry are at the core of the hierarchy of needs for the development of infrastructure. The construction industry acts as a catalyst for growth in other sectors such as manufacturing, transportation, and financial services due to its broad ties with many other industries (Yong & Mustaffa, 2013). At the same time, workers in the construction industry constitute a significant portion of the working population and the construction industry makes a significant contribution to the Gross Domestic Product (GDP) (Nilashi et al., 2015). For these reasons, the development of the construction industry is always one of the most important goals of governments, as the construction industry provides employment for much of the population and improves the health of the national economy. So, governments formulate policies to support construction activity, but they are faced by the question "how does one measure the success achieved in construction projects?" It is therefore necessary to look into construction projects from a more detailed perspective, i.e., to examine the paths to success in construction projects, to identify the success factors, and to investigate the relationships between these factors in the context of each stakeholder.

Every residential project has a multi-factor and multi-shareholder process. This feature causes the residential construction sector to be more unstable and complex than other sectors. Compared to other industries, the success of a residential construction project is difficult to predict because residential construction involves complex interactions between many stakeholders and significant risks that may create serious consequences (Ribeiro et al., 2013). The fact that the activities performed on a residential construction site are quite heterogeneous (Chau, 2004: from Ribeiro et al., 2013) adds to the difficult processes in the building construction industry in every respect. This situation may lead to various conflicts that can prevent the successful completion of even the best managed project (Elattar, 2009). Many problems that result in disagreements between the parties are caused by inadequate cooperation, lack of trust, and poor communication (Chan et al., 2004). It is important to set up a general framework to define success in residential construction projects. The idea is to minimize or even eliminate buyers' dissatisfaction and the unnecessary expenses associated with buyers' dissatisfaction with the constructed unit. One of the biggest building blocks of the urbanization phenomenon, which aims to meet the needs of the rapidly growing urban population of our age, is the construction of enough apartment buildings. This situation requires the successful design and construction of many residential projects to the satisfaction of the many buyers. Despite the significant increase in the number of new residential buildings in recent years in Turkey, the need for residential buildings completed to the satisfaction of buyers is still ongoing (GYODER, 2018). Residential projects constitute a large part of the building construction industry. Thousands of residential projects begin every year in Turkey and are expected to be completed within a certain period of time. For example, 1,375,398 residential units were sold in 2018 and almost half of these units had been newly completed (Construction Sector Report, 2019). Residential projects include government-subsidized projects, commercial developments, and turn-key projects. Most apartment buyers are familiar with commercially developed apartment buildings and commonly prefer to buy from developers. Typically, the sale is made before the building is completed (build/sell) and often before construction starts (sell/build) (Kılıçarslan, 2017). Such an arrangement represents a common sale system. Whether this sale system is considered successful depends on various factors.

To date, there is no clear generalized definition of project success (Baccarini 1999: from Rashvand & Majid, 2014). There are many different definitions in the literature that describe the success of a project. The lack of a universally accepted project success definition and the fact that the concept of success remains unclear in the minds of the stakeholders make it difficult to qualify a project as successful or unsuccessful (Tabish & Jha, 2011). For example, for buyers, project success is based on criteria such as completion time, cost, quality of construction, aesthetic value, financial appeal; for designers, it is based on buyer satisfaction, and well-defined scope of work; and for the contractor, it is based on completion time, cost, quality, profit, and satisfied expectations of all parties (Han et al., 2012). A project that is thought to be successful by the buyer may not necessarily comply with the contractor's success criteria (Belassi & Tukel, 1996). When project success is analyzed in general, three main success criteria are considered: budget, schedule, and quality (Elattar, 2009). In line with these main success criteria, relevant sub-criteria are also considered, and a customized model is developed for each project. Toor and Ogunlana (2010) report that the three main criteria are not sufficient due to changing user/buyer demands, environmental regulations, and different building functions. They state that old-fashioned performance criteria (i.e., cost, time, quality) could not be the sole determinants of project success and that other criteria such as safety and environment have become quite important (Alzahrani & Emsley, 2013). Traditionally, success can be defined as the extent to which project goals and expectations are met (Chan et al., 2002). A project is considered successful if it is finished on schedule or earlier, within the specified budget, and meets output and service quality and profit expectations (Ling & Bui, 2010).

When a construction project is completed on schedule, within budget, in compliance with specifications, and receives stakeholder satisfaction, it is widely accepted as successful (Chan et al., 2002; Nguyen et al., 2004). Success criteria are the criteria by which the success or failure of a project will be evaluated. Success factors are inputs of the management system that directly or indirectly affects the success of the project (Nguyen et al., 2004). In short, the factors or effects that contribute to the result can be called the factor of project success (Masrom et al., 2015). There are many differences between the success factors in construction projects and the success factors in other sectors (such as informatics, production) rather than their similarities (Toor & Ogunlana, 2008). The reason of this; Each construction project has its own unique features and has its own success factors. There are many lists or models in the literature about success factors. The critical success factors among them contain various substances that affect success or failure. The reasons such as the area, environment and where the study was revealed different success factors. The purpose of this study is to examine the effect of demographic characteristics of the housing buyers on the success of the project.

Research Method

The sale of an apartment can take place before construction begins, after construction begins but before construction is finished, or after construction is finished. A questionnaire was developed for this study that investigates the sale of apartments before the start of construction or during construction. The questionnaire was administered by a consultant. The sample of respondents was composed of apartment buyers in three large metropolitan areas in Turkey, Istanbul, Ankara, and Izmir. The surface areas of the provinces where these cities are located are the largest in Turkey. Interviews were held with 250 apartment buyers in these three cities. These buyers bought an apartment in the design phase or during construction in the last two years. The buyers were asked 20 questions about buyers' demographic information such as their education level and their monthly income, and about the project characteristics such as the quality rating, the cost, the success of the transaction, and the duration of the construction. Ten hypotheses were developed to test the effects of buyers' demographic features on transaction success (see Table 1).

Table 1. Hypotheses.

No	Hypotheses
1	There is no significant relationship between the gender of the buyer and the success of the transaction.
2	There is no significant relationship between the age of the buyer and the success of the transaction
3	There is no significant relationship between the monthly income of the buyer and the success of the transaction.
4	There is no significant relationship between the educational level of the buyer and the success of the transaction.
5	There is no significant relationship between the payment method made by the buyer and the success of the transaction.
6	There is no significant relationship between the buyer's prior experience with purchasing an apartment and the success of the transaction.
7	There is no significant relationship between the buyer's reason for buying an apartment and the success of the transaction.
8	There is no significant relationship between the contract duration and the success of the transaction.
9	There is no significant relationship between the contract price and the success of the transaction.
10	There is no significant relationship between the quality of the construction and the success of the transaction.

SPSS 16.0, SPSS 20.0 and Microsoft Excel 2020 were used to analyze the data collected. The Kolmogorov-Smirnov significance level and the kurtosis-skewness coefficients were examined for the compatibility of the data to a normal distribution. The Mann-Whitney U Test was used to examine the effects of the participants' demographic characteristics on the success of the transaction.

Results and Discussion

First, the normality of the data collected was tested. Since the Kolmogorov-Smirnov significance level was less than 0.05 for all data and since some of the kurtosis-skewness coefficients exceeded the [-2.00 +2.00] range, it was concluded that the data did not fit the normal distribution. Therefore, the non-parametric Mann-Whitney U Test was used in the analysis of the data. Survey data were obtained from the three largest provinces in Turkey.

Table 2. Apartment buyers surveyed, by province.

Province s	Surface areas of provinces surveyed (Turkish Statistics Institute 2019) (Millions of square meters)	Number of Apartment Buyers (n)	Apartment Buyer Distribution (%)
İstanbul	16.2	117	47
Ankara	10.8	77	31
İzmir	7.5	56	22
Total	**34.5**	**250**	**100**

The surface areas of these provinces (Turkish Statistics Institute, 2019) and the distribution of the respondents in these three provinces are presented in Table 2. The responses related to the participants' demographic characteristics including gender, age, province of residence, educational status, occupation, and monthly income are summarized in Table 3.

Table 3. Distribution of residential buyers by demographic characteristics.

Demographic Information about Buyers		**Number of Respondents (n)**	**Percentage of Respondents (%)**
Gender	Female	80	32
	Male	170	68
Age	Between 25-29 years old	71	28
	Between 30-34 years old	73	29
	Between 35-39 years old	63	25
	Between 40-44 years old	25	10
	45 years old and over	18	7
City	İstanbul	117	47
	Ankara	77	31
	İzmir	56	22
Education status	Middle school diploma	2	1
	High school diploma	56	22
	Associate degree	39	16
	Undergraduate degree	126	50
	Graduate degree	27	11
Occupation	Unemployed	18	7
	Self-Employed	20	8
	Manager	18	7
	Technical personnel	43	17
	Civil servant	79	32
	Worker	72	29
Monthly income	Between 2,500-4,000 TL	38	15
	Between 4,001-5,500 TL	74	30
	Between 5,001-7,000 TL	69	28
	Between 7,001-8,500 TL	33	13
	Between 8,501-10,000 TL	13	5
	Over 10,000 TL	20	8
	Declined to answer	3	1
	Total	**250**	**100**

As can be seen in Table 3:

- Male buyers represent the majority of the respondents with 68% of all buyers, while female buyers constitute only 32% of buyers, an expected result in a patriarchal society.
- If one considers the age distribution of the buyers, it is clear that mostly young and middle-aged individuals in the 25-39 age group (82% of the participants) buy apartments from developers.
- The education level of the participants is generally high with 61% having a college degree, 38% an associate degree or a high school diploma, and only 1% less education.

- Most apartment buyers are civil servants, workers, and technical personnel (78%), indicating that salaried (fixed income) individuals tend to buy apartments more than managers, self-employed, and unemployed individuals (22%).
- Buyers of all income levels purchase apartments from developers.

Table 4. Information about apartment purchase transactions (provided by 250 buyers).

Residential Development Project Information		**Number of Respondents (n)**	**Percentage of Respondents (%)**
Payment format	Cash	36	14
	Credit	65	26
	Down payment + instalments	127	51
	Only instalments	22	9
Prior experience with buying an apartment	Yes	149	60
	No	101	40
Reason for buying an apartment	For residential purposes	157	63
	For investment purposes	93	37
Duration of construction	0-12 months	25	10
	12-18 months	63	25
	18-24 months	63	25
	24-30 months	64	26
	30 months and over	35	14
Contract price per apartment	0-150 thousand TL	16	6
	150-200 thousand TL	61	24
	200-250 thousand TL	58	23
	250-300 thousand TL	44	18
	300 thousand TL and above	71	28
Quality rating	Luxury construction	35	14
	Class 1 construction	70	28
	Class 2 construction	75	30
	Class 3 construction	53	21
	Simple construction	17	7
The most important selection criterion	Duration	59	24
	Cost	59	24
	Quality	132	53
The second most important selection criterion	Duration	79	32
	Cost	111	44
	Quality	60	24
The third most important selection criterion	Duration	112	45
	Cost	80	32
	Quality	58	23
Success of the transaction (duration)	Successful	221	88
	Unsuccessful	29	12
Success of the transaction (cost)	Successful	222	89
	Unsuccessful	28	11
Success of the transaction (quality)	Successful	206	82
	Unsuccessful	44	18

The buyer-provided information about how an apartment is purchased from a developer, the payment plan, the reason for buying, the success of the transaction relative to the time-cost-quality trilogy is summarized in Table 4.

As can be seen in Table 4:

- Apartment buyers choose the most suitable form of payment when purchasing from a developer. A little more than half of the buyers (51%) prefer to make a down payment and pay subsequent installments. This is the most preferred form of payment for fixed income and middle-income buyers. This result suggests that apartment buyers do not have sufficient cash resources and are unable to obtain the desired amount of credit from a bank, or they do not want to take out loans for other reasons. The purpose of development projects is to produce some sort of cooperative arrangement to meet the needs of individuals who cannot afford to buy residential property with instant cash (Önver, 2016).
- While 63% of the respondents indicated that the apartment is purchased for residential purposes; 37% stated that it is for investment purposes. This finding is in line with Baş Aras's (2020) study which found that while 54.89% of the participants were purchasing housing because they needed it, 21.28% were buying to improve their current conditions, and 20.85% were buying for investment purposes.
- Concerning the time-cost-quality trilogy, 132 apartment buyers marked "quality" as the most important selection criterion. The overall success of the transaction was calculated based on the perceived transaction success and the time, cost and quality weights specified by the respondents (see bottom six rows in Table 4).

As seen in Table 1, ten hypotheses were set up to examine the effects of the demographic characteristics of apartment buyers and the features of the residential development project on the success of the transaction. The Mann-Whitney U Test was used since the survey data did not fit a normal distribution. Because the distribution of some sample groups is not homogeneous and some groups are very small, the groups were combined before the Mann-Whitney U test was used. The newly grouped data are shown in Table 5. The remaining variables (e.g., gender, prior experience with buying an apartment, and reason for buying an apartment) have not been re-grouped. The summary of the Mann-Whitney U Test results is shown in Table 6.

The reason for buying an apartment has a statistically significant impact on the success of the transaction. The most important reason for buyers who buy an apartment for investment purposes behave in a more professional manner in their selection. The buyer who buys an apartment for the purpose residing in it is limited by psychological needs, familial reasons (such as proximity to school), and personal needs, and can be emotional when deciding to buy an apartment. Also, these buyers are probably buying for the first time. Indeed, according to Lundgren and Lic (2009), people's choice of housing varies depending on psychological factors. Apartment buyers' prior experience in buying similar units has no effect on the success of the transaction. The main reason for this finding is that every construction project is undertaken in specific conditions in the period it is built (economic conditions, volatility in the real estate market, etc.) (Kuruoğlu, 2002: Açıkalın et al., 2008; Canpolat et al., 2011). Each residential development project has different risks. For this reason, the successful transaction in a previously completed project does not mean that the next transaction will definitely be successful.

Table 5. Information on the data re-grouped for the Mann-Whitney U test.

Variable	New Grouping	Number of Respondents (n)
Education status	At most a high school diploma	97
	At least an undergraduate degree	153
Payment method	Cash payments	101
	Installments	149
Duration of construction specified in the contract	Less than 18 months	88
	More than 18 months	162
Price specified in the contract	Less than 200 thousand TL	77
	More than 200 thousand TL	173
Construction quality specified in the contract	Class 1 and above	105
	Class 2 and below	145
Monthly income	Less than 5,500 TL per month	112
	More than 5,500 TL per month	135
Age	Younger than 34 years	144
	Older than 34 years	106

Table 6. Mann-Whitney U test analysis summary.

No.	Relationships Reviewed	Mann–Whitney U-test: p-values	Statistical Significance
1	Gender - Transaction success	0.604	No
2	Age - Transaction success	0.902	No
3	Educational status - Transaction success	0.707	No
4	Monthly income - Transaction success	0.482	No
5	Payment format - Transaction success	**0.004**	**Yes**
6	Prior experience with buying an apartment - Transaction success	0.065	No
7	Reason for buying an apartment - Transaction success	**0.001**	**Yes**
8	Project duration - Transaction success	0.861	No
9	Project cost - Transaction success	**0.036**	**Yes**
10	Project quality - Transaction success	0.854	No

The transaction success perceived by a buyer who buys an apartment by paying in instalments is higher than the perception of a buyer who buys by paying cash. The reason for this can be that the buyers who pay in instalments follow the progress on the construction site better and the developer focuses more on the buyer's satisfaction with the transaction in order to ensure the continuity of the buyer's periodic instalment payments. As a matter of fact, any irregularity in the buyer's instalment payments can put the developer's financial situation in trouble. On the other hand, when a developer receives a one-time cash payment at the beginning of a project, it is possible that time, cost and quality may suffer as site activities become more relaxed. The apartment buyer can come from all segments of the society. It turned out that the educational status, age, monthly income, and gender of the buyer have no effect on the success of the transaction. Indeed, there is no evidence in the literature that these factors affect the success of the transaction.

Conclusion

Residential development projects constitute an important part of the construction industry and are extremely important as they represent a big chunk of the money spent on construction, they address the needs of all segments of the society, and they assume a locomotive duty in the country's economy. The transaction involved in buying an apartment from a developer has various risks. Some of these transactions are successful, while others are not. Transactions that are perceived by buyers to be unsuccessful are extremely common in Turkey. This problem primarily affects both buyers and developers, and indirectly the country's economy. It is stated in the literature that there are many factors that affect the success of a transaction that involves the purchase of an apartment from a developer.

Studies focusing on transaction success generally address the risks arising from contract terms and management issues in the life cycle of the project. Apart from these risks, there may also be risks arising from the characteristics of the buyer, which may affect the success of the transaction between the developer and the buyer. In this study, the risks related to buyer characteristics that could affect the success of the transaction were emphasized because it was observed that the buyer's reason for the purchase, the purchase price, and the form of payment may have an effect on the success of the transaction. It was found in this study that buyers who purchased apartments for investment purposes were more satisfied with the transaction than buyers who purchased apartments for residing in them. While buyers who purchased for their own residential needs made decisions based on factors such as the location of the apartment, the commuting distance to the workplace, the distance to the school, the surface area; buyers who purchased for investment preferred apartments that will increase in value in the future, hence allowing the buyer to turn the investment into cash and hopefully profit after some time. A significant relationship was found between the contract price and the success of the transaction. Apartments with high contract prices generally address middle- and higher-income groups. Buyers belonging to the middle- and higher-income groups are more likely to make payments regularly and are less likely to cause financial distress to the developer. It was also found that the success of the transactions that involved payment by instalment is higher. A buyer making periodic payments to a developer encourages the developer to continue the work. In addition, the developer who receives a one-time payment may be tempted to spend the money for unrelated activities.

In conclusion, it may be stated that it is to the buyer's advantage to pay in instalments and to pick apartments that will appreciate in the future. The data used in this study was obtained from apartment buyers in Istanbul, Ankara and Izmir. In future studies, it is recommended that all provinces be considered. In addition, the study can be expanded by including new variables such as marital status, number of children, and work status of spouses.

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The Effects of Pandemic on the Construction Sector: A Case of Coronavirus

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Abstract

The construction sector plays a key role in the world's economy. However, it is always affected significantly whenever there is a pandemic and the latest of its kind is the Coronavirus also known as the COVID-19. During pandemic, construction workers, factory workers, managers, supervisors and the construction team always faces restriction such as quarantine thereby interrupting work. Construction firms and contractors are always the most vulnerable and faces challenges from the known to the unknown. Some of the key areas been affected by pandemics in the construction industry includes the global economy, material chain supply, bidding processes, legal issues, delays in work and labor shortages.
The aim of this research is to identify the major effects of pandemics that affect the construction industry. For this purpose, online questionnaires were administered to the construction firms who are actively executing projects during the outbreak of the coronavirus. Consequently, the main effects of COVID-19 on the construction sector were identified and their impact was analyzed.

Keywords: *construction sector, coronavirus (COVID-19), economy, impacts, pandemic.*

Introduction

The construction sector continues to grow at a fast rate due to technological advancement. It plays a significant role in nation building thereby supporting the economies of both the developed and the developing countries through the execution of mega projects. Prior to the outbreak of the coronavirus pandemic, the GlobalData Construction Intelligence Centre had already predicted the acceleration of the growth in the global construction industry in 2020 up to 3.1 percent from 2.6 percent in 2019. But due the spread of COVID-19 globally, it resulted in a severe disruption in the global economy and notable among them is China and other top economies worldwide and in 2020, the forecast for growth has now been revised down to 0.5 percent (GlobalData, 2020).

The construction sector continues to face major challenges which can be deemed anticipated or unexpected. Major challenges such as labor shortage, increasing construction material costs, technological advancements and disruption, etc. are anticipated and are given much attention right from the project inception. Several major events and issues continue to plague the construction industry across the globe ranging from earthquakes, destructive hurricanes, wildfires as well as epidemics and pandemics. The consequences of these challenges have a major impact on the construction sector in several ways and this study focuses on the impact of pandemics, a case of COVID-19 in the construction sector.

The World Health Organization (WHO) and nations have put measures to prevent the spread of the pandemic. Some of these measures are quarantining the affected persons, imposing lockdowns and ban on national and international travels. These measures significantly interrupt and cause restrictions to the progress of work of construction activities. According to Epstein et.al, (2020) the global spread of coronavirus is generating unprecedented delays resulting in increasing costs, disruptions in supply chains and uncertainty on construction projects due to the measures to curb the spread of the virus. Similarly, Hendrickson and Rilett (2020), opined that, the disruption of the world by COVID-19 has resulted in a mammoth social , environmental and economic impacts and the consequences of this pandemic can only be compared with the world war one and two as well as the 1918 flu pandemic. The construction sector been the locomotive sector is not immune to the consequences of COVID-19, hence the predicament has the potential to have dire impacts which can range from short term to long-term. Therefore, understanding the impacts and analyzing their implication and the role it plays in wider economic development is a crucial task for academic research.

A thorough search in the literature revealed rare research on the impact of pandemics in the construction sector. However, Laing (2020) researched on COVID-19 impact on the economy using the mining sector as a case study. This study aims at identifying the main impact of COVID-19 in the construction sector by filling this gap. The findings of the study will help stakeholders in the construction industry to take into consideration the likely potential impact of pandemics that will enable them in planning and decision making in their future projects. The study will serve as reference for future studies and help the construction sector identify the main areas in the construction sector and to what extent it has been affected by the pandemic. To achieve this aim, literature was first reviewed from journals, major construction magazines and reliable newspapers. Consequently, questionnaires were generated from these findings and administered to active construction firms.

Coronavirus Pandemic

There have been several recorded cases of pandemics. The major ones include Spanish Flu (1918-1919), Hong Kong Flu (1968-1970) (Patrick & Krewski, 2016) and COVID-19 (2019-Present) (Wang et.al, 2020). The novel coronavirus 2019 was recorded in Wuhan by the Chinese health authorities in December 2019 (Lin et.al., 2020). Subsequently, on 11th March 2020, WHO upon assessment, declared COVID-19 disease a pandemic (WHO, 2020). The number of infected persons as at July 21, 2020 was 14,729,037 with 610,564 deaths recorded globally (John Hopkins University, 2020). The major pandemics and the deadliest outbreaks that has hit the world since the 18th century to the 20th century is given Fig. 1.

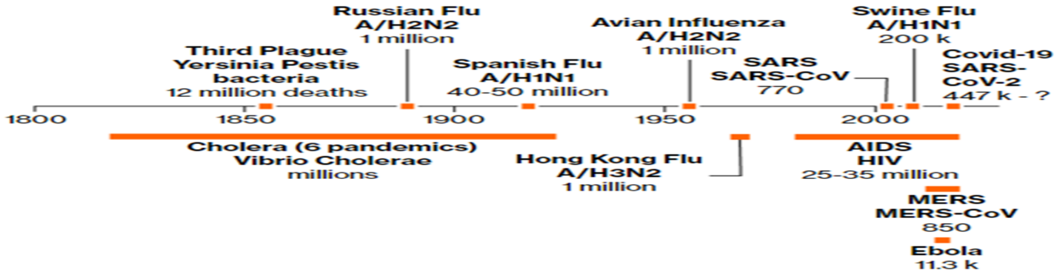


Figure 1: Major pandemics from 1800 to 2020 (Bloomberg CityLab, 2020).

While measures are taken to prevent the transmission of COVID-19, the impact of the disease is enormous on the construction sector, therefore, the impacts of COVID-19 on the construction industry is reviewed in the next section.

The Impact of COVID-19 in the Construction Industry

COVID-19 continues to spread globally affecting construction activities. As a result, the construction industry clients and contractors are considering all the guidance to complete their projects. Some of the major impact areas the clients and contractors focus most include employment guidance and the impact on project delays, chain supply disruption, legal issues among others may have negative effects on project completions. Franzese (2020) opined that, supply chain disruptions, workforce shortages owing to illness, self-isolations and preventative quarantines is unavoidable. Similarly, Hurriyet Daily Newspaper (2020) added that, delays, contract and project cancellations and low demand for real estate have affected the construction sector due to the preventive measures to curb the spread of the pandemic. Ayemba (2020), listed construction contracts issues, labor shortages, lack of project financing and construction materials shortages as the as the main impacts of COVID-19. In view of this, the main impact COVID-19 in the construction sector is discussed in detail below.

The impact of the coronavirus outbreak has affected all the major phases in construction sector and the bidding phase is not exceptional. Kendall (2020) stated that, commercial construction projects bidding has recorded a massive drop in the USA since the first case of COVID-19 was recorded. The weekly average of total projects bidding in the U.S. is approximately 20,000. However, it recorded a sudden plunge. The record of 15% increase year over year saw the percentage bottomed at -14.4% in April 2020. Consequently, the projects bidding meetings that were scheduled for bidding from March 18 to 20, 2020 recorded 63.1 percent as scheduled while 14.1% of the meetings dates extended and 16.5% were completely cancelled. Accordingly, the bid dates were verified which saw 80% of the bid dates maintained as originally advertised, 10.3% was extended while 9.7% was cancelled.

Furthermore, on the impact on supply chain, The New York Times (2020) reported that, the impact the construction industry is facing due to COVID-19 resulting is in the delay or slowing down work on both residential and commercial projects because getting materials from overseas is difficult, which is threatening construction works. Howes and Short (2020) listed difficulties in procuring materials and plant as one of the major impacts of coronavirus. The European International Contractors (EIC) (2020) added that, countries like China and Italy have slowed or shut down their production sectors which have led to a sharp decrease in production of a wide range of materials such as steel, cement, etc. and contractors that depend on the two countries' goods and materials are most likely to face higher costs and consequently will see more projects cancellations. Limited public transportation and travel bans slowed down project delivery making it difficult for sub-contractors to perform or provide required material for project execution. Hurriyet Daily News (2020) buttressed that, the construction sector has connections with more than 200 sub-sectors and disruptions in material supply chain arising due to the closure of international borders may cause extra costs to the companies. Consequently, firms will face legal issues which may require compensation due to the failure to fulfil the responsibilities in the contracts without force majeure.

The construction sector is experiencing higher levels of project delays and cancellations since the outbreak of coronavirus pandemic. This is attributed to prevalent preventive measures to curb the virus. In March 2020, some Asian countries including china experienced minor delays. Europe, Middle East and African countries followed in a quick manner. Delays and cancellations of projects enhanced in South America because of the lockdowns in many countries (GlobalData, 2020). Over 20 percent of projects were delayed or cancelled due to COVID-19 in Europe, Middle East and Africa in April 2020 as shown in the figure below.

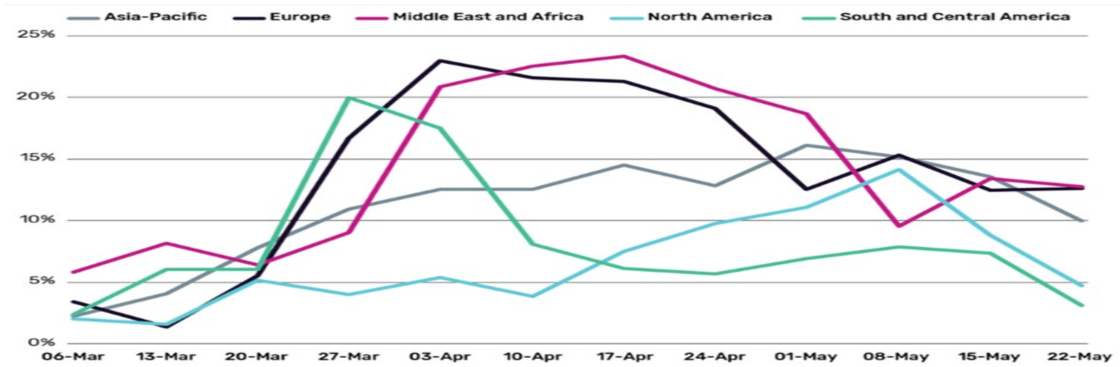


Figure 2: Share of project delays by regions (GlobalData, 2020).

Similarly, China and India experienced a moderate share of delayed projects, though construction projects in China were primarily delayed in the earlier part of 2020 and increasing numbers of projects are now proceeding. Australia has the lowest impact due to the effective containment of the disease as shown in the (Fig. 3).

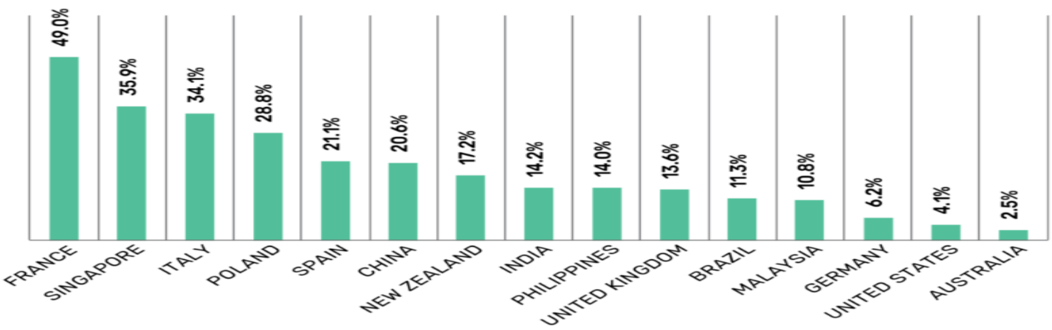


Figure 3: Share of project delays by countries (GlobalData, 2020).

Turkey also experienced some level of disruption in many construction sites and notable among them is the Galataport development project, where workers protested due to the death of a construction worker who contracted coronavirus. Following the protests, the contractors executing the project shut down the site (GlobalData, 2020).

COVID-19 has severely hit-hard all the sectors thereby affecting the global economy. Since the world economy's recovery is not certain, several infrastructures projects, hospitals projects as well as residential projects considered to be critical are ongoing while the non-essential ones like entertainment are drastically reduced. Laing (2020), said apart from the infections and deaths COVID-19 has caused, it has also wreaked havoc with global economy significantly and COVID-19 is the first global crisis recorded since the Great Depression. Similarly, EIC (2020) stated that, the outbreak of COVID-19 has triggered interruption in the major economic activities and it is anticipated that, the impacts will be more severe than the global financial crunch in 2007/2008, which has already hit businesses, households, markets and financial institutions. It concluded that, global economic growth could see a drop to 1.5% in 2020. Kendall (2020) opined that, the construction sector has been faced with extreme challenges because of the lockdown and closure of construction sites, public projects funding that solely rely on tax revenues decreased, shortages of supply chain both nationally and internationally and clients cancelling projects or putting projects on hold as a result of global economic uncertainty. The World Bank (2020) revealed that, all the nations projected to grow have downgraded. Regardless of the extraordinary efforts made by governments to minimize the downturn with monetary policies and fiscal support the world will experience the deepest global recession in decades as shown in the forecasts in Fig. 4.

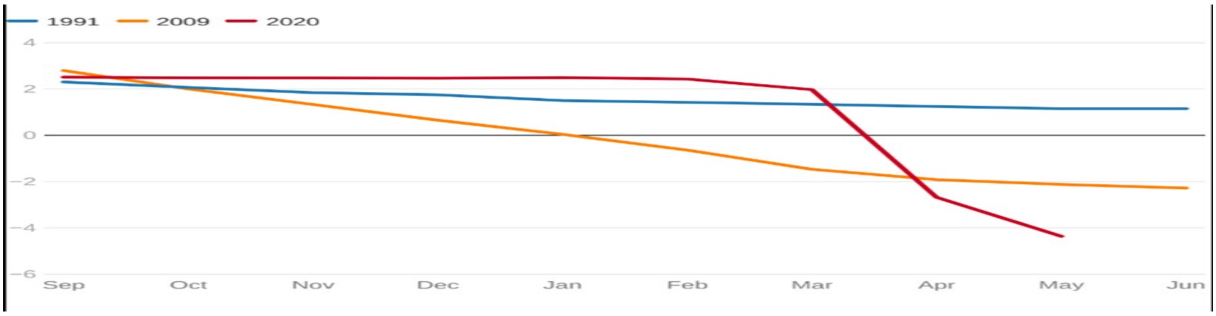


Figure 4: Consensus forecasts of global GDP (The World Bank, 2020).

Legal impact of COVID-19 is very crucial as coronavirus pandemic continue to spread globally. With workers self-isolating, firms facing import and export issues and site closures, majority in the construction industry are facing unprecedented issues and anticipate further issues as the consequences as the virus spreads globally. The COVID-19 pandemic is enlightening the construction firms hence, there are several contractual and practical issues that needs to be considered for reviewing both risks and liabilities under current contracts and when negotiating future contracts. BuildUK (2020) listed some of the key areas to anticipate legal issues as; timing obligations and consequences for late delivery of materials or services, termination and damages. Furthermore, EIC, (2020) added that, contractors are faced with material supply chains disruptions and the smaller firms are faced with the risk of bankruptcy while major contractors are forced into legal disputes over non-performance and unnecessary payments. Loulakis and McLaughlin (2020) indicated that, parties are negotiating to revise their contracts. In legal terms, suspension of work, force majeure or comparable justifiable delays, material escalations, change in law, protection of work, safety and health requirements as well as notice requirements provisions and clauses will govern most of the issues faced by the construction firms ranging from disruption in materials chain supply, closure of sites etc.

The global unemployment has hit 190 million (The United Nations (UN) (2020). Ichniowski (2020) reported that the construction workforce plunged by 975,000 in April 2020 in the USA which is the steepest drop since late 1930s. Consequently, the industry's unemployment rate soared to 16.6 percent due the coronavirus. Howes and Short (2020) opined that, due to travel bans and lockdowns, workers from China who work in the UK faces difficulties in moving to and from China and various countries have restricted entry of Chinese nationals or foreigners who have travelled to China while majority of airlines have halted their flights to China. Also, there are difficulties in some of the compulsory measures that needs to be carried out on site daily such as additional cleaning and temperature checking for labour and visitors, mandatory leave, quarantine orders, additional accommodation for labour replacement affects the project schedule. In addition, The New York Times reported that, Boston closed all construction sites which have affected tens of thousands of the workforce. However, managers were urged to lay the workers temporarily and not to fire them.

Methodology

This study employed a quantitative research method and an online survey form was used as a tool for the data collection. The questionnaire was prepared to determine the impact of COVID-19 in the construction sector. The total number of questions were 24. The construction firms the questionnaire were administered to are Turkish construction firms executing projects both within and outside Turkey. Prior to the formation of the questions, the relevant literature was reviewed to prepare a draft form of the questionnaire. Two experts were consulted for the confirmation for the validity of the content. Eventually, corrections were made, and piloting was carried out to ascertain and prevent the possible difficulties that may arise during the questionnaire administration for efficient and reliable results. The target population were Turkish construction firms who are actively executing projects during emergence of the pandemic. The survey was conducted online between June and July 2020.

Findings and Discussions

In this section, the findings of the impact of COVID-19 is presented. The online survey received a total of 73 responses from construction firms working within and outside Turkey. Data obtained from experts who participated in the survey were presented in pie charts and bar charts to determine the impact of COVID-19 in the construction sector are interpreted below. Percentages are based on the number of responses to each answer. In order to get comprehensive descriptive information about the data acquired from the professionals responding the questionnaires, frequency analysis was performed, and the frequency distributions of the data were examined for discussion. Consequently, the responses given by the construction experts in the research sample to the questions were attained as pie charts, bar chart and frequency distributions.

Impact of COVID-19 on Supply Chain

54 of the respondents representing (94.7%) responded that, ban on national and international borders is the highest cause of material supply chain disruption, delay or cancellation, followed by the compliance of government directives, 46 respondents representing (80.7%). The rest are price hikes, quarantine of suppliers' employees been affected with COVID-19, financial difficulties and transporters not working represented 38 (66.7%), 21 (36.8%), 15 (26.3%) and 2 (3.6%) respectively. The impact felt by the firms include delays in project execution, cost overrun, legal issues and job loss.

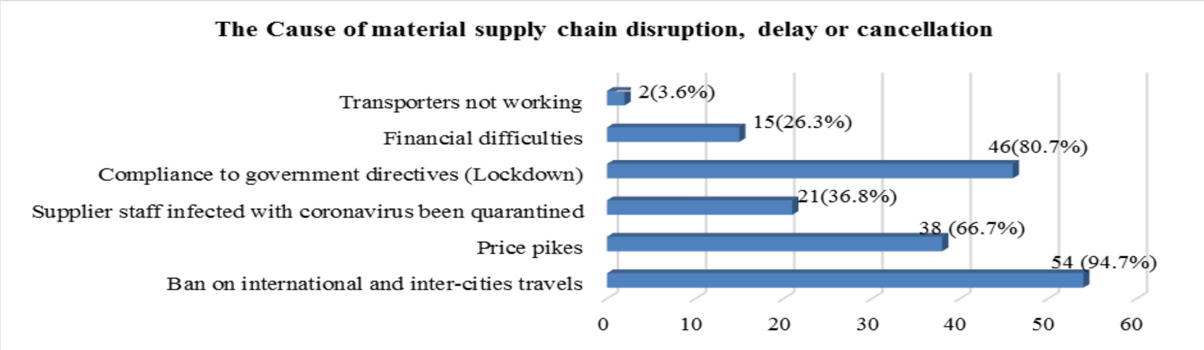
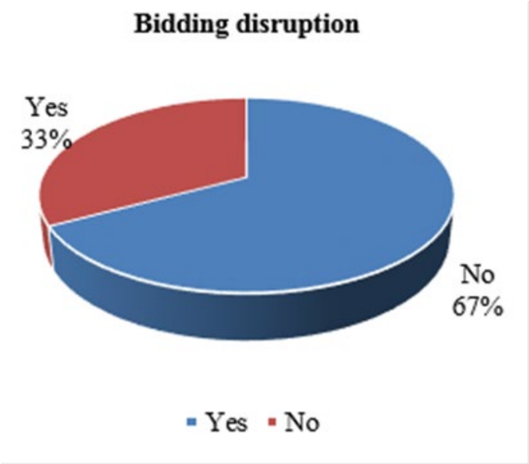


Figure 5. The causes of material supply chain disruption, delay or cancellation.

Evidence from Turkey Building Material Producers Association (IMSAD, 2020), indicates that, approximately 85 percent of the sector experienced order and project cancellations from abroad whilst 46.8% faced cancellations within Turkey while 56.5% predicted that their sales budgets of the construction sector could decrease by 20 percent or more in 2020. Similarly, at Los Angeles' Port, imports from China which includes construction materials went down by 23% in February as compared to the same period last year (The New York Times, 2020).

Bidding Disruption

33% of the respondents had disruption in their bidding schedules while 67% did not encounter bidding schedules interruption. As a result of the disruptions, 72% of firms had their bidding processes rescheduled, 20% of the respondents had some of their biddings both cancelled and reschedules 8% of their bidding dates cancelled.



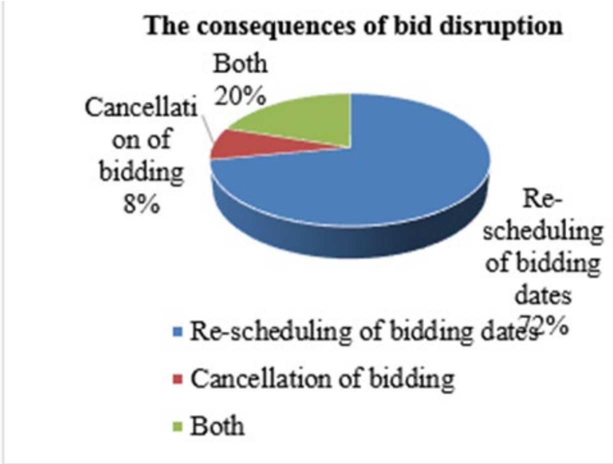


Figure 6 (a): Whether bidding was disrupted. Figure 6 (b). Bidding disruption consequences.

Evidence from Kendall (2020), indicate that, in the United States, verified bid dates of projects recorded 80% of the bid dates been scheduled to be opened as originally advertised, 10.3% was extended while 9.7% was cancelled.

The Delay of Construction Projects

The causes and the impact of project delays is represented in figure 4.3. Shortage of labour by main contractor or subcontractor constitutes 28%, lockdown orders from the government also represents 28%, shortage of construction materials, equipment or parts represents 25%, disruption in subcontractor's deliveries constitutes 13% while legal battle represents 6%. Consequently 52 of the respondents representing (92.9%) experienced forced majeure/free project extension, 13 respondents representing (23.2%) faced contract termination and 2 respondents representing (3.6%) faced monetary penalties.

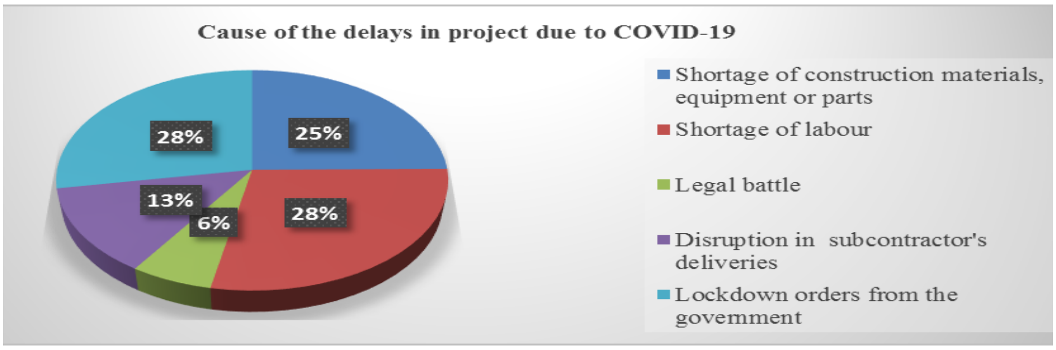
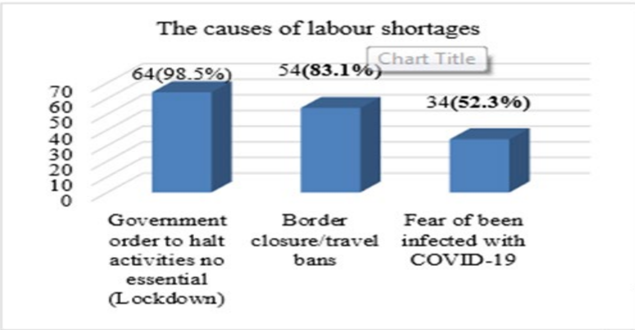


Figure 7: Cause of the delays in project due to COVID-19.

Evidence from the American Associated of General Contractors (2020) report indicates that at least 45% of contractors are experiencing delays or disruptions in their projects as a result of coronavirus pandemic. Similarly, Mufti (2020) reported that, the Indonesia the postponed projects and rescheduled to be opened in 2021 due to the budget changes to reallocate a large portion of the budget funds to help contain the spread of COVID-19 pandemic which has resulted in delays of many projects. GlobalData (2020) added that, over 15% of global construction projects were either cancelled or delayed in April 2020 due to the pandemic, which at the normal circumstance is around 3 percent and 6 percent. In France, approximately 50 percent of projects had schedules delayed or cancelled from the beginning of March to 22 May. Similarly, evidence from Ghana according to the report by Graphic Online, indicates that, construction works have resumed work after 11 weeks when the company suspended work because 82 workers of the company were infected with the coronavirus disease and quarantined themselves until their recovery (Sottie, 2020).

The Impact of COVID-19 on Labour

From the figures (4.4a, and 4.4b), 64 of the respondents representing (98.5%) experienced the labour shortage due to government orders to halt non-essential activities and lockdown, 54 respondents representing (83.1%) and 34 of the respondents representing (52.3%) said due to border closure/travel bans and the fear of been infected with COVID-19 respectively. Furthermore, 58 of the respondents representing (87.9%) said labour shortages in their firms resulted in project delays, 49 respondents representing (74.2%) experienced higher wages, 41 respondents representing (62.1%) renegotiation of contracts and 10 of the respondents representing (15.2%) had their contracts terminated.



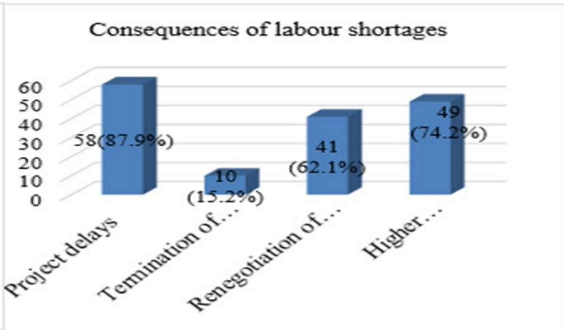


Figure 8 (a): Causes of labour shortages. Figure 8 (b). Effects of labour shortages.

Evidence from Turkey by Bal (2020) shows that, as of February 2020, there were 1.3 million employees in the construction industry, which constitutes 5.2 percent of the total employment in Turkey. During the outbreak of COVID-19, out of a total 4.2 million people unemployed, 640,000 were former construction sector employees. Similarly, the Bureau of Labour Statistics' latest monthly U.S. employment report, released on May 8, painted a grim picture, showing that construction's total workforce fell in April by 13% from the March level (Ichniowski, 2020).

The Impact of COVID-19 on the Legal Issues

Legal challenges of COVID-19 and their causes on the firms is presented in Figure 4.5. 38% of the respondents experienced legal issues due to non-compliance of government restriction orders, followed by material supply chain disruption with 24%. The rest are delays in work constituting 22% and delays in paying claims representing 16%. Two solar developers declared "force majeure" on solar farms under construction in southwest and northeast Wisconsin (StarTribune, 2020). Similarly, the Supreme Court in China has also weighed in on the impact of force majeure clauses. The Court held that the party asserting force majeure must provide notice, mitigate its losses, and provide evidence that its performance was prevented.

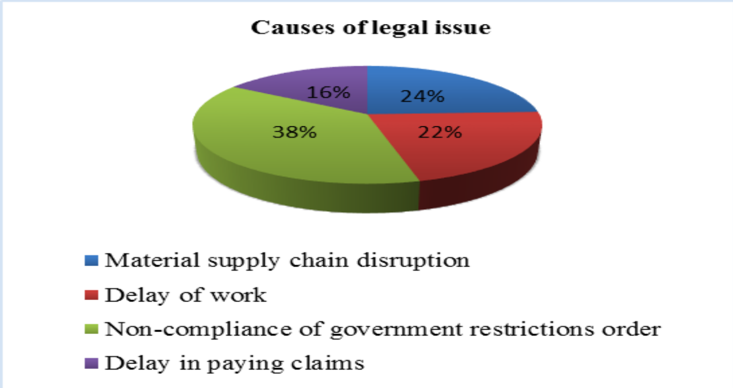


Figure 9: Legal challenges of COVID-19 and their causes.

Reasons Why Firms Halted Their Projects

The outbreak of COVID-19 has brought numerous challenges to the construction industry globally. As part of proactive measures taken to contain the spread of the coronavirus by various governments and firms, it resulted in the disruption of activities of construction projects at various levels. In the quest to find out the main factors that lead to the halting of projects, lockdown and travel bans recorded 63 respondents representing (80.6%), concern about workers contracting COVID-19 recorded 58 (80.6%), compliance with government order to halt activities deemed non-essential recorded 56 respondents representing (77.8%), loss of funding and payment issues (delays in paying claims) recorded 33.3% while legal challenges and reduced demand for projects recorded 22.2% and 18.1% respectively. Fig. 10 shows the data of the reasons why projects were halted during the outbreak of coronavirus.

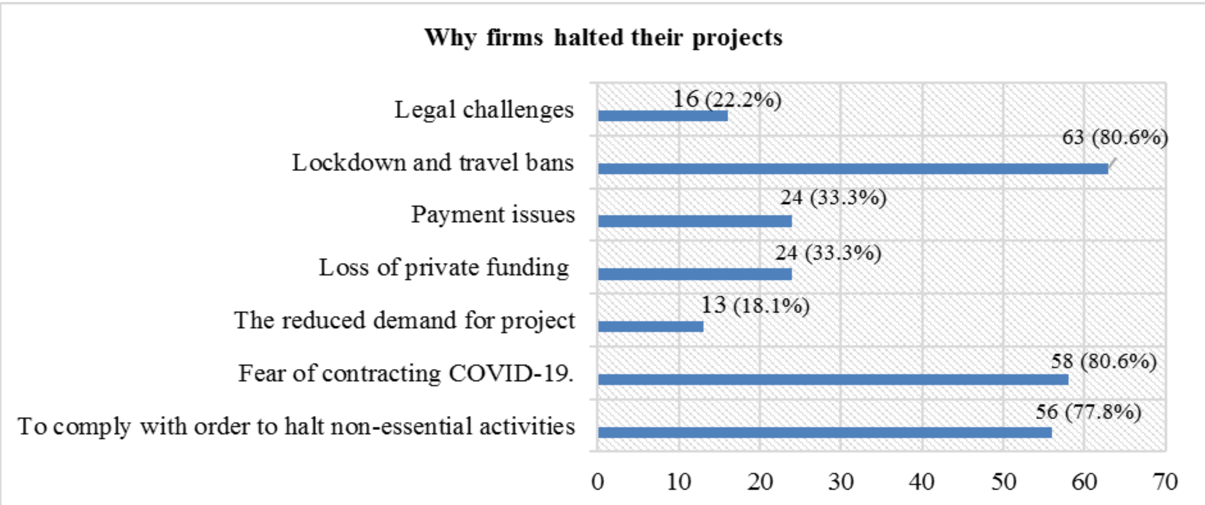


Figure 10. Reasons why projects were halted during the outbreak of coronavirus.

Furthermore, in the pursuit general effects of COVID-19 on the construction firms, economic uncertainty, labour shortages, employment issues, project delays, legal issues, material supply chain disruption and bidding process disruptions were recorded as the main effects of the pandemic. The rest are; cost overruns, shortages of subcontractors, lack of project financing and capital liquidity crunch also followed in that order as shown in Fig. 11.

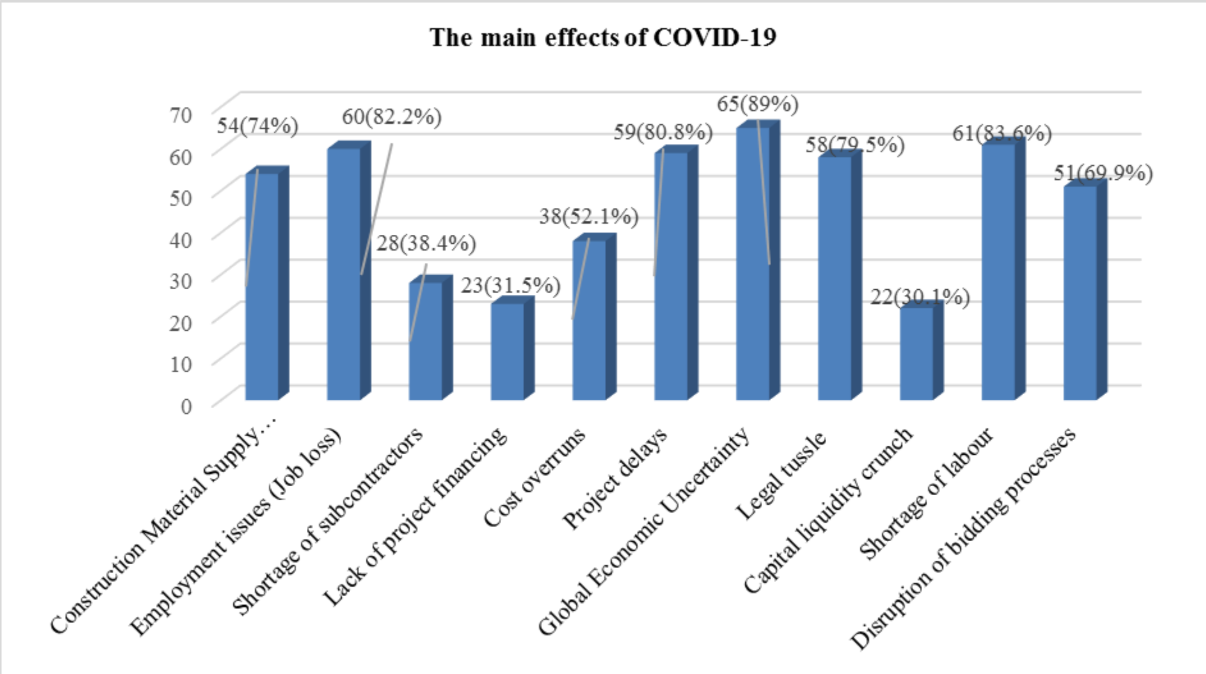


Figure 11: The main effects of COVID-19.

Conclusions

The aim of this study was to investigate the major impact of COVID-19 pandemic in the construction in the sector. For this purpose, online questionnaires were administered to Turkish construction firms who are actively executing projects within and outside Turkey during the pandemic. The impact of COVID-19 revealed through the literature review and the data obtained from experts who participated in the survey were presented in pie chart and bar charts for examination and discussion. Percentages are based on the number of responses to each answer. This research contributes mainly to the increased knowledge of construction management especially the expectations during pandemic and epidemics. The main limitation of the study is that the full impact will be known after the pandemic is over. However, as at July 22, 2020, there was no vaccine for COVID-19, and it is uncertain as to when the pandemic will be eradicated globally.

This research constitutes the basis for further study regarding the impact of coronavirus in the second wave since some countries are still battling with the first wave while others are facing the second wave of the pandemic. This study clearly revealed that, economic uncertainty, labour shortages, employment issues, project delays, legal issues, material supply chain disruption and bidding process disruptions were recorded as the main effects of the pandemic, cost overruns, shortages of subcontractors, lack of project financing and capital liquidity crunch are other major impacts of COVID-19. The study therefore concludes that, the construction industry has been enormously affected by the pandemic and the main impacts must be critically taken into consideration by the construction firms before entering contractual terms in the future projects to minimize the impact.

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Analysis of Industrial Formwork Systems Supply Chain through Value Stream Mapping: A Case Study

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Abstract

In the construction industry, reinforced concrete (RC) has been adopted as the main structural material in almost all types of construction projects from infrastructure to building projects worldwide. In this context, RC is undoubtedly the most popular structural material in Turkey. Formwork is an integral part of RC structure supply chain, which can affect the overall performance of RC structures. Therefore, in RC structures, a detailed examination of various supply chain configurations for formwork among all stakeholders (e.g., engineers, contractors and formwork fabricator) can provide insight into the improvement of the time, cost, quality, and safety performance of these structures. The main types of formwork systems are traditional and industrial. In general, the traditional formwork system supply chain has higher total time waste and lead time than that of industrial formwork system. Stakeholders with different roles and responsibilities at various project phases in RC structures, which can be represented by different supply chain configurations, can be examined in more detail for industrial formwork systems. The objectives of this study are to analyze the performance of various supply chain configurations for industrial formwork systems and to examine the main reasons behind waste. For this purpose, an ongoing building project in which 500 m^2 of industrial wall formwork would be used was examined as a case study. In the context of this project, three different supply chain configurations were analyzed using the value stream mapping method, and then the findings were presented and compared with each other. The results of this study revealed that the industrial formwork supply chain, where the formwork fabricator was involved early with the engineer and the contractor at the design phase of the project, had higher performance than other supply chain configurations. Moreover, the main reasons underlying the higher performance of early stakeholder involvement at design phase of the project were investigated and some recommendations were made for performance improvement.

Keywords: *case study, industrial formwork system, supply chain, value stream mapping.*

Introduction

RC is the most commonly used structural material in the construction industry in Turkey and around the world, since it provides more flexibility, ease of handling and economical solutions compared to other materials (Polat and Ballard 2003; Işık et al., 2016). The main components of the construction of the RC structures are formwork, rebar and concrete. The basic activities performed by using these components in reinforced concrete structures consist of the erection of the formwork, the placement of the rebar, the pouring of concrete, the curing of concrete, and the stripping of the formwork (Terzioglu et al., 2019). As formwork is involved from the start to the end of the construction of RC structures, it is an essential part of the RC structure supply chain, which may have an impact on the overall performance of these structures. Moreover, the formwork may also be the largest cost factor, which could be as high as 60% of the unit cost of the RC, depending on the type of structure (Krawczyńska-Piechna, 2017). Therefore, in RC structures, examination of the different configurations of the supply chain for formwork among all stakeholders (e.g., engineer, contractor and formwork fabricator) can help to improve the time, cost, quality, and safety performance of these structures.

Formwork systems are basically categorized as traditional and industrial. Industrial formwork systems reduce waste, eliminate unnecessary material movements, and also improve inventory management and a well-organized working environment (Abou Ibrahim and Hamzeh, 2015). Therefore, industrial formwork system supply chain generally performs better than traditional formwork system supply chain in terms of lead time and time waste (Terzioglu et al., 2019). Field studies were conducted by interviewing practitioners and visiting companies involved in the industrial formwork supply chain concluded that there are three different configurations commonly used in the Turkish RC construction industry. For industrial formwork systems, stakeholders with different roles and responsibilities at different project phases in RC structures, that can be represented by different supply chain configurations, can be discussed in more detail. This study aims to analyze the performance of three different supply chain configurations for industrial formwork systems and examine the main reasons behind waste. For this purpose, an ongoing building project in which 500 m^2 of industrial wall formwork would be used, was studied as a case study. In the context of this project, three different supply chain configurations were analyzed using the value stream mapping method, and then the findings were presented and compared with each other. The results of this study indicated that the industrial formwork supply chain, where the formwork fabricator was involved early with the engineer and the contractor at the design phase of the project, had higher performance than other supply chain configurations. The main reasons underlying the higher performance of early stakeholder involvement in the design phase of the project were also investigated. Finally, a set of recommendations are presented to improve the performance of the industrial formwork supply chain and future research studies are proposed.

Description of Supply Chain Practices for Industrial Formwork Systems

The main activities in the formwork supply chain are the design of the structural framework and the formwork, the detailing of the formwork, the production of the formwork system components, the delivery of the produced formwork system components to the contractor, the preparation of the job, the assembly of the components, and the installation of the formwork (Terzioglu et al., 2019). These activities are performed by engineering companies, formwork fabricators and contractors, which are the main stakeholders of the formwork supply chain.

In order to determine the supply chain configurations used for industrial formwork systems in the Turkish RC construction industry, field studies were conducted by meeting practitioners, and companies involved in the industrial formwork supply chain were visited. The data collected from these processes were analyzed using the value stream mapping method, which explains the flow of material and information from customer order through delivery to the customer, and identifies waste and its root causes (Tommelein et al., 2002). The results of the analysis concluded that there are three different supply chain configurations widely used for industrial formwork system as process maps. These process maps are presented in Figure 1, 2 and 3. The process maps identify the different roles and responsibilities of stakeholders in the supply chain process as configuration 1, configuration 2, and configuration 3 for industrial formwork system. These roles and responsibilities of the stakeholders in line with processes and activities are explained in detail in a research carried out by Terzioglu et al. (2019).

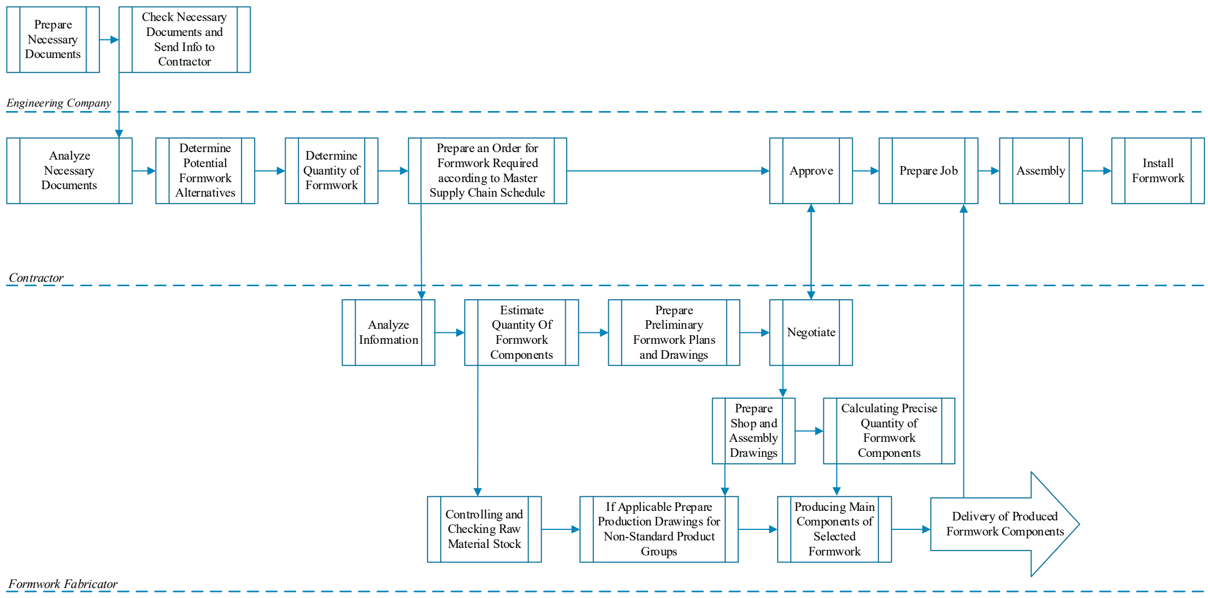

Figure 1: Configuration 1 (Terzioglu et al., 2019).

In configuration 1, the contractor determines formwork alternatives, selects the most suitable formwork alternative, and determines the initial quantities of the selected formwork to prepare the project schedule. In this configuration, the contractor and its technical team must have knowledge and professional experience with the industrial formwork systems and the local formwork market situation. An advantage of this configuration could be that, if the contractor successfully completes the activities undertaken, the formwork fabricator spends less time in the detailing process, and thereby reduces overall lead time. On the other hand, a disadvantage of this configuration could be that, if the selected formwork system does not exist in the local market, it may cause rework of the design activities, and thereby increases overall lead time.

In configuration 2, the formwork fabricator performs the design, scheduling, determination of the initial formwork quantities, detailing and fabricating activities. The fabricator is regarded as an expert in the design and detailing of the formwork. The fabricator is accustomed to work with many contractors on different types of projects, and thus often has the experience needed to deal with the complexities of projects. The fabricator provides information to contractors on which alternative formwork systems are appropriate for their projects. Planning the time required to construct the structural framework is an important task in project management. This information is best provided by the fabricator because of its expertise and knowledge of assembly, erection, and striking times of the systems. An advantage of this configuration is that less time is spent searching for alternatives which are not available on the market or need to be imported from abroad, as the fabricator selects formwork alternatives based on the stock of raw material and the local market situation. On the other hand, a disadvantage of this configuration is that the fabricator takes over most of the activities and responsibilities, and thereby may be overloaded. If there is a delay caused by the fabricator, it directly affects the assembly and installation activities, which may extend the contractor's lead time. In addition, if the contractor experiences financial difficulties related to the project budget, it may reject the formwork systems selected by the fabricator. This situation leads to the rework of all activities previously carried out. Therefore, a strong flow of information must be provided between the contractor and the fabricator in order to ensure that the proposed alternatives meet the needs and requirements of the contractor.

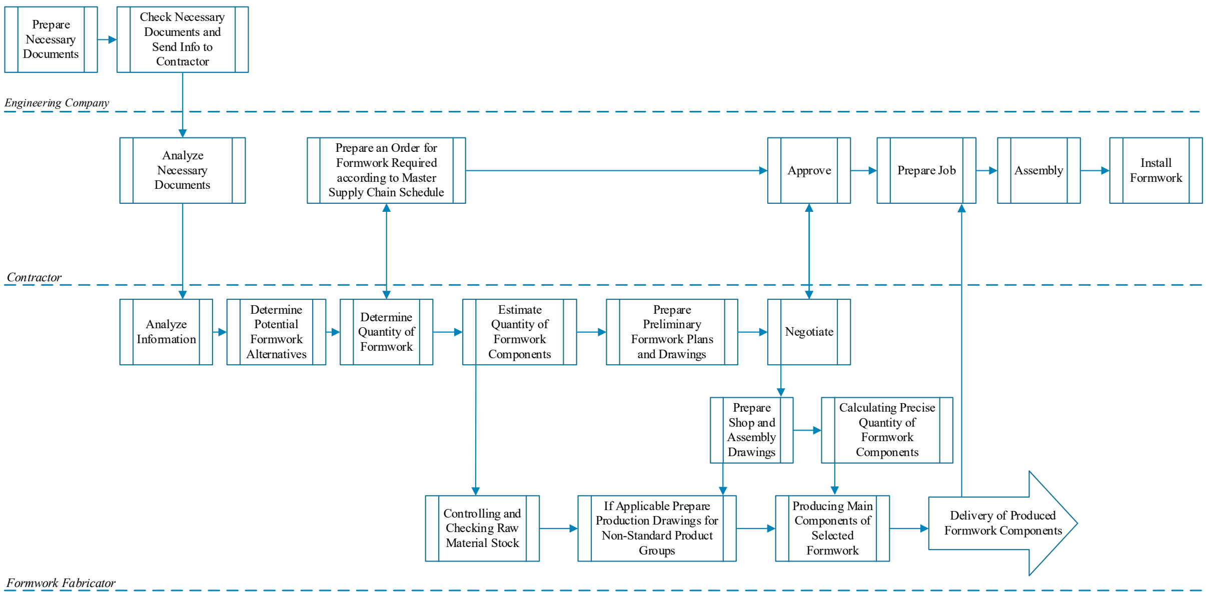

Figure 2: Configuration 2.

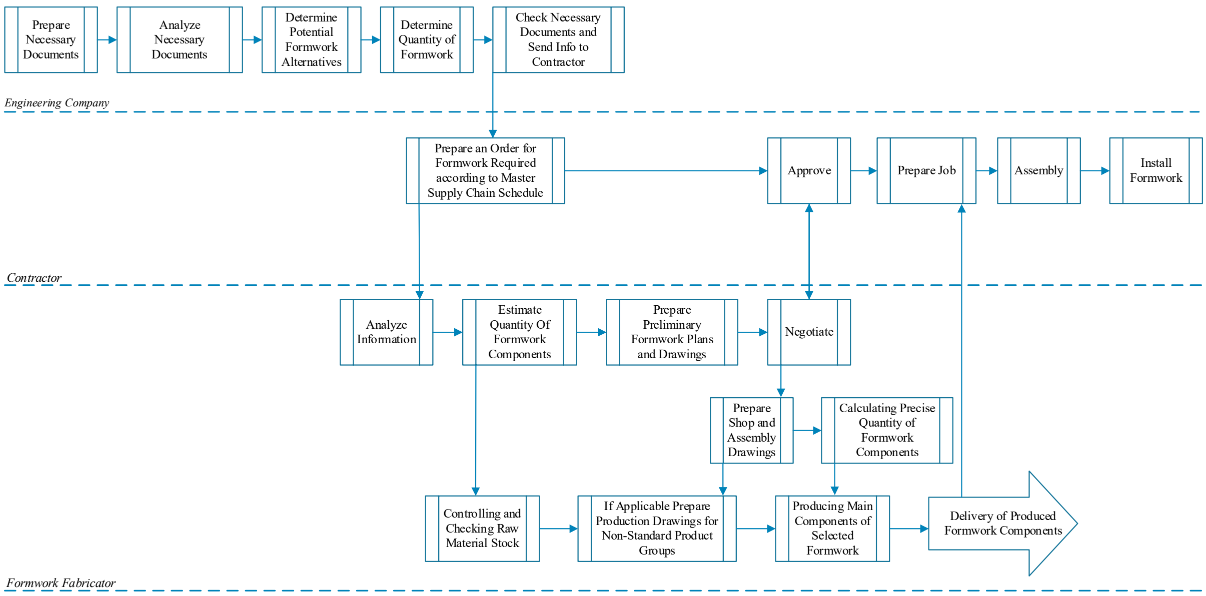

Figure 3: Configuration 3.

In configuration 3, the engineer performs the design, scheduling, and determination of the initial formwork quantities activities. In this configuration, the engineer must have the necessary experience, expertise in formwork systems and in-house technical capacity in the formwork field. An advantage of this configuration is that since the design of the structural framework is carried out by the engineer, the formwork performance in the project can be maximized by pre-selecting the most appropriate formwork systems or by making structural design revisions easily. On the other hand, a disadvantage of this configuration is that the fabricator is not involved in the activities performed by the engineer, so interruptions and delays in the flow of information between stakeholders may occur, which negatively affects the overall lead time of the supply chain. If the project budget is exceeded or there is a different opinion about the implementation of the system during construction, the formwork systems selected by the engineer may not be accepted by the contractor. This situation causes the rework of all activities previously carried out.

The fabricator is always responsible for the detailing and fabrication of the formwork, while the design of the formwork is conducted by different stakeholders. The design of the structural framework and preparation of the relevant documents is always carried out by the engineer, whereas the contractor always prepares the job, assembly and installation of the formwork. The activities related to the supply chain of the industrial formwork system are presented in Table 1, which will be carried out by stakeholders in different configurations.

Table 1. Activities performed by each stakeholder.

Activities / **Stakeholders**	**Design**	**Detail**	**Fabrication**
Engineer	3		
Contractor	1		
Fabricator	2	1, 2, 3	1, 2, 3

Table 2. Main characteristics of industrial formwork supply chain configurations.

Cfg*	**Characteristics**	**Advantages**	**Disadvantages**	**Comments**
1	Contractor designs, selects formwork alternatives, and determines quantities. Fabricator prepares details, and supplies formwork.	Less number of cycles, Less lead time, Involvement of contractor in the design and scheduling processes.	High interdependence between the contractor and the fabricator, High rework.	Preferred if the contractor is able to execute the design of the formwork.
2	Fabricator designs, selects formwork alternatives, determines quantities, prepares details and supplies formwork.	Less number of cycles, Less lead time, Early involvement of fabricator in design stage, Less rework, Least the interdependence of the stakeholders.	High mutual dependence between the contractor and the fabricator, Most of the work is done by the fabricator.	Preferred if the fabricator is able to execute the design of the formwork.
3	Engineer designs, selects formwork alternatives, and determines quantities. Fabricator prepares details, and supplies formwork.	Less number of cycles, Less lead time, Involvement of engineer in the design and scheduling processes.	Requires good communication and flow of information between all stakeholders. High rework.	Preferred if the engineer is able to execute the design of the formwork.

*Cfg: Configurations.

The decision to determine the most appropriate configuration for the project depends on the experience of the different stakeholders, their operational and managerial skills, the project delivery methods and the project characteristics (Terzioglu et al., 2019). The characteristics, advantages and disadvantages of the three different industrial formwork supply chain (SC) configurations are summarized in Table 2.

Analysis of Supply Chain Configurations for Industrial Formwork Systems

The performance and efficiency of a formwork supply chain can be measured using time, cost and quality parameters. The aims of the analysis of supply chain configurations are to identify the reasons for the waste and to improve the performance that can be achieved by resolving the problems of each supply chain configuration and selecting the most suitable solutions for the project. In this study, only the time parameter is used to measure the efficiency of different supply chain configurations.

Lead time is the time actually measured from the start to the finish of the design, detailing, assembly, and installation of the formwork activities, while value-added time is the time spent on improving the outcome of an activity. On the other hand, non-value-added activities are incorrectly planned processes that do not use resources effectively, and generate waste in the supply chain (Love et al., 1999). In this study, lead time and value-added time are compared with each other, and non-value-added time is determined and eliminated. As a result, the lead time of the overall supply chain can be decreased (Terzioglu et al., 2019).

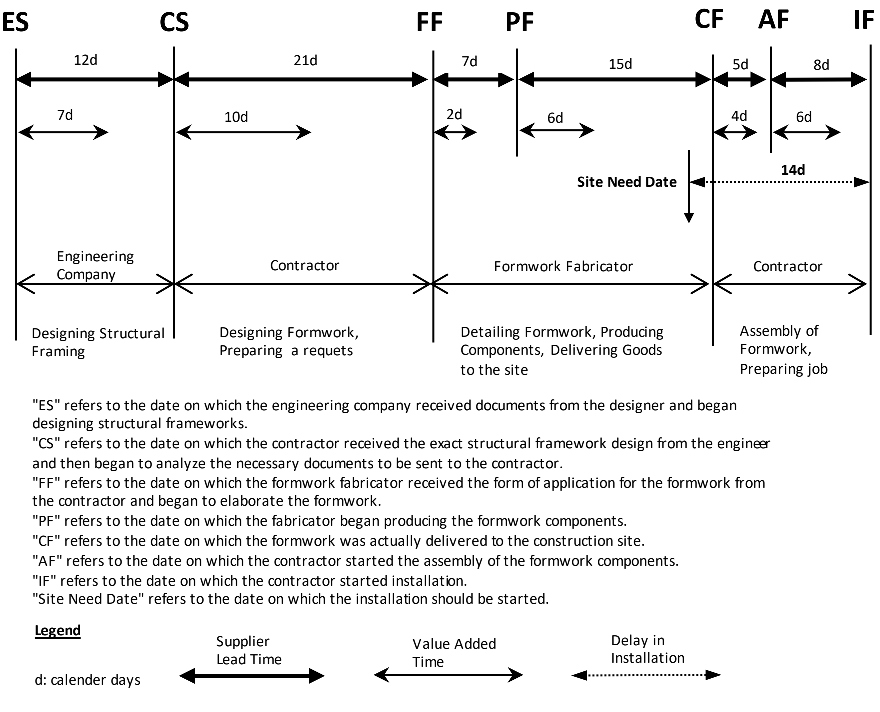

Figure 4: The results of the supply chain performance analysis of configuration 1.

The analysis of configuration 1 was carried out by Terzioglu et al. (2019) and the results are presented in Figure 4. Based on the results, total value-added time is 35 days for all activities, while total lead time is 68 days, which means that 49% of total time is wasted. Value-added times, lead times and wasted times for all activities in the supply chain configuration 1 are presented in Table 3.

Table 3. Time information for all activities in the supply chain configuration 1.

Activities	Value-Added Time	Lead Time	Wasted Time (%)
Designing structural framework	7	12	42
Designing formwork, preparing a request form	10	21	52
Detailing formwork components	2	7	71
Producing formwork, delivering goods to site	6	15	60
Preparing job	4	5	20
Assembly of formwork components	6	8	25
Total Values	**35**	**68**	**49**

The results of the supply chain performance analysis of configuration 2 are presented in Figure 5. The supply chain starts with the design of the structural framework by the engineer, and the lead time (12d) and the value-added time (7d) is the same as in configuration 1. The lead time of the contractor is 13 days. Compared to configuration 1, it can be observed that the contractor's lead time is reduced by 8 days in this configuration. The contractor analyzes the documents received from the engineer, and then sends them to the fabricator. In other words, the contractor does not design the formwork solution in this configuration.

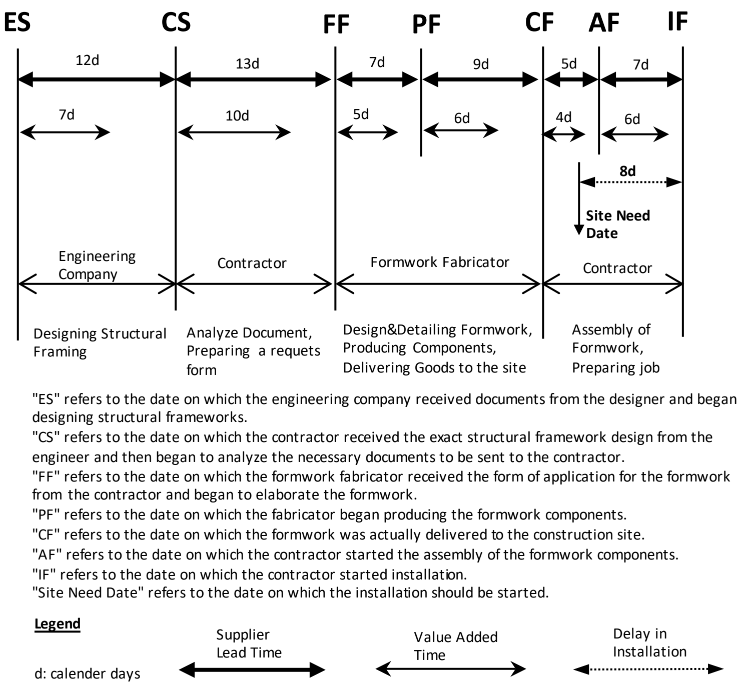

Figure 5: The results of the supply chain performance analysis of configuration 2.

The main difference between this SC configuration and others is that the fabricator is involved early in the design phase of the formwork. The fabricator selects the formwork alternatives and determine the quantity by exchanging information with the technical and procurement department of the contractor. In general, the fabricator has better knowledge of stock and quantity, and uses standardized methods to optimize the formwork solution before negotiations begin, so that rework can be reduced. Once the fabricator and the contractor start negotiations, non-standardized formwork solutions can be eliminated, and solutions can also be better adapted, which may further reduce the waste during the design phase of formwork.

In this configuration, as the non-standardized formwork components can be reduced by the early involvement of the fabricator, the lead time is also reduced to 16 days (7d+9d) at the later stages of production and detailing. The value-added time spent on detailing and producing is 11 days (5d+6d), which is 3 days longer than in configuration 1, since the fabricator designs and details in parallel and in coordination with the contractor.

Based on Figure 5, although the value-added time for assembly is 6 days, the actual time for assembly activities is 7 days. In this case, the delay is reduced by 1 day compared to Figure 4 due to the reduction of non-standard formwork components, which may result in rework. Figure 5 when examined, 38 days are spent on all activities in the supply chain and the total supply chain time is 53 days. The results revealed that 28% of the total time is wasted, and this configuration provides 28% reduction in non-value-added activities compared to configuration 1. Value-added times, lead times and wasted times for all activities in the supply chain configuration 2 are presented in Table 4.

Table 4. Time information for all activities in the supply chain configuration 2.

Activities	Value-Added Time	Lead Time	Wasted Time (%)
Designing structural framework	7	12	42
Analyze documents, and preparing a request form	10	13	23
Designing and detailing formwork components	5	7	29
Producing formwork, delivering goods to site	6	9	33
Preparing job	4	5	20
Assembly of formwork components	6	7	14
Total Values	**38**	**53**	**28**

The results of the supply chain performance analysis of configuration 3 are presented in Figure 6. The SC configuration 3 starts with the design of the structural framework by the engineer. The main difference between this SC configuration and others is that the design of the formwork is performed by the engineer in parallel with the design of the structural framework. In order to fit the standardized formwork systems, the engineer optimizes the structural framework. However, it should be noted that this process requires high expertise, in house capability and knowledge about formwork systems. The engineer's lead-time is 20 days and value-added time is 11 days. The reason for the waste in this activity is the redesign of the structural framework and formwork in order to maximize output in later stages. The contractor analyzes the documents received from the engineer, and then sends them to the fabricator. The lead time of the contractor is 15 days and value-added time is 7 days. If the cost of the formwork systems selected by the engineer exceeds the project budget, the contractor may reject these systems. In this case, the formwork system is redesigned before the contractor sends the documents to the fabricator. The fabricator spends 10 days on detailing and 12 days on the production of the formwork components. Although the total lead time of the fabricator is the same in configuration 1 and configuration 3 (22d), the non-value-added time is lower in configuration 3. The reason for the relatively small amount of waste is associated with the development of the formwork design by the engineer in previous phases. On the other hand, compared to configuration 2, the waste in the detailing phase is 21% higher in this configuration, as the formwork design performed by the engineer does not always fit the standard formwork components of the fabricator.

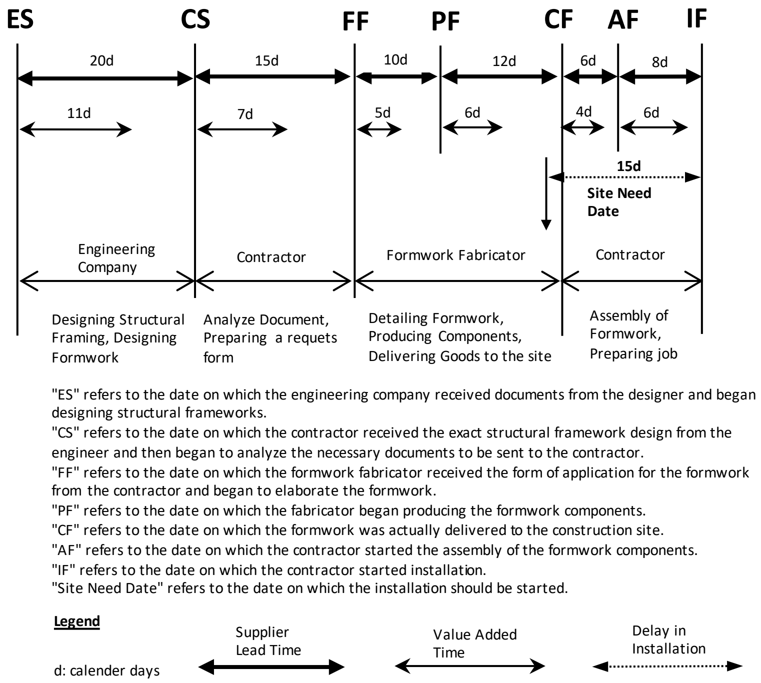

Figure 6: The results of the supply chain performance analysis of configuration 3.

Based on Figure 6, the durations for assembly activity are the similar as configuration 1. Although the value-added time for assembly is 6 days, the actual time for assembly activities is 8 days. Total value-added time is 39 days for all activities, while total lead time is 71 days, which means that 45% of total time is wasted. The results indicate that this configuration is 4% less than configuration 1 and 17% more than configuration 2 in terms of wasted time. Value-added times, lead times and wasted times for all activities in the supply chain configuration 3 are presented in Table 5.

Table 5. Time information for all activities in the supply chain configuration 3.

Activities	Value-Added Time	Lead Time	Wasted Time (%)
Designing structural framework, and formwork	11	20	45
Analyze documents, and preparing a request form	7	15	53
Detailing formwork components	5	10	50
Producing formwork, delivering goods to site	6	12	50
Preparing job	4	6	33
Assembly of formwork components	6	8	25
Total Values	**39**	**71**	**45**

Evaluation of Industrial Formwork Supply Chain Configurations

Early stakeholder involvement is a key aspect of lean construction that can reduce waste in the supply chain. The success of a project is strongly affected by the early involvement of stakeholders, as decisions taken at the early phase of the project reduce the risk of change at the later phase, and also help to improve the design and construction processes (Aapaoja et al., 2013). The most common supply chain configuration for the industrial formwork system in the Turkish construction industry is configuration 2, in which the fabricator is involved early in the design phase. Configuration 3 requires the engineer to be expert and knowledgeable in formwork design. In the Turkish construction industry, the engineer mainly specializes in the design of structural frameworks, and less specialized in the design of formwork. Therefore, configuration 3 is the least commonly used supply chain configuration for the industrial formwork system in Turkey. On the other hand, configuration 1 is preferred for the supply chain of the industrial formwork, if the contractor has in-house capacity for the design of the formwork (Terzioglu et al., 2019).

SC configuration 1 has a total waste of 49%, SC configuration 2 has 28%, and SC configuration 3 has 45%. The results reveal that the total waste percentage in configuration 2 is lower than the total waste percentages both configuration 1 and 3, and the total lead time in configuration 2 is only 53 days. The major factor for the improved performance of the supply chain in configuration 2 is the early involvement of the fabricator in the design phase, resulting in less rework in the later phases. The main reasons for the wasted time in the activities of each industrial formwork supply chain are summarized in Tables 6, 7 and 8.

Table 6. Reasons for wasted time in the activities of supply chain configuration 1.

Activities	Reasons for Wasted Time
Designing of structural framework	Lack of coordination among stakeholders.
Designing of formwork, preparing a request form	Lack of interdependent information and data flow between fabricator and contractor, Lack of internal coordination between technical and procurement departments, Lack of standardized data format exchange system.
Detailing of formwork components	Lack of standardized methods for non-standard components and orders.
Producing of formwork, delivering goods to site	Inflexible production systems.
Preparing job	Inadequate inventory management.
Assembly of formwork components	Lack of expertise of workers on non-standard components, Rework due to worker mistakes.

Table 7. Reasons for wasted time in the activities of supply chain configuration 2.

Activities	Reasons for Wasted Time
Designing of structural framework	Lack of coordination among stakeholders.
Analyze documents, and preparing a request form	Lack of interdependent information and data flow among all stakeholders, Lack of standardized data format exchange system.
Design and detailing of formwork components	Lack of standardized methods for orders.
Producing of formwork, delivering goods to site	Inflexible production systems.
Preparing job	Inadequate inventory management.
Assembly of formwork components	Rework due to worker mistakes.

Table 8. Reasons for wasted time in the activities of supply chain configuration 3.

Activities	Reasons for Wasted Time
Designing of structural framework, and formwork	Lack of coordination between engineer and contractor.
Preparing a request form	Lack of interdependent information and data flow between contractor and engineer, Lack of standardized data format exchange system.
Detailing of formwork components	Lack of standardized methods for non-standard components.
Producing of formwork, delivering goods to site	Inflexible production systems.
Preparing job	Inadequate inventory management.
Assembly of formwork components	Lack of expertise of workers on non-standard components, Rework due to worker mistakes.

Conclusion

Formwork is one of the most significant elements in the supply chain of the RC structures. There are mainly two types of formwork systems, namely traditional and industrial. In general, industrial formwork system supply chain performs better than traditional formwork system supply chain in terms of lead time and time waste. For industrial formwork systems, different roles and responsibilities of stakeholders at different project phases in RC structures can be reflected in various supply chain configurations. Field studies were performed by interviewing practitioners and visiting companies involved in the industrial formwork supply chain stated that there are three configurations widely used in the Turkish RC construction industry. The objectives of this study are to evaluate the performance of three supply chain configurations for industrial formwork systems, and to investigate the key reasons behind the waste. For this reason, an ongoing building project in which 500 m^2 of industrial wall formwork would be used was examined as a case study. In the context of this project, three different supply chain configurations were analyzed using the value stream mapping method, and then the findings were presented, and compared with each other.

The results of this study indicated that the industrial formwork supply chain configuration, where the formwork fabricator was involved early with the engineer and contractor at the design phase of the project, had higher performance than other supply chain configurations. The results also concluded that the expertise of the fabricator is an important and effective factor in the performance of industrial formwork supply chain, and is required in the design, detailing and production of formwork solutions. Moreover, waste in the industrial formwork supply chain can be further reduced by implementing standardized information flow, standardized solutions for non-standard problems, accurate data transfer, flexible production systems, effective inventory management, and better coordination among stakeholders.

In future studies, the effects of using Building Information Modeling (BIM) in industrial formwork design on the performance of the supply chain can be investigated. In addition, different industrial formwork solutions can be developed to measure the lead time of the activities at the beginning of a project, thereby reducing waste in the early phases.

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A Categorization of BIM-Related Legal Issues

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Abstract

As Building Information Modeling (BIM) brings effectiveness and better quality into the sector, it has broadened its usage worldwide throughout recent years. This expansion also motivates researchers to investigate potential problems that may occur while adapting and using BIM. Since it has modified the nature of the relationships between the parties differently than the traditional project delivery, legal issues such as Model Ownership and Intellectual Property, Contractual Relationship of Parties, Design Liability may become more critical. Hence, institutions and authorities have published protocols and standard forms of contracts to overcome such issues. However, lately, in the courts of the leading countries in BIM, like the UK and the USA, there are several BIM-related case law that are recording the encountered issues due to some perceived legal problems mentioned above. Therefore, in this paper, a categorization of potential legal issues is developed by investigating related publications. By categorizing potential BIM-related issues, this paper not only eases the way for examining related claims but also suggests conducting a case law examination with these categories to see how much of the legal issues mentioned in the literature are causing problems.

Keywords: *BIM, case law, legal issues, contractual issues.*

Introduction

As the project gets complicated day by day, the need for a more comprehensive and effective way of working in construction becomes more dominant. Having Building Information Modelling (BIM) system utilized in the project ensures a number of advantages such as a reduction in the final cost, improvement in labor productivity, and acceleration of completion (Dodge Data and Analytics, 2015). For such reasons, engineers and contractors in the construction industry are getting more included in BIM. As the acceleration of the use of BIM in the leading countries of the sector like the US and UK increasing for last years (Dodge Data and Analytics, 2015; National Building Specification, 2019), other countries in the world such as France and Canada follow this trend (Dodge Data and Analytics, 2017; McCabe et al., 2019).

Collaboration is the key to BIM success. In order to create a functionally working collaboration, there should be set a standardized way of working and mutual trust between the stakeholders. Hence, the role of protocols and contracts in the projects become more significant. Although people's anticipation of legal issues related to BIM has decreased in recent years (McCabe et al., 2019), it still seems as one of the most important reasons for holding people from adopting BIM (National Building Specification, 2015, 2019).

As BIM had penetrated into the sector, researchers have conducted surveys and published papers on the legal aspects of BIM, and several studies have characterized the potential legal issues. There are various issues categorized differently in each publication. In this study, a unique categorization of potential legal issues will be done by investigating related publications. As a final remark, the number of case law in the BIM-leading countries will be mentioned to encourage case law examination by using the categorization of these study to see how they are related in the real cases.

Potential Legal Issues Associated with BIM

There were 55 publications that mentioned the legal issues related to BIM until 2017 (Fan et al., 2018). In addition to these articles, it can be seen that between 2018 and 2020, there are 20 more publications and case studies that mentioned legal aspects of BIM or how to overcome these obstacles, when the keyword "BIM Legal Contract" is used for searching through Scopus. After the elimination of the publications that are not directly considered the legal issues, a total of 13 publications are found between 2018 and 2020. While 3 of them are conference papers, 9 are journal articles, and 1 is a book. Additionally, a book from 2015 is added to those publications. Although all researchers and authors use different titles when explaining the problems they put forth, the mentioned problems can be categorized under a few titles by considering their explanations of the issues (Table 1).

Table 1. Potential legal issues.

ID	Legal Issue Category
C1	Standard of Care
C2	Intellectual Property Rights and Model Ownership
C3	Contractual Relationship and Responsibilities of Parties
C4	Coordination and Control of the Design
C5	Legal Status of BIM
C6	2D-3D Utilization

In this regard, by giving more importance to the issues mentioned by a considerable number of authors and investigating the work of Fan et al. 2018 at the sub-title level, the subjects included in all research studies can be examined under these six categories that we have identified (Table 2). Although publications referred to the issue of standard of care under different titles such as Policy and Consideration, they can be related to C1. C2, which is the topmost issue in the literature regarding BIM, on the other hand, mentioned under almost the same titles as IP Rights or Copyright. While C3 is mainly referred to under liability related titles, C4 is mostly stipulated under managemental issue. The legal status of the BIM model and 2D-3D Utilization are the least mentioned issues, and each paper considered different aspects of these categories. Also, the weights of these categories are given in Figure 1.

Table 2. Legal issues mentioned in the publications.

		C1	C2	C3	C4	C5	C6
Fan et al. (2018)	The use of BIM contract documents					3	
	Inappropriate level of BIM details when delivering						1
	Liability exposures to design errors				23		
	Standard of care	9					
	Model Ownership and IPR		39				
	Unclear Rights and Responsibilities			30			
	Coordinating and controlling the model				8		
	Privity of contract and rights to rely on	15					
(Dougherty, 2015)	Standard of Care	*					
	Responsible control of the design				*		
	Spearin Warranty			*			
	Model development, use, and reliance	*					
	Legal Status of Model					*	
	2D-3D Conversions						*
	Copyright and Intellectual Property		*				
	Duty to Inform			*			
(Adibfar et al., 2020)	Copyright		*				
(Abd Jamil & Fathi, 2020)	Technology Compatibility						*
	Auditing Procedures		*		*		*
	Responsibilities, ICT Protocols			*			
(Fan, 2020)	Principle and Policy	*			*	*	*
	Responsibility and Risk			*			
	Intellectual Property		*				
	Management and Tool				*		
(Dao et al., 2020)	Rights and obligations of Stakeholders			*			
(Liao et al., 2019)	Ownership and IPR of BIM		*				
	Unclear design delegation			*			
	Liability of the BIM consultant				*		
	Payments related to the use of BIM	*					
(Abd Jamil & Fathi, 2019)	Intellectual Property		*				
	Liability	*		*			
	Process-related risks allocation				*		
(Jo et al., 2018)	Ownership of the BIM Model		*				
	Intellectual Property Rights		*				
	Model Management and Record				*		
	Allocation of Risk			*			

Table 2 (cont'd). Legal issues mentioned in the publications.

		C1	C2	C3	C4	C5	C6
(Abd Jamil & Fathi, 2018)	Compensation and Consideration	*					
	Conflicts of Contract			*			
	Data Security				*		
	ICT Protocols			*			
	Intellectual Property		*				
(Almarri et al., 2019)	Is the Model contract document					*	
	IPR		*				
	Unallocated risks			*			
(Fan et al., 2019)	Contract Structure and Policy	*		*			*
	Contractual Relationships and Obligations			*			
	BIM Model and Security		*				
(Arshad et al., 2019)	Intellectual Property		*				
	Professional Liability			*			
	Cost compensation	*					
	Standard of Care	*					
	Legal Validation						*
	Model Management				*		
(Borrmann et al., 2018)	Rights to Data		*				
	Liability			*			
	BIM Management				*		
(Sardroud et al., 2018)	Liability Issues			*			
	Intellectual Property Rights		*				
	Technological Aspects				*		
	Behavioral Risks			*	*		
TOTAL		25*	52	46	36*	5	6

*Total numbers are decreased due to repeating papers in (Fan et al., 2018).

After considering these categorizations of issues with the work of Fan et al. 2018, the number of publications and the weights of them becomes clearer, as shown in Figure 1. Intellectual Property and Model Ownership related issues are the most mentioned issues in the publications with 31%. It is followed by professional liability related problems, Contractual Relationship and Responsibilities of Parties, and Coordinating and Control of the Design. The fourth issue is the Standard of Care, with 15%. The last two issues with 3% are Legal Status of the Model and 2D-3D Utilization. Therefore, in the remaining part of this section, the six categories that we have identified will be explained in detail.

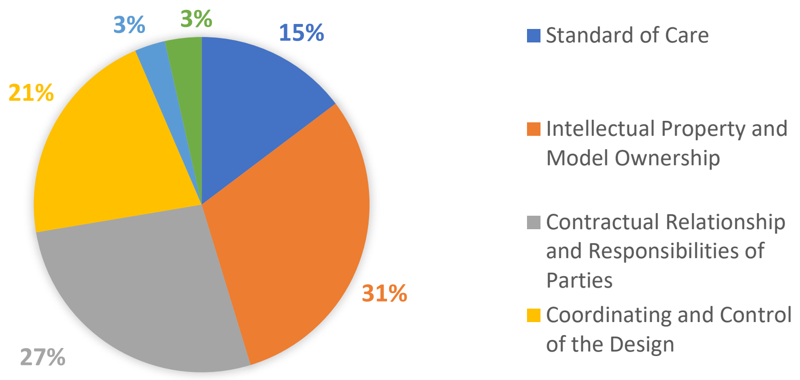

Figure 1: Weights of legal issues mentioned in the literature adopted from (Fan et al., 2018).

Standard of Care

As a Tort Law concept, the Standard of Care indicates that an architect/engineer must utilize the same level of care with the professionals of their expertise in the same circumstances while giving services related to their duty of care. As in the past, every technology that is new to the industry, and being adapted later becomes a standard and an indispensable element of the industry as it is accepted. Just like CAD in the past, with the inclusion of BIM in the construction sector, it is starting to introduce innovative and efficient methods as well as creating new expectations. For instance, it is now easier to detect clashes and prevent other design-related issues prior to construction by enabling BIM tools; thus, it is not abrupt to say that the expectations from architects/engineers will be higher with regard to their professional skill and care. As BIM evolves, the number of errors will decrease, and these expectations will ultimately become the new standard. The number of errors will decrease as the number of projects utilizing BIM increases. However, these standards are not yet decided by a protocol or any contract document, but they can be defined by the courts (Arensman and Ozbek, 2012).

Additionally, the perception of the standard of care can create reliance issues. Apart from the software reliance issue due to excessive and essential usage of the software, collaborators should rely on information that is provided by another party. Especially in a platform like BIM that needs an existing collaborative nature, parties continuously share information throughout all phases of the project in which others should rely on and perform their work based on them. Architects/engineers need to get too many inputs from their collaborators and carry out their work, and they still need to satisfy the requirements of their standard of care. Therefore, limitations of liability and indemnification agreements may need to be included in the agreements of the collaborators, even if it restricts the collaboration to some extent. On the other hand, BIM alters the way how the doctrine of privity protects the designers of the project, therefore affects the standard of care. The doctrine of privity of contract preserves parties from being sued by third parties who have not a direct contractual relationship. However, recent case law displayed that the courts discuss negligence claims regarding the contractor's reliance on the information supplied by the uncontracted architects/engineers by knowing that the information will be trusted by the contractor. Also, the information is later understood to be faulty by negligence or misinterpretation (Simonian, 2010).

Inevitably, this conversion on the standard of care brings a compensation problem as well. As the risk and the expectations shifted towards designers, it is reasonable for them to expect monetary compensation. In fact, as BIM presents a more efficient way for processes, it aimed to reduce time wasted in design as well as in construction. Therefore, the price that designers obtain will be deducted since they are commonly paid for hourly rates. Apart from reduced person-hours of designers, the implementation cost of BIM will be a burden on the shoulders of them. The cost includes not only the necessary software and hardware but also includes training of employees for BIM. However, neither employers nor contractors will be willing to pay for such cost compensation.

Intellectual Property Rights and Model Ownership

The construction sector is keeping up with BIM. Therefore, the information that is provided becomes more comprehensive. The models are three-dimensional and intelligent, they contain detailed physical and functional information that can be benefited throughout the project life cycle, and the transmission of data has increased. All of these factors started to highlight the issues related to Intellectual Property Rights. In BIM, everyone provides input to the model, which makes it unclear who has done what. In some circumstances, it may become more complicated since each collaborator can create new models with the information provided by each other, and therefore each may have a derivative model, and even if a single model emerges, it can become a model that many stakeholders are entitled to.

There may be more than one opinion regarding ownership. First of all, some may argue that the owner of the information is the creator of that information. In a similar way, the owner of the information can grant a perpetual right of use license to another party to use that information in relation to that specific project such as calculations, fabrications, marketing, etc. In contrast, another view can argue that collaborators producing information must grant all rights and ownership of the model to the employer. Thus, the employer holding this license can use these models and information in further projects.

In addition to all these, some other problems can be mentioned that can be associated with ownership. Even if architects give a license to use the model to the contractor, another party, or even a competitor, later can access that information that the creator party wants to protect its intellectual property rights. Confidential trade secrets are now easier to access, and it is more difficult to detect which user or a third party that is not directly involved in the contract reaches that information, as things are now done in a digitalized environment. While the protection of business knowledge is counted as an important topic, it is also an important problem that a party can reach and use a family or an element created by another collaborator who has spent hours and days while creating them. Worse than that, the ways of protecting rights such as copyright are related to the protection of a unique product, so it is not applicable to universal and non-exclusive products such as BIM elements. For this reason, the owner of an element that needs hard work for creation can neither apply for a patent with regard to its production nor claim any rights on it in a possible controversy.

Contractual Relationship and Responsibilities of Parties

BIM, which emerged with a multi-disciplinary nature, rearranges the contractual relationships of the parties differently from conventional procurement methods. Contractors or subcontractors involved in the early stages of the project may establish relationships with the main contractor or owner and have a direct impact on the projects. Notwithstanding that, BIM creates new roles and responsibilities such as BIM Coordinator, BIM Manager, BIM Modeler, etc. These roles become more crucial, especially in large and complex projects. When the flow of information is faster than the control of these procedures, it may become an important issue. A model manager, for example, is responsible for the coordination of information that goes into the model and ensures effective use of the model (Sebastian, 2011).

This collaborative environment causes the parties to be involved in each other's procedures. As in the case of the early involvement of a specialty contractor or a fabricator to a contract, it allows them to give advice to the contracting party. This, in some cases, results in the avoidance of responsibility under means and methods. Traditionally, a contractor is in charge of the means and methods, even if s/he is obligated to use the plans and specifications supplied by the employer. On the other hand, the Spearin doctrine protects a contractor from faulty or misinterpreted information provided by the employer. Yet, this does not mean that the contractor has no liability if the owner has approved their means and methods. However, in common law, these risks shifted towards the contractor and the designer instead of the owner (Henderson, 2010).

Coordination and Control of the Design

In traditional construction, the architect is responsible for the design. But the way of designing is changing with BIM. There is more than one contributor to the design, from manufacturer to erector. Therefore, the responsibility and control of design may go beyond the reasonable control of the architect. The sector should also evolve with these and keep up with the new foundations. These changes can also be followed by the "Rules of Conduct" published by the National Council of Architectural Registration Boards (NCARB). In 2018 they made an important change in the professional rules of conduct. Previously, they defined the circumstances in which architects can sign and seal the technical submissions as (i) they prepared by them (ii) they prepared by under the architects' responsible control. Responsible control is defined as the amount of control the architect has on the submission by using its profession with regard to the required standard of care. Reviewing and correcting inputs of others to the submission does not include in responsible control since it may go beyond the architect's professional knowledge. In the latest version, they indicated that an architect should sign and seal technical submissions under its responsible control except for stated circumstances (NCARB, 2018) later defined in the provision as :

> *An architect of record may sign and seal technical submissions not required by law to be prepared by an architect, including information supplied by manufacturers, suppliers, installers, contractors, or from the architect of record's consultants when that information is intended to be incorporated into the architect of record's technical submissions, and the architect of record has reviewed such information and can reasonably trust its accuracy.*

Controlling and coordination of the information is essential from schematic design to the as-built phase. In every milestone or for all uses of BIM, it is important to have a negotiated level of development (LOD) to not to face with reliance issues as mentioned above but also not to cause any inefficiency during the design phase. Even if one seeks to obtain a LOD 500 for a specific part of the project, for example, it should be defined at which stage they want to reach to such LOD. In this manner, the inclusion of end-users' needs prior to deciding LOD's of crucial parts is one of the essentials of BIM. Therefore, the coordination of stakeholders has a noticeable effect after the completion of the project on the operational use of the model.

Legal Status of BIM

The legal status of the BIM model can vary according to the project. While in some, it is not a contract document but used between parties and does not submit to the agencies as it is a "co-contract document" in which it governs the affairs between parties or an "inferential document" in which the model stands for only visualization purposes (Pandey et al., 2016). Also, parties can maintain the conventional way of designing without including the BIM model as a contract document. In this application, the producer of one model is not obligated to validate the integrity and accuracy of the model they provided, but this reasonability stays with the receiver of the model (Ku and Pollalis, 2009). In order to facilitate that use, the coordinator of the collaboration process describes the geometric rules and 3D design and construction-related information to the downstream contributor. This is called an "accommodation document" (Ashcraft, 2008). On the other hand, if a legally binding rule or model is not found, one cannot impose the desired geometries as precise guides to use. The priority of the model receiver is that the model he receives is reliable for his own use. From this point of view, if the shared information and models are shared for the purpose of "information only," instead of producing a model from these inputs, the users only refer to this information and create their own model by using the original 2D contract documents; thus, the collaboration is undermined. The model creator should assure the users of the integrity and the accuracy of the model in order to facilitate that concern, and the process will be more efficient since everyone will not create their own separate model. By inducing such a validation system, every contributor can derive their model from supplied models. However, the designer is concerned since the reuse or alteration of their model may be beyond their liability. Even if this concept is also valid for 2D models, the risk is higher when these processes are pursued in an electronic environment (Larson and Golden, 2007).

2D-3D Utilization

As the sector moves towards BIM, traditional 2D design documents or projects of the buildings are wanted to be converted into 3D models. While this conversion takes place, the required LOD should be defined well. It is crucial to satisfy the intended purpose of the conversion. Apart from that, in the project that uses a 2D documents as the contract documents and then converts those into a 3D format, it may constitute a problem to revise 2D models used as a baseline when 3D models are used to continue with the design (Dougherty, 2015). Sometimes conversation from 3D to 2D can cause a validation problem for the quality of the model since the handovers are made on 2D formats traditionally (Abd Jamil and Fathi, 2020). Also, it may be ambiguous which model should have the priority, in such circumstances where there is a conflict between 2D and 3D documents.

Conclusion

The demand for BIM will increase eventually, but in order to utilize BIM in a more effective way, it is important to have knowledge and awareness of its potential legal problems. The six categories mentioned in this paper summarizes the whole picture of the related literature in this field. On the other hand, as the implementation of BIM procedures has increased, institutions around the globe have published a number of protocols and standard forms of contract aimed at envisioning and covering possible legal issues. However, as mentioned in the literature (Arensman and Ozbek, 2012; Eadie et al., 2015), BIM could not be tested since there was no case law in the courts.

Nevertheless, when "Construction Project," "Building Information Model," and "BIM" keywords have been searched on "Leagle", it is found that there are 12 cases which can be correlated with BIM in the USA. By using the same keywords, the search has been repeated on the database of "Bailii", and by using "BIM Case Law UK" on Google, it has been seen that there is 4 BIM-related case law in the UK. Thus, a total of 16 cases have been seen on the courts of these two BIM-leading countries (Figure 2).

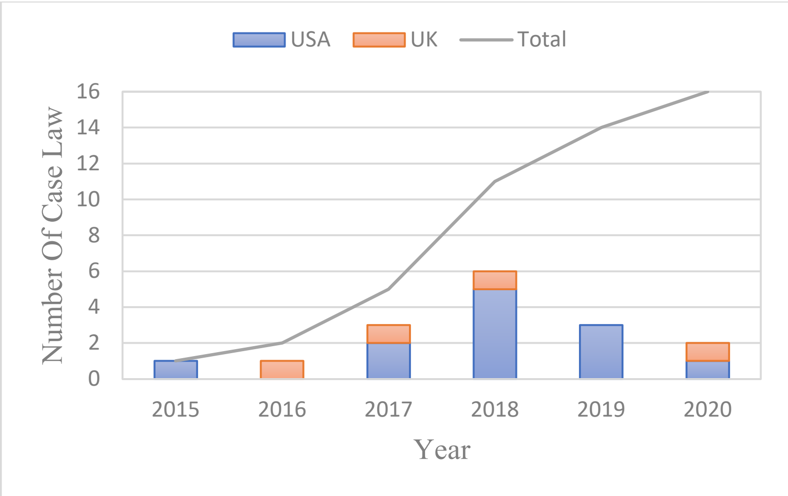

Figure 2: Distribution of case law by year.

As a future study, these case law can be explored in detail and matched with the categorization presented in this paper in order to see how literature foresaw the potential issues and how they relate to real cases. In this way, the detailed examination of these cases will not only characterize the root causes of legal cases but also provide data to prevent possible future legal problems while using BIM.

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Towards Using Human-Computer Interaction Research for Advancing Intelligent Built Environments: A Review

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Abstract

For many years, primitive building components that are almost entirely transparent with their simple logic and physical interfaces (i.e., light switches, operable windows) provided occupants sophisticated opportunities to regulate indoor environmental conditions including temperature, lighting, and air quality. However, as buildings are expected to incorporate more automated services, intelligent applications and artificial intelligence in the near future along with the improvements in the field, it is foreseen that conventional touch-input modalities will be subjected to change and there will be a radical transition in the way people interact with the built environment. The field of human-computer interaction (HCI), which is a multidisciplinary research domain focusing on human aspects of the developments in computer technology, holds a great potential to assert its expertise for creating human-centered solutions in the process of integrating novel technological applications to buildings. The main aim of this research, therefore, is to understand and assess how the accumulation of knowledge in the HCI research field can be utilized in studying new interaction modalities in intelligent built environments. In this direction, it is intended to review the applicable research methodologies that can be derived from the HCI research community to envision the gradual change in human experiences with and within the buildings alongside the advancements in information, communication, sensor, and actuation technologies.

Keywords: *human-building interaction, human-computer interaction, HCI, intelligent buildings, interface design*

Introduction

Conventional buildings comprise many primitive interfaces that enable their occupants to regulate and adjust their habitats according to their preferences. In recent years, many researchers have tried to explore and understand the way people interact with their surrounding built environments and how these interactions affect the building performance under the keywords of "occupant behavior" and "human-building interaction". Hong, Yan, D'Oca, and Chen (2017) outlined the primary human-building interactions as opening/closing windows, lowering blinds, adjusting thermostats, turning the lights on/off, and operation of plug-ins. Although such interaction possibilities grant a noteworthy personalized control for occupants, resultant problems like inefficiency in energy use, decreased human comfort, and lack of control for building managers fostered the automated operation of building systems and integration of intelligent building control applications. As comprehensive technological advancements in information, communication, sensing, and actuation systems have rapidly evolved in the last decade, incorporating innovative tools into the fabric of buildings became more feasible. Such developments, together with the improvements in artificial intelligence and the growth of the Internet of Things (IoT) concept, can be seen as profound indicators of a radical shift in human-building interaction modalities. In intelligent built environments, traditional touch-input procedures can be replaced with a common building interface that provides a communication ground between occupants and buildings, and regulates interaction dynamics.

Human-computer interaction (HCI) is a research field that concentrates on the interaction between people and computers in all forms, and has a particular focus on the relationship between emerging technology and its users (Pargman et al., 2019). As the employment of HCI in studying human-building interactions was demonstrated as a seminal approach to steer the evolution of the built environment (Alavi et al., 2017), it is evident that an interdisciplinary bound will be established between building researchers and HCI research domain. HCI can contribute to human-building interaction research in the fields of interface design, development, and evaluation of interactive building components and assessing human behavior with interactive artifacts (Nembrini & Lalanne, 2017). Considering these, this paper aims to make an overall review of the research methods that are used by the HCI community and to evaluate their applicability to study new interaction modalities and interface options in intelligent built environments.

Human-Building Interactions in Built Environments

People have certain comfort expectations of their environments, and when these expectations are not met, they perform actions to adjust their surroundings or align themselves with the environment. In modern buildings, occupants have been given the opportunity to interact with static building components to adjust the environment according to their comfort levels. For example, individually controlled window ventilation has been a universal consent, and it was demonstrated as a beneficial strategy for ensuring a relaxed state for occupants (Brager et al., 2004). Meaningful and deliberate human-building interactions are seen to contribute to both energy consumption and indoor environmental quality. The opening of a window for an individual’s desire for fresh air can undermine a building’s overall thermal balance, just as dropping off a blind to prevent glare can lead to loss of valuable solar penetration that warms the building (Wigginton & Harris, 2002).

Hong *et al.* (2017) demonstrated that in addition to the adaptive behavior where occupants adapt the environment to their needs, occupant presence and reporting complaints regarding discomfort to building managers also have an influence on overall building performance. Indoor environmental conditions are affected by the release of carbon dioxide, water vapor, body heat, sound, and odor, which are resultants of human presence and actions. On the other hand, just as occupants have a considerable influence on the built environment, contextual factors of the built environment affect occupants and their interactions. Ozcelik, Becerik-Gerber, and Chugh (2019) demonstrated that interactions of occupants with the surrounding built environments are affected significantly by contextual factors as well as varying thermal and visual comfort conditions, and personal preferences. O’Brien & Gunay (2014) broadly explained the influential contextual factors for human-building interactions.

Since intelligent buildings with embodied technological appliances and new types of system components will supposedly have a certain contextual difference, current human-building interaction studies that are mostly conducted within the scope of conventional building systems need to be further elaborated through anticipating upcoming circumstances. Considering the massive impact of buildings on energy consumption, global environment, occupant health, well-being, and productivity, it is significant to envision the gradual change of buildings with the advancements in information, communication, sensor, and actuation technologies, and to investigate future of interactions between occupants and their surroundings.

Transformation in the Building Interface

In his book, Reyner Banham (1969) affirmed that changes in occupant's comfort expectations and changes in methods of satisfying these expectations (*i.e.*, mechanical environmental controls) with consistently developing technology lead to the most fundamental architectural changes. Considering the accelerated advancements in information, communication, and automation technologies in recent years, a probable transformation in the interface of building components seems inevitable. In addition, furnishing buildings with the cutting edge sensor and actuation technologies have been demonstrated to provide more flexibility in comfort adjustments, which leads to reductions in energy expenditures (D'Oca et al., 2018).

As buildings of the future are expected to incorporate artificial intelligence and new forms of interactivity, it is likely to have a wide range of changes in human experiences with and within the buildings (Alavi et al., 2019; Topak et al., 2019). Luna-Navarro et al. (2020) presented a classification scheme for occupant-façade interactions, demonstrating the interactive scenarios transition in intelligent buildings. Research conducted by Bader *et al.* (2019) showed that buildings with interactive components would lead to new ways of human-building interactions, and conventional touch input modalities will be subjected to change. In fact, this transition has already become a fact of the present with the expanding growth of the IoT products. A natural dialogue ground for regulating occupant interactions with various building appliances has been introduced by many companies with virtual personal assistants like Amazon Alexa, Microsoft's Cortana, Apple's Siri, and Google Assistant (Këpuska & Bohouta, 2018). We believe that the next step of evolution will be the establishment of a common building interface that organizes and operates all building services and components based on the data inputs from both occupants and environmental parameters, backed by the use of artificial intelligence, which perceives occupant-specific preferences and routines, and supports human-centric building operation (Figure 1).

In general, since most researchers and companies naturally concentrate on improving specific service domains like HVAC, lighting, or access control separately, the interfaces of building systems will have different transformation processes. This situation reflects itself in task-specific products with various types of interface options in the market, which is propagated even more with the IoT concept. On the other hand, all building services are expected to operate coherently to ensure human comfort and convenience while maximizing energy efficiency. This can be better achieved with comprehensive system architecture and a common interface model enabling building occupants to have full control of their environments (Davani et al., 2018). This argument can be grounded through exemplifying possible scenarios. For example, when an occupant desires a cooler indoor environment and delivers this request to the building interface, the most convenient action to satisfy this request can be determined by the building using the collected data from the environment and the building systems. Instead of turning on the mechanical cooling, the building may decide or suggest opening the windows, which is a more energy-efficient solution satisfying the same requirement. In other words, a common interface model can permit the building to respond to the needs of its occupants through triggering the building system that provides the most effective and efficient action and can grant comprehensive controllability in intelligent environments for people.

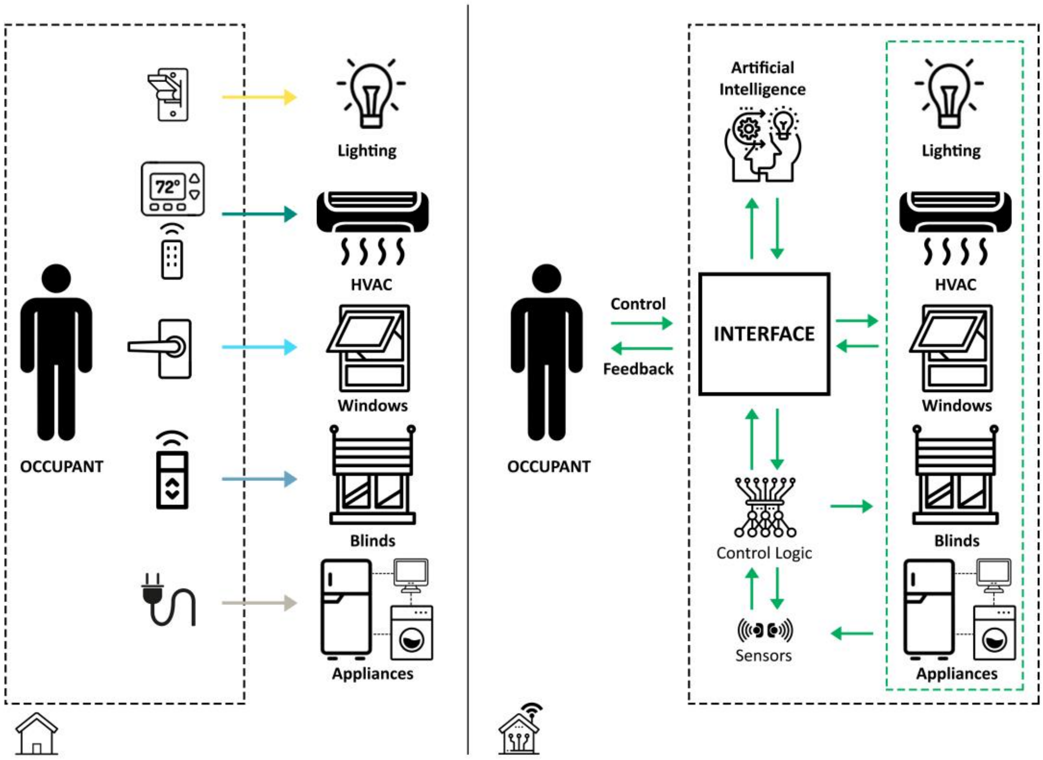

Figure 1: Transformation in the Building Interface

Just as new technologies may enable novel possibilities and challenges and consequently change the existing human interaction modalities in built environments, changes in human behaviors caused by new experiences will both require and lead to modifications and improvements in novel services and integrated technologies. Keskin and Mengüç (2018) emphasized that, once the organic interdependency between research fields of occupant behavior and technological innovation is well established based on their common attributes and hybrid conceptualizations, the dialectic relationship between human factors and innovative components in buildings would be quite straightforward to understand. Ramos, Gago, Labandeira, and Linares (2015) stressed the significance of feedbacks received from occupants and asserted that occupant behaviors might function as a design influencer for building systems. Being the main subjects of buildings, occupants should be the central components of any technology integration strategy for achieving success and overcoming the problems of wide-scale acceptance and utilization. Considering the interrelated effects of people and built environment on each other, just as occupants experience and affect the buildings, a building should perceive and respond to its occupants in its own way and provide necessary means for intervention for an enhanced operational management (Clements-Croome, 2013).

The human-building interaction research, advancing upon the foundations that the human-computer interaction research has laid, may have a substantial influence on the technological development processes in buildings. Deriving methodological insights from HCI may enable building researchers to comprehensively study critical questions like "how do building interfaces, their context, and their underlying control logic affect behavior and perceived control?" and "what interface features and characteristics are most effective at delivering a comfortable environment, outstanding perceived control, and reductions in energy consumption?", which are pursued by IEA Annex 79 research group and outlined by O'Brien et al. (2020).

Insights from Human-Computer Interaction Research

HCI research is situated as an intermediary domain between human-related studies and computer science. The main aim of most HCI studies is to gain undiscovered insights about how humans interact with technology and enabling new developments upon that knowledge. As Carroll and Rosson (2013) asserted, HCI governs innovative approaches, through ensuring a balance between human priorities and technology advancements. A novel task for the HCI community is recently suggested by Alavi and Lalanne (2020) as: "to bring the knowledge created in various areas of social science to the format and position that can effectively shape the development of non-human intelligent actors and inform the policies governing whether and how they should be adopted". This is a very legitimate and valid proposition also for building researchers, considering how such interdisciplinary research can help to reshape the built environments through integrating innovative technologies without overlooking human values. Building researchers and practitioners have the responsibility of developing technology integration strategies for creating more comfortable, healthy, and efficient built environments, without compromising humanitarian priorities.

Research methods that are most frequently used by the HCI community include field experiments, surveys, case studies, interviews, focus groups, ethnography, and usability tests (Shneiderman et al., 2016). Table 1 demonstrates these research methods, which is constructed based on the comprehensive explanations provided by Lazar, Feng, and Hochheiser (2017). Within these methods, ethnography and usability tests deserve further investigation since they are relatively unusual for building researchers. Ethnographic methods used in HCI generally aims to examine the technology usage in residential, commercial, and educational settings (Lazar et al., 2017). Building researchers can utilize this method for understanding human needs, behaviors, and actions in buildings and sorting out the requirements for system integration of new technologies. Conducting ethnographic research can be a very useful starting point for realizing the digital transformation in built environments. While ethnographic studies are for grasping the nature of a group, a problem or a context, usability tests generally used for developing and improving interface design in complex systems (Lazar et al., 2017). Usability is defined in ISO 9241-11 (2018) as: ''the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use''. Usability research in the built environment was introduced by the CIB W11 working commission (Alexander, 2010), aiming to reveal an overall framework that will bring sustainable benefits for all building stakeholders. Krukar, Dalton, and Hölscher (2016) pointed out the similarity in usability characteristics defined in HCI and architectural design. Accordingly, a triangle of user characteristics, task properties, and user interface in HCI research reflects itself in architectural design with a similar triangle of building occupant, building-specific tasks, and building interface. Nembrini and Lalanne (2017) mentioned the need for usability measurements in buildings, in terms of both the built structure and the interior elements. Karjalainen (2010) used usability tests to develop temperature control interface prototypes. Although the number of researches about the usability of innovative interface prototypes in buildings is limited, the accelerated transformation in the building interface is about to reveal a largely undiscovered research field. Clearly, there is an obvious burden in developing interface prototypes for a built structure when compared to those in HCI, in terms of both cost and effort. However, one of the usability testing techniques that is called “Wizard of Oz” benefit from a hidden individual, performing actions that an upcoming system may have the capability to provide autonomously, while simulating an intended prototype (Lazar et al., 2017). This technique could suggest considerable advantages for building researchers, enabling flexibility and cost-effectiveness in experiments.

Table 1: Research methods in Human-Computer Interaction

Research Method	**Main Aims**
Surveys	• Describing populations, explain human behaviors and explore uncharted waters • Measuring attitudes, awareness, intent, feedback about user experiences, characteristics of users, and over-time comparisons
Case Studies	• Generating theories and hypotheses, present evidence for the existence of certain behaviors • Understanding novel problems or situations for informing new designs • Developing models that can be used to understand a context of technology use • Documenting a system, a context of technology use, or the process that led to a proposed design
Interviews and Focus Groups	• To help build an understanding of the needs, practices, concerns, preferences, and attitudes of the people who might interact with a current or future system • Gathering requirements, evaluating prototypes, and summative evaluation of completed product
Ethnography	• Understanding the dynamics of a human group and the context in which specific interfaces or systems are developed and implemented • Understanding systems requirements and user needs
Usability Testing	• To improve the quality of an interface by finding flaws that need improvement • Testing prototypes through involving representative users attempting representative tasks in representative environments.

Concluding Remarks

Technology has been continuously transforming the built environments, with changing magnitudes throughout the last century. Lately, this transformation has been accelerated and reached a considerable pace, with the developments in artificial intelligence, the Internet of Things concept, sensing, computing, and automation systems. Using the methodological capabilities of HCI research as a steady baseline has an immense potential to bring out unveiled insights about technological transformation in the built environments, and to formulate new development and creativity directions for practitioners and researchers, as well as designers. The built environment has immersive and multimodal aspects that comprise many processes over various spatial and time scales, which differentiate itself from the tasks that are isolatedly studied under HCI. However, once the necessary adjustments are arranged not to compromise the unique features of buildings, the accumulated methodological knowledge in HCI has the potential to facilitate a simplified path for the built environment researchers, pursuing studies to transform human habitats.

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A Meta-Analysis Study on the Sustainability Performance of Project Delivery Systems

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Abstract

Construction projects have begun to complicate because of new developing technologies and materials, and also increasing programs and user participation in projects. Thus, this also leads to complicate project delivery systems (PDSs). However, various PDSs are developed both to manage this complex relationship and to meet the needs of the sector today. The selected PDS affects the cost, time and quality performances of a project. Therefore, the selection of a proper PDS is very important for the success of the project. For the increasing number of sustainable projects, the PDS also affects the sustainability performance of the project. Comparing to conventional projects, sustainable building projects differ in terms of design, construction, and operation. Therefore, it is expected that the PDSs selected for the management of these projects will also differ. However, it is seen that generally sustainable building projects are conducted by using existing PDSs. This study aims to evaluate the impact of PDSs used in construction projects on the sustainability performance of the project through meta-analysis. In this context, it is desired to determine the PDSs that contribute positively to sustainability performance and the parameters that are effective in the PDS for sustainable projects. As a result, although sustainability performance is obtained at different scales with existing PDSs, the operation phase of the project is the most important process for sustainable projects. For this reason, it is expected that a PDS that will be used for sustainable projects should include the operational phase of the project.

Keywords: *meta-analysis, project delivery systems, sustainable construction, sustainability.*

Introduction

Projects in the building sector are becoming more and more complex with the project scope and user needs, as well as developing technology and building materials, and the user's participation in the project. One of these projects is "sustainable buildings", which have globally become an important phenomenon. Environmental benefits provided by sustainable buildings can be listed as energy and water efficiency, conservation of natural resources and the use of renewable resources and environmentally friendly materials, conservation of green spaces, and the least harmful arrangements (Kubba, 2012). There are also social impacts such as improved indoor quality, and user health and productivity (Lapinski et al., 2006). The fact that sustainable buildings have less operating costs during their usage provides economic benefits (Pulaski et al., 2006; Gultekin et al., 2013). In this context, the social and economic benefits of sustainable projects, especially environmental, increase the tendency towards these projects. However, considering these benefits, it is very important for the building sector to successfully deliver sustainable buildings.

The success of a project depends on the time, cost, and quality that form the project management triangle. These success criteria, which are valid for conventional projects, are not sufficient for sustainable projects. In other words, the project management triangle is not the best representation of project success alone for sustainable projects (Dakhli et al., 2017). Therefore, project success driven by sustainability should be evaluated on 5 criteria: cost (economic), time, quality, environment, and society (Grevelman & Kluiwstra, 2010; Ebbesen & Hope, 2013). However, while the success of a project is evaluated according to these criteria, various factors affect these criteria in the project. One of these factors is the project delivery system (PDS) selected for the project (Sobin, et al., 2010; Olubunmi, 2015).

PDS is a method that shows how the project is designed and built (CMAA, 2012) while establishing the order of the parties' relations, roles and responsibilities, and the activities required to provide a facility (Konchar & Sanvido, 1998). PDSs, which were preferred in the form of design, tender, and construction (Design-Bid-Build / DBB) until the Second World War, with the emergence of the construction manager (CM or CMR) in the 1970s and the merging of design and construction responsibility in the 1990s (Design-Build / DB) has changed considerably in the last 70 years (Franz & Leicht, 2016). As construction projects became more complex, this situation began to complicate project delivery (Baccarini, 1996). However, various PDSs are being developed both to regulate this complex relationship and to meet the needs of the sector today. Because the unique structure and character of each project sometimes lead to the need for alternative and flexible PDS. For this, it is seen that projects either develop new PDSs or use existing PDSs by modifying them (Kenig, 2011; Franz & Leicht, 2016; Martin et al., 2016). Considering the complexity and needs of sustainable projects, it is very important to develop a PDS for these projects (Gunhan, 2016; Widjaja, 2016). However, it is seen that recently PDSs are used in sustainable projects by making necessary arrangements in existing ones. It must be noted that this affects the performance and success of sustainable projects.

With this awareness, the studies on the impact of PDSs for sustainable projects have increased over the last decade. The evaluation of the studies carried out in this issue is very important for PDSs that will be addressed for sustainable projects. In this context, in this study, a "meta-analysis" is conducted, which enables determining the research trends especially on PDSs and their sustainability performances, and in which areas there is concentration and in which areas the studies are lacking or limited. Besides, with the help of meta-analysis, it is aimed to find answers to the questions; (i) what is the direction of the relationship between PDS and the sustainability performance of a project, (ii) which PDS or PDSs are more advantageous for sustainable projects, and (iii) which attributes of project delivery impact on PDSs for sustainable projects.

Method

In this study, a literature review was conducted for the studies examining the performances of PDSs used in sustainable projects. However, literature reviews are a subjective process in selecting and reporting the findings. A literature review may be more useful and serve the purpose better if certain procedures are used to minimize subjectivity. Thus, "meta-analysis" has emerged as a statistical analysis of a large group of analysis results obtained from individual studies in order to combine the findings (Glass, 1976; Betts & Lansley, 1993). Therefore, the meta-analysis method is used in this study to conduct the literature review more systematically.

Determining the classification parameters of the subject to be meta-analyzed is one of the most important points of meta-analysis (Betts & Lansley, 1993). Classification is of great importance in any subject analysis, in determining how the research trend is concentrated, in which areas there is concentration and in which areas there are gaps (Zhao, 2017). Therefore, it is very important to determine the parameters that cover the subject to be examined. Meta-analysis studies conducted on project and construction management are covered under four main groups as author/publication, content, form-input/output, and purpose-outcome (Betts & Lansley, 1993). Various studies using meta-analysis method were used to determine the classification categories and sub-categories (Betts & Lansley, 1993; Koğ, 2016; Aydın & Yaman, 2018) and the content category has been enhanced to provide a more comprehensive content analysis Molenaar et al., 2010; Montalbán-Domingo et al., 2019). Because content analysis is a systematic technique based on objective analysis and it can be used with meta-analysis as it enables the analysis of a large amount of written material through the frequencies, meanings, and relationships of the data (Krippendorff, 1989). Table 1 shows the main four categories, sub-categories belonging to the meta-analysis classification in the study and the factors including them.

Table 1. Meta-analysis classification categories.

Category	Sub-category	Factors
Author/Publication	Author	*Names of authors*
	Year	*Publication year*
	Journal	*Name of journals*
	Main Heading	*Topics of publications*
	Institution	*University, Research Center, Private Sector, Public Sector*
	Country	*Name of the first author's country*
	Keywords	*List of the keywords*
Content	Subject	*Effects of project delivery systems on sustainability* *Effects of stakeholders on sustainability* *Sustainable project delivery*
	Area	*Architecture, AEC, Construction, Civil Engineering, Construction Management, Facility Management, Property Management*
	Study Level	*Sector, Firm, Project, Professionals, All*
	Analysis Level	*Private Sector, Public Sector, PPP, General*
	Project Type	*Residence, Office, Education, Heath, Mixed, Infrastructure, Other*
	Project Delivery System (PDS)	*Name of the examined project delivery system(s)*
	Process	*Conceptual Design, Design, Bid, Construction, Operation, PLC*
	Stakeholders	*Owner, Designer, Contractor, Sub-contractor, Consultant, Project Manager, User, Other*
	Sustainability Dimension	*Environmental, Economic, Social, Environmental-Economic, Environmental-Social, Economic-Social, All*
	Sustainability Labelling	*Green Building Certification System*
	Relation between PDS and Sustainability	*Yes (+), Yes (-), No, Not mentioned*
	Advantageous PDS for Sustainability	*List of adventurous project delivery system(s)*
Form & Input-Output	Source of Data	*Literature (Review), Observation, Interview, Survey, Case Study*
	Type of Data	*Qualitative, Quantitative, Mixed Method*
	Methods	*Name of the method(s) in the publication*
	Contribution	*Insight, Model Building, Statistical Results, System Building*
Purpose & Outcome	Problem	*Purpose of the publication and problem scope*
	Result	*Result of the publication and result scope*
	Opportunities and Threats	*Opportunities and Threats for future studies*

Studies on PTS performance can be accessed from a variety of sources, including books, journal articles, conference papers, academic theses, and reports. Access to all these resources can be obtained through various databases. Therefore, it is very useful to use databases to access related resources. However, databases may differ in terms of the studies they cover. Accordingly, Scopus has a wider range of scientific publications compared to Web of Science (WoS) (Falagas et al., 2008). In addition, the indexing process of Scopus is relatively faster, allowing to include recent studies recently published (Meho & Rogers, 2008). In the literature, Scopus is a frequently preferred database for systematic literature reviews on sustainable buildings and green buildings (Darko et al., 2019; Ahmad et al., 2019). Another important point after the classification for meta-analysis is the selected research database. For this reason, within the scope of the study, English articles in Scopus and published in refereed journals as they meet a certain academic standard were analyzed.

After the database was determined, a systematic and comprehensive search was conducted. In this search, the related publications were determined in three stages. In the first stage, searches were made for the publications with the help of keywords determined using the Boolean Operator in Scopus. The use of boolean operator is very important in terms of facilitating access to targeted studies, due to serving the relationship between keywords in the databases results in an intersection. Accordingly, within the scope of the study, the search limit was created as "ALL("sustainable project delivery" OR "project delivery system" OR "project delivery method" OR "procurement method") AND TITLE-ABS-KEY("sustainability" OR "sustainable construction" OR "green building" OR "sustainable building" OR "high performance building")" and the studies performed in the last decade (2010-2020). Thus, 389 publications were reached as a result of the limitation made with the title/abstract/keyword. In the second stage, the abstracts of these 389 studies were examined in detail and it was evaluated whether they were suitable for the target determined within the study. After this process, the number of related studies decreases to 77 publications. However, since the study only aims to examine the articles in refereed journals, the number of publications to be meta-analyzed at this stage was determined as 56. In the last stage, during the detailed examination of publications for meta-analysis, it was seen that 10 articles were not intended for the study problem and these publications were left out of the evaluation. Finally, the meta-analysis of 46 studies was conducted. According to the classification criteria (Table 1), the publications were tabulated with the help of Microsoft Excel® and the results were presented in tables and graphs. Furthermore, SPSS was used to evaluate some relationships between the obtained results.

Results and Discussion

Meta-analysis results are shared under four categories according to the classification in Table 1. In addition, project delivery attributes (PDAs) that have impacts on PDS performance in sustainable projects are examined under a separate subtitle within the scope of the study.

Author/Publication Relationship

Table 2 presents the results of the author/publication relationship. Accordingly, it is seen that some of the publications are handled by certain authors from different perspectives. The names of the most famous writers on this topic are Korkmaz, Olanipekun, Riley, and Xia (Table 2). While the publications were mainly conducted with two authors, there were no studies with more than six authors.

Table 2. Numerical distribution of publications by author-publication relationship.

Author	No. of Article	Affiliation	Country
Sinem Mollaoğlu Korkmaz	5	Michigan State University	USA
Ayokunle Olubunmi Olanipekun	4	Queensland University of Technology	Australia
David Riley	4	Pennsylvania State University	USA
Bo (Paul) Xia	4	Queensland University of Technology	Australia
Tayyab Ahmad	3	The University of Melbourne	Australia
Ajibade Ayodeji Aibinu	3	The University of Melbourne	Australia
Michael Horman	3	Pennsylvania State University	USA

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total
No. of Article	4	3	1	3	5	0	6	7	3	11	3	46

Journal	No. of Article	Country
Journal of Construction Engineering and Management	6	USA
Sustainability	5	Switzerland
Journal of Management in Engineering	4	USA
Journal of Cleaner Production	3	The Netherland
Procedia Engineering	3	The Netherland
Building and Environment	2	The UK
International Journal of Managing Projects in Business	2	The UK
International Journal of Sustainable Building Technology and Urban Development	2	The UK
Journal of Architectural Engineering	2	USA
Journal of Green Building	2	USA

Main Heading	Effect of Project Stakeholders on Project Delivery	Owner Commitment and Motivation	Sustainability Pillars of Project Delivery	Sustainable Project Delivery Evaluation Criteria	Sustainable Project Delivery	Education on Sustainable Project Delivery	Management of Sustainable Projects	Traditional PDSs for Sustainable Projects	Sustainable Design	Delivery System Selection	BIM in Project Delivery
No. of Article	2	5	4	9	5	2	3	9	4	2	1

Institution	University	University-Research Center	University-Private Sector	University-Research Center-Private Sector
No. of Article	40	2	3	1

Country	USA	Australia	China (Mainland)	China (Hong Kong)	Finland	South Korea	India	The UK	Spain	Qatar	Malaysia
No. of Article	14	8	5	3	2	3	4	3	2	1	1

Keywords	Distribution of mentioned keywords in the publication

When the numerical distribution of the publications in the last decade is analyzed, it is seen that there was no study for PDSs and their sustainability relationship in 2015, but the number of studies increased after that year compared to previous years. Moreover, studies have increased significantly in 2019 (Table 2). This can be evaluated because of the fact that PDS is seen as an important factor affecting success and performance in the management of sustainable projects and the increase in alternative PDS developed in recent years.

Most of the studies that have examined the topic have been published in the Journal of Construction Engineering and Management, and Journal of Management in Engineering which are the refereed journals listed by Wing (1997). In addition to these journals, Sustainability is one of the top three journals with the highest number of these publications (Table 2).

Depending on examination of the contents and titles of the studies, the studies were evaluated according to their main titles and as a result, they were grouped under 11 titles. It is seen that these studies mostly address the sustainable project delivery evaluation criteria and traditional PDSs for sustainable projects (Table 2). These are followed by a sustainable project delivery as a developing issue in the last decade.

Considering the institutional distribution of the studies, almost all of them are carried out by universities where their first authors are academicians. Although joint studies are conducted with the research center or private sector, this number is very limited. Accordingly, it can be concluded that the studies are considered theoretically, but the possibility for testing the developed suggestions or models is limited.

The distribution of publications by country varies depending on the institutions of the first authors, but it is more in countries where sustainable building production is intense. Therefore, the countries with the most studies are the USA, Malaysia, and China, respectively (Table 2). This shows a similarity with the top 10 regions on LEED-certified projects (Stanley, 2019). Although Turkey is one of the top 10 regions, there are no studies conducted on this issue in Turkey.

Finally, the keywords of the studies were evaluated under the author/publication relationship and the share of these words was visualized with the help of the wordle®. Accordingly, while sustainability, delivery, construction, green and building are the most involved keywords, design-build (DB) and public-private-partnership (PPP) are among the most given keywords among PDSs in the studies (Table 2).

Content Relationship (Analysis)

Since the content relationship was handled by expanding it with content analysis, the results were given in two groups (Fig. 1). Four subgroup results are shared under the first group: subject, area, study level, and analysis level. The values in Fig. 1 refer to the numerical distributions of the publications. Accordingly, the subject of more than half of the studies is the effects of PDSs on sustainability. This is followed by sustainable project delivery and the effects of stakeholders on sustainability, respectively.

When the area in which the subject is related in the building sector is evaluated, it is seen that almost all of the studies include the AEC (Architecture, Engineering and Construction) Industry (Fig. 1). Again, a large part of the studies make general analyzes in terms of the level of analysis while doing sectoral examination as the study level (Fig. 1).

Figure 1: Numerical distribution of publications by content analysis.

Depending on the content analysis, the relationship between PDSs and sustainability in the publications has been studied in detail. When the types of projects discussed in publications are examined, it is seen that approximately 43.5% do not make a special distinction regarding the project type. In the rest of studies, PDSs of mixed-use buildings are mostly addressed in terms of sustainability (Fig. 1).

As previously mentioned in Table 2, the most commonly handled PDSs are the conventional PDSs such as DBB, DB and CMR in parallel with the examination of the sustainability performance of the existing PDSs (Figure 1). These are followed by alternative PDSs like IPD and PPP, which have increased in the last 10 years. As included in SmartMarket Report (2014), IPD and DBOM are increasingly taking part in recent studies as new developing PDSs that significantly affect efficiency for sustainable projects.

While PDSs regulate the relationship between stakeholders within the project life cycle (PLC), there is a process that includes it depending on the selected PDS. Accordingly, the bidding process is the most focused process in the studies (Fig. 1). However, when it comes to sustainability, since the entire service period of the building is taken into account, the publications evaluate PDSs in the entire PLC.

The fact that the actor who decides on PTS in a project is the owner is also the most mentioned person in the works for stakeholders (Fig. 1). The contractor who is a significant role in the effective and successful application of the project follows this. Although sustainable projects are complex projects with many actors, the main motivation for these projects belongs to owners, so a significant part of the studies examines the factors that affect the motivation and commitment of the owner (Olanipekun et al., 2018; Zhang et al., 2019).

Sustainability defines a balance between environmental, economic, and social dimensions (Brundtland, 1987). This is also called “the triple bottom line” (Elkington, 2013). Accordingly, when examining sustainability performance in publications, it is seen that the difference between dimensions is considered (Figure 1). In studies dealing with one of these dimensions, it is the economic dimension. This is a result of the economic dimension being both a sustainability dimension and a criterion of the project triangle that affects project success. Therefore, the economic dimension differs from the other two dimensions.

One of the tools or labeling that document the sustainability of a building or project is the Green Building Certification System (GBCS). Depending on the fact that a significant part of the studies is conducted in the USA, the sustainability criterion considered in the studies is LEED (Fig. 1). It is also the reason that it is an international GBCS that spreads to the largest geography worldwide (Umaroğulları et al., 2020). Moreover, it is seen that some national GBCSs are also used as sustainability labeling.

In this study, it is tried to find answers to three questions as a result of the meta-analysis. The first is the relationship between PDS and the sustainability performance of a project. Accordingly, while 17 studies have no inference about this relationship, 2 studies state that there is no relationship between PDS and sustainability (Fig. 1). The results of the other studies show this relationship. However, not all of these studies contain information in terms of the direction of the relationship. In the studies presented in Figure 1 as “+”, this states that when the integration among stakeholders has increased, the sustainability performance of the PDS has increased, too. “-” indicates the studies that have a relationship but the direction of this relationship is not specified.

The second question that is tried to be answered is which of the PDS or PDSs are used is more advantageous for sustainable projects. The advantage or disadvantage provided by PDS was not mentioned in 16 studies. It is stated that the most advantageous PDS among conventional PDSs is DB. This is a result of the PDS's limited opportunity for stakeholders to work together on the project. However, as the developing PDS where all stakeholders are involved in the project at the same time, IPD is the most advantageous PDS after DB (Fig. 1). Although it is the most preferred PDS in many countries in the world, according to studies, DBB is the most disadvantage due to its fragmented structure. While DBB is found disadvantageous for sustainable projects, in only one study, it is stated that DBB can be used in sustainable projects informally by the attendance of stakeholders at an early stage (Montalbán-Domingo et al., 2019).

Form and Input-Output Relationship

The form and input-output relationship of the publications were examined under four subgroups: the source of the data, the type of data, the contribution, and method (Fig. 2). Accordingly, it is seen that while some studies have more than one source of data, more than one method is used together.

The studies were conducted based on literature data (32%), case and survey studies data (25%), and interview data (18%). Particularly, literature data are included in studies that examine the sustainability performance of existing PDSs. Interview data, on the other hand, are generally analyzed included in the studies with literature data.

When the data type of the publications are examined, the studies have 74% qualitative, 15% both qualitative and quantitative (mixed method) data together and 11% of them have quantitative data (Fig. 2). Due to the fact that most of the studies contain literature data, the number of studies with qualitative data is also high. While all quantitative data belongs to survey studies, mixed data is available in studies where more than one data source is used together. It has been observed that qualitative data are included in studies examining the sustainability performance of existing PDSs and sustainable project delivery evaluation criteria.

According to the contributions of the studies, it was determined that the biggest contribution was in the form of general insights (67%). 20% model building, 7% system building, and 6% statistical results, respectively follow this (Fig. 2). The fact that a large part of the studies deals with the issue theoretically over the existing PDSs leads to an overall view. Studies that develop models are studies in which an approach is developed for sustainable projects instead of existing PDSs. In these studies, it is seen that the approaches, which will include the operation process of PDS, are created with the awareness of the importance of the operation process of the sustainable project (Widjaja, 2016). In some studies, to build a model, process mapping for sustainable projects have been developed (Zanni et al., 2014; Ahn et al., 2017).

The methods used in the studies under the method subgroup are classified and examined. The most used methods are given numerically in Fig. 2. Thus, the three most used methods are benchmarking, qualitative analysis, and content analysis. Besides, descriptive statistics, especially for statistical results, are used. According to the meta-analysis, benchmarking is used especially in sustainable design and sustainable project delivery issues. It can be said that qualitative analysis is a method used in studies examining the sustainability performance of existing PDSs. Content analysis is a method used to evaluate the owner's commitment and motivation in addition to these issues.

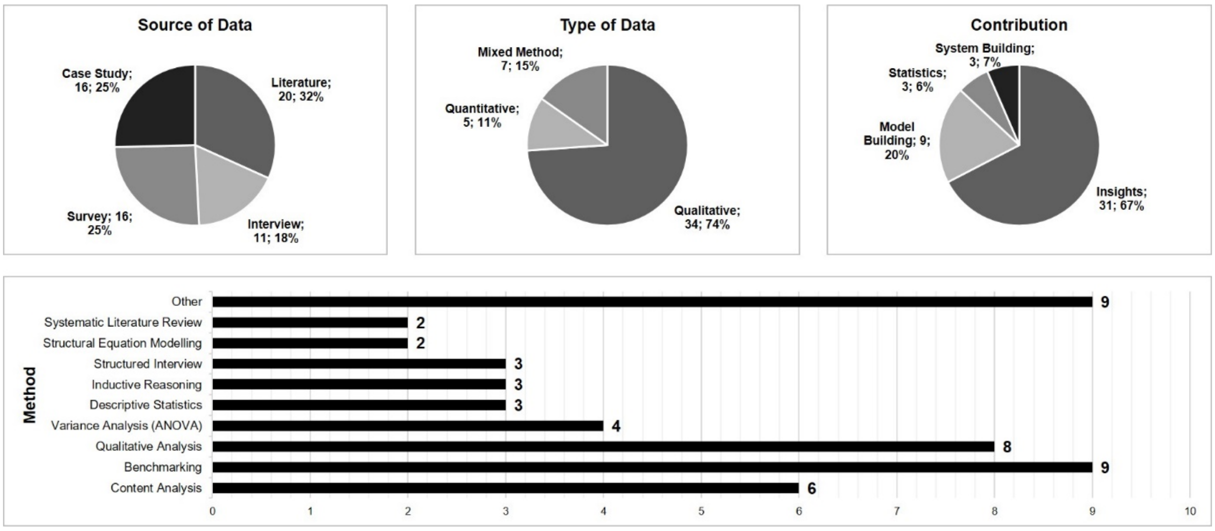

Figure 2: Numerical distribution of publications by form and input-output relationship.

Purpose and Outcome Relationship

The purpose and outcome relationship is addressed in three subgroups: problems, results, and opportunities and threats. In Fig. 3, the data are given together numerical and proportional.

As a problem, the reasons why the publications addressed the topic were examined. In this context, problems are categorized under three sub-categories: identification, examination, and lack. Accordingly, while half of the studies are for examination purposes, 26% define lacks and 24% make identifications (Fig. 3). It is seen that the examinations are carried out especially to determine the criteria of sustainable project delivery evaluation and to analyze the effects of existing PDSs on sustainability. The main motivations in the studies addressing the lack are the participation of the stakeholders, the need for a sustainable project delivery system, and planning the process. The studies conducted on the commitment and motivation of the owner are in the form of identification obtained as a result of the literature review.

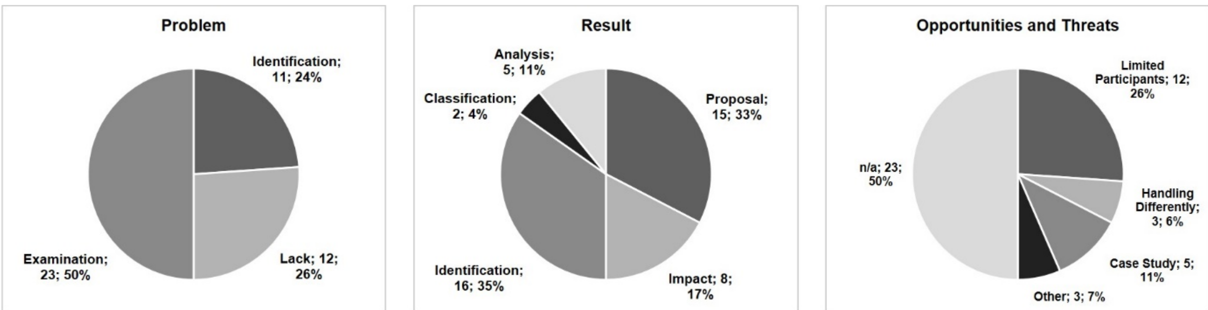

Figure 3: Numerical distribution of publications by purpose and outcome relationship.

The results of the publications were classified according to five sub-categories: identification, classification, analysis, impact, and proposal. 35% identification, 33% proposal, 17% impact, 11% analysis, and 4% classification results were obtained in publications (Fig. 3). It is seen that the sustainable project delivery criteria are the most defined studies in the publications, followed by sustainable project delivery. Accordingly, effective cooperation, early participation of stakeholders, and commitment of all participants are three important success factors for managing sustainable building projects (Venkataraman & Cheng, 2018). The suggestive results consist of the proposals that the sustainable project delivery process should be included in architectural and/or engineering education and the studies that develop models and systems. Impacts include the success and performance effects of existing PTS on sustainable projects.

Based on the findings obtained in half of the publications, it was found that no opportunity or threat was specified. The biggest threat is the low number of participants in the publications (Fig. 3). Lack of participants shows itself as a limited number of countries involved in the study, low numerical size and diversity of stakeholders, and an insufficient number of projects or buildings involved in the study. Another important evaluation is the necessity of supporting the studies developed especially as suggestions with a case study.

Project Delivery Attributes (PDA) for Sustainable Projects

Within the scope of the meta-analysis, the project delivery attributes (PDA) that affect the delivery process of sustainable projects were also tried to be determined. Accordingly, while PDAs are specified in some publications, it is seen that these features are not included in some studies. Table 3 shows the PDA listed according to the examined studies. PDS is an element that affects PDA and is also affected by PDA (Li et al., 2019). For this reason, it is very important to examine PDAs while examining PDSs for sustainable projects.

The PDAs obtained because of the examination are classified according to their environmental (Env.), social (Soc.), and economic (Eco.) dimensions, which are the three dimensions of sustainability. Accordingly, 29 PDAs have been determined, 16 of which are social, 8 environmental, and 5 economic (Table 3). Since PDSs regulate the relationship between stakeholders, the most share among the features obtained is social PDAs and the five most important PDAs also belong to this group. The three most important factors among social PDAs are Soc1: Owner Character, Commitment and Motivation, Soc8: Project Team Organization and Characteristics, and Soc9: Solid Relationship and Communication in Project Team. Eco2: Finance & Payment Method / Contract Type and Eco4: Involvement of Operation Phase and Its Cost are the most significant economic PDAs. The most important factor among environmental PDAs is Env6: Available, Specialized and Innovative Technologies. Accordingly, the execution of a sustainable project depends primarily on the owner's commitment and motivation. However, the project team formed within this process and the communication within the team affect this process. In this context, the type of payment and the contract type, which show the economic relationship between the stakeholders, are also very important. Since sustainable projects should be evaluated within PLC, the operation should be included in the project delivery process and costs arising from this should be taken into consideration. Sustainable projects use specialized materials, systems and technologies as projects with their unique needs. It must be noted that it is an important environmental PDA affecting PDS as the competence of the stakeholders who will evaluate them in the project affects the stakeholders that will be involved in this process.

Conclusions

In this study, a literature review was conducted on the impact of PDS, which is an important factor in sustainable project management in recent years, on sustainability performance and success. For this purpose, articles in refereed journals in the last decade and Scopus were analyzed by using the meta-analysis method. The analysis was carried out under four main categories as author-publication, content, form and input-output, and purpose-outcome relationship. Moreover, PDAs that affect PDS for sustainable projects were also classified and analyzed according to the sustainability dimension.

As a result of the literature review, it was determined that a large part of the studies examine the existing PDS in terms of sustainability. Accordingly, the most suitable PDSs for sustainable projects among the existing PDSs are DB and IPD. In the studies before 2010, it is stated that the DB has contributed positively to the project's sustainability success and performance thanks to its more integrated and collaborative approach (Konchar & Sanvido, 1998). Today, it has been observed that this trend has not changed, but IPD is an alternative PDS for sustainable projects since it was a new developing PDS ten years ago. The idea that the operational process is an important and longest process in sustainable projects and that sustainability performance depends on the management of this process indicates that DBOM (Design-Build-Operate/Maintain) PDS will be used in the future. To sum up, when the suitability of existing PDSs for sustainable projects is evaluated, the ranking is obtained as DB, IPD, CMR, PPP. In this context, these results are similar to the study of Tang et al. (2019).

Table 3. Project delivery attributes (PDA) for sustainable projects.

Project Delivery Attributes (PDA)	Klotz & Horman, 2010	Korkmaz, Riley & Horman, 2010	Korkmaz, Riley & Horman, 2011	Scanlon & Davis, 2011	Swarup, Korkmaz & Riley, 2011	Korkmaz, 2012	Korkmaz, Swarup & Riley, 2013	Wang, Wei & Sun, 2014	Gunhan, 2016	Kantola & Saari, 2016	Naoum & Egbu, 2016	Widjaja, 2016	Ahmad & Aibinu, 2017	Ahn et al., 2017	Olanipekun et al., 2017	Olanipekun, Xia & Nguyen, 2017	Patil & Laishram, 2017	Olanipekun et al., 2018	Venkataraman & Cheng, 2018	Ahmad, Aibinu & Stephan, 2019	Ahmad et al., 2019	Gunhan, 2019	Li et al., 2019	Raouf & Al-Ghamdi, 2019	Tang, NX & Skitmore, 2019	Zhang et al., 2019	TOTAL
Soc1: Owner Character, Commitment and Motivation	X	X	X	X	X	X	X	X		X			X		X	X		X	X	X	X	X	X	X		X	20
Soc2: Identifying the Key Decision Makers		X		X	X				X											X							5
Soc3: Experience on Sustainable Construction Projects		X			X		X	X					X		X	X		X	X	X			X				11
Soc4: Contractual Relationship between Stakeholders	X	X	X		X	X							X							X	X			X			9
Soc5: Project Team Procurement Approach		X	X		X	X							X							X	X		X	X			9
Soc6: Technical Knowledge & Expertise of Stakeholders		X													X	X	X		X	X			X			X	8
Soc7: Timing of Stakeholders / Early Involvement		X			X	X	X			X	X	X	X	X	X	X	X		X	X				X			15
Soc8: Project Team Organization and Characteristics		X	X	X	X	X		X		X	X	X	X	X	X	X			X	X	X	X		X	X		19
Soc9: Solid Relationship & Communication in Project Team		X		X	X	X	X	X	X	X	X		X				X			X		X	X	X	X	X	17
Soc10: Integration in Design and Stakeholders		X	X			X		X				X		X			X	X	X		X			X		X	12
Soc11: Identifying Risks & Opportunities/Risk Management				X						X							X						X	X	X		6
Soc12: Government Policies, Political Commitments																	X		X	X			X			X	5
Soc13: Required Education and Training	X	X			X	X	X	X	X					X	X	X	X	X				X	X	X	X		16
Soc14: Design Charrettes	X				X		X						X	X					X			X		X			8
Soc15: Monitoring and Control								X												X					X		3
Soc16: Commissioning	X	X	X					X	X			X			X					X		X	X	X		X	12
Eco1: Resource Availability and Use/ Cost Management													X						X	X			X		X		5
Eco2: Finance & Payment Method/Contract Type		X			X	X			X				X							X				X			7
Eco3: Life-cycle Analysis and Cost Analysis	X							X	X													X			X		5
Eco4: Involvement of Operation Phase and Its Cost			X					X	X		X	X								X		X					7
Eco5: Trade-Off Mechanism & Awarding				X												X								X			3
Env1: Prioritizing Sustainability Issues				X		X	X			X			X					X		X			X				8
Env2: Timing of Introduction Green		X			X	X				X			X			X		X	X	X							9
Env3: Facilitating an Understanding of Sustainability				X					X			X				X			X							X	6
Env4: Green Building Certification System & Eco Labeling						X	X						X			X				X				X		X	7
Env5: Construction Process		X	X			X				X										X	X	X			X		8
Env6: Available, Specialized and Innovative Technologies								X	X	X	X		X				X		X	X			X	X	X	X	12
Env7: Use of Building Information Modeling					X				X		X	X					X					X		X		X	8
Env8: Simulation and Energy Modeling	X	X					X		X			X	X	X								X					8

Sustainable building production in Turkey is continued intensively and this places Turkey the sixth country in the most LEED-certified regions in the world (Stanley, 2019). However, this literature review did not find a study conducted in Turkey in particular. Therefore, it has been tried to determine the relationship between the PDSs and the countries. Accordingly, whether there is a relationship between the PDSs examined in the publications and the countries, and the advantageous PDSs for sustainable projects and the countries were analyzed by the chi-square test. It was determined that there was no relationship between the countries and PDSs examined in the study (X^2 = 12,908 p = 0,609) and also the advantageous PDSs for sustainable projects (X^2 = 14,303 p = 0,503). This indicates that sustainable projects are a global phenomenon and do not differ geographically in terms of PDSs.

In summary, a PDS that will be developed for sustainable projects over time should be a PDS that brings all stakeholders together, incorporates the project's operational process into PDS, and considers the developing technologies, materials, and systems. However, it must be noted that for a new PDS, some regulations will also be needed in terms of project law (Circo, 2010).

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APPENDIX A. List of articles investigated in the meta-analysis.

ID	Reference
1	Gunhan, S. (2016). Integrating research findings into sustainable building delivery teaching. *Procedia Engineering, 145*, 158-163.
2	Klotz, L., & Horman, M. (2010). Counterfactual analysis of sustainable project delivery processes. *Journal of Construction Engineering and Management, 136*(5), 595-605.
3	Korkmaz, S., Riley, D., & Horman, M. (2011). Assessing project delivery for sustainable, high-performance buildings through mixed methods. *Architectural Engineering and Design Management, 7*(4), 266-274.
4	Olanipekun, A.O., Chan, A.P.C., Xia, B.P., & Ameyaw, E.E. (2017). Indicators of owner commitment for successful delivery of green building projects. *Ecological Indicators, 72*, 268-277.
5	Olanipekun, A.O., Xia, B., & Nguyen, H.T. (2017). Motivation and owner commitment for improving the delivery performance of green building projects: A research framework. *Procedia Engineering, 180*, 71-81.
6	Scanlon, J., & Davis, A. (2011). The role of sustainability advisers in developing sustainability outcomes for an infrastructure project: lessons from the Australian urban rail sector. *Impact Assessment and Project Appraisal, 29*(2), 121-132.
7	Widjaja, K. (2016). Sustainable design in project delivery: A discussion on current and future trends. *Journal of Green Building, 11*(2), 39-56.
8	Zhang, J., Li, H., Olanipekun, A.O., & Bai, L. (2019). A successful delivery process of green buildings: The project owners' view, motivation and commitment. *Renewable Energy, 138*, 651-658.
9	Ahmad, T., & Aibinu, A.A. (2017). Project delivery attributes influencing green building project outcomes: A review and future research directions. *Built Environment Project and Asset Management, 7*(5), 471-489.
10	Korkmaz, S., Riley, D., & Horman, M. (2010). Piloting evaluation metrics for sustainable high-performance building project delivery. *Journal of Construction Engineering and Management, 136*(8), 877-885.
11	Swarup, L., Korkmaz, S., & Riley, D. (2011). Project delivery metrics for sustainable, high-performance buildings. *Journal of Construction Engineering and Management, 137*(12), 1043-1051.
12	Mollaoglu-Korkmaz, S., Swarup, L., & Riley, D. (2013). Delivering sustainable, high-performance buildings: Influence of project delivery methods on integration and project outcomes. *Journal of Management in Engineering, 29*(1), 71-78.
13	Xia, B., Skitmore, M., Wu, P., & Chen, Q. (2014). How public owners communicate the sustainability requirements of green design-build projects. *Journal of Construction Engineering and Management, 140*(8), 04014036.
14	Wang, N., Wei, K., & Sun, H. (2014). Whole life project management approach to sustainability. *Journal of Management in Engineering, 30*(2), 246-255.
15	Olanipekun, A.O., Xia, B., Hon, C., & Darko, A. (2018). Effect of motivation and owner commitment on the delivery performance of green building projects. *Journal of Management in Engineering, 34*(1), 04017039.
16	Montalbán-Domingo, L., García-Segura, T., Amalia Sanz, M., & Pellicer, E. (2019). Social sustainability in delivery and procurement of public construction contracts. *Journal of Management in Engineering, 35*(2), 04018065.
17	Sanders, M., Parrish, K., & Earni, S. (2013). Savings to sustainability: Application of a novel approach to delivering a sustainable built environment. *Journal of Architectural Engineering, 19*(3), 156-163.
18	Korkmaz, S. (2012). Case-based and collaborative-learning techniques to teach delivery of sustainable buildings. *Journal of Professional Issues in Engineering Education and Practice, 138*(2), 139-144.
19	Bynum, P., Issa, R.R.A., & Olbina, S. (2013). Building information modeling in support of sustainable design and construction. *Journal of Construction Engineering and Management, 139*(1), 24-34.
20	Nawi, M.N.M., Nifa, F.A.A., & Ahmed, V. (2014). A review of traditional project procurement towards integrated practice. *American-Eurasian Journal of Sustainable Agriculture, 8*(2), 65-70.
21	Molenaar, K.R., Sobin, N., & Antillón, E.I. (2010). A synthesis of best-value procurement practices for sustainable design-build projects in the public sector. *Journal of Green Building, 5*(4), 148-157.
22	Kantola, M., & Saari, A. (2014). Commissioning for nearly zero-energy building projects. *Construction Innovation, 14*(3), 370-382.
23	Kantola, M., & Saari, A. (2016). Project delivery systems for nZEB projects. *Facilities, 34*(1/2), 85-100.

APPENDIX A. List of articles investigated in the meta-analysis (continued).

ID	Reference
24	Strong, K., Glick, S., & Syhail, G. (2019). Comparing US public university and US private sector project costs. *Journal of Facilities Management, 17*(2), 220-234.
25	Naoum, S.G., & Egbu, C. (2016). Modern selection criteria for procurement methods in construction: A state-of-the-art literature review and a survey. *International Journal of Managing Projects in Business, 9*(2), 309-336.
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28	Patil, N.A., Tharun, D., & Laishram, B. (2016). Infrastructure development through PPPs in India: criteria for sustainability assessment. *Journal of Environmental Planning and Management, 59*(4), 708-729.
29	Ahn, Y., Shin, H., Jeon, M., & Jung, C. (2017). Construction process framework for a green building projects. *International Journal of Sustainable Building Technology and Urban Development, 8*(4), 349-364.
30	Yun, S., & Jung, W. (2017). Benchmarking sustainability practices use throughout industrial construction project delivery. *Sustainability, 9*(6), 1-20.
31	Ma, L., Le, Y., Li, H., Jin, R., Piroozfar, P., & Liu, M. (2018). Regional comparisons of contemporary construction industry sustainable concepts in the Chinese context. *Sustainability, 10*(11), 1-17.
32	Liang, Y., & Wang, H. (2019). Sustainable performance measurements for public-private partnership projects: Empirical evidence from China. *Sustainability, 11*(13), 1-15.
33	Zhu, J.-W., Zhou, L.-N., Li, L., & Ali, W. (2020). Decision simulation of construction project delivery system under the sustainable construction project management. *Sustainability, 12*(6), 1-21.
34	Orsi, A., Guillén-Guillamón, I., & Pellicer, E. (2020). Optimization of green building design processes: Case studies within the European union. *Sustainability, 12*(6), 1-16.
35	Ahmad, T., Aibinu, A.A., & Stephan, A. (2019). Managing green building development – A review of current state of research and future directions. *Building and Environment, 155*, 83-104.
36	Li, Y., Song, H., Sang, P., Chen, P.-H., & Liu, X. (2019). Review of Critical Success Factors (CSFs) for green building projects. *Building and Environment, 158*, 182-191.
37	Circo, C.J. (2010). Will green building contracts transform construction and design law?. *Urban Lawyer, 43*(2), 1-37.
38	Ahn, Y.H., Jung, C.W., Suh, M., & Jeon, M.H. (2016). Integrated construction process for green building. *Procedia Engineering, 145*, 670-676.
39	Tang, Z.W., Ng, S.T., & Skitmore, M. (2019). Influence of procurement systems to the success of sustainable buildings. *Journal of Cleaner Production, 218*, 1007-1030.
40	Francis, A., & Thomas, A. (2020). Exploring the relationship between lean construction and environmental sustainability: A review of existing literature to decipher broader dimensions. *Journal of Cleaner Production, 252*, 119913.
41	Huo, X., Yu, A.T.W., Zezhou, W., & Jayantha, W.M. (2019). Site planning and design of green residential building projects: case studies in China. *Engineering, Construction and Architectural Management, 27*(2), 525-543.
42	Ahmad, T., Aibinu, A.A., Stephan, A., & Chan, A.P.C. (2019). Investigating associations among performance criteria in Green Building projects. *Journal of Cleaner Production, 232*, 1348-1370.
43	Zanni, M.-A., Soetanto, R., & Ruikar, K. (2014). Defining the sustainable building design process: Methods for BIM execution planning in the UK. *International Journal of Energy Sector Management, 8*(4), 562-587.
44	Raouf, A.M., & Al-Ghamdi, S.G. (2019). Effectiveness of project delivery systems in executing green building. *Journal of Construction Engineering and Management, 145*(10), 03119005.
45	Gunhan, S. (2019). Analyzing sustainable building construction project delivery practices: Builders' perspective. *Practice Periodical on Structural Design and Construction, 24*(1), 05018003.
46	Venkataraman, V., & Cheng, J.C.P. (2018). Critical success and failure factors for managing green building projects. *Journal of Architectural Engineering, 24*(4), 04018025.

Causes of Delays in Construction Projects: A Literature Review

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Abstract

The success of a construction project is mainly determined by whether it is completed on time, within budgeted cost and at the desired quality level. However, nowadays, construction projects have a dynamic and complex nature, which is highly affected by various external factors (e.g., weather, soil, economic conditions, etc.) and internal factors (e.g., management skills, type of project, productivity of laborers, etc.). This dynamic and complex environment results in uncertainties, which in turn bring about severe delays and cost overruns. Delays have several adverse impacts on project success such as penalties, excessive increases in costs, productivity losses, disputes, bankruptcies, etc. Moreover, at the macro-economic level, delays in construction projects may negatively affect the economic and social growth of a country due to their contributions to Gross Domestic Product (GDP), employment, and other industries. Therefore, identification of the factors that may cause delays and thereby taking necessary precautions to minimize the harmful impacts of delays are the key point to successful completion of a construction project. A great number of studies focusing on the causes of delays in construction projects have been carried out by many researchers. The main objective of this study is to identify and better understand the causes of delays in construction projects. For this reason, a comprehensive literature review was conducted and the results are summarized. This study forms the basis for further studies on the relevant topic and provides a guidance on improving the performance of construction projects by taking pro-active actions against the causes of delays.

Keywords: *construction projects, delays, causes of delays, literature review.*

Introduction

A construction project is usually considered to be successful if it is completed on time, within the budgeted cost and at the required quality standards (Chua et al., 1999). However, completion of construction projects without delay is a challenging task due to the uncertain, complex, and dynamic nature of these projects (Kartam, 1999). Therefore, delays significantly affect the success of a construction project (Abd El-Razek et al., 2008). Several studies revealed that most of the construction projects in both developed and developing countries are not completed on the expected time (Arditi et al., 1985; Sullivan and Harris, 1986; Semple et al., 1994; Kaming et al., 1997; Frimpong et al., 2003; Assaf and Al-Hejji, 2006). Consequently, delays are common and one of the most important problems in construction projects (Arditi et al., 1985).

Delay can be defined as “an act or event that extends the time required to perform tasks under the contract” (Stumpf, 2000). In this context, delays are quite complex. Some delays may affect project duration, while others may not. Whereas some delays are the responsibility of the contracting parties (e.g., owners, contractors, consultants and suppliers), others may not. For example, delays caused by natural disasters (*Acts of God*) occur beyond the control and responsibility of any contracting party. Some delays may occur concurrently, while others may occur alone. In addition, some delays may cause successor delays (Bubshait and Cunningham, 1998; Arditi and Pattanakitchamroon, 2006).

Almost every construction project delayed to some degree. A construction project may delay due to many different factors. These factors range from those related to the physical, social, and financial environment of the project to those related to the management of the project (Frimpong et al., 2003). The magnitude of delays differs from project to project depending on the project characteristics, since each construction project is unique (Alaghbari et al., 2007). Controlling and monitoring the factors causing delays is essential for the completion of projects on the scheduled time (Sambasivan and Soon, 2007), as delays are one of the most destructive variables affecting the success of construction projects (Lo et al., 2006). Delays are often accompanied by time extensions, cost overruns, reduced productivity, disputes between project stakeholders, and abandonment and termination of contracts (Sambasivan and Soon, 2007). Therefore, identification of the factors that may cause delays and thereby taking necessary precautions to minimize the negative impacts of delays are the key point to the successful completion of a construction project. As a result, conducting a comprehensive literature review on the potential sources of delays is an initial and important step in identifying these factors. The main objectives of this study are: (1) to identify and better understand the causes of delays in construction projects; (2) to guide the improvement of the performance of construction projects by taking pro-active actions against the causes of delays; (3) to encourage construction practitioners to focus on delay problems that may arise in their future projects; and (4) to form the basis for further studies on the relevant subject.

Literature Review

Delays in construction projects are a global phenomenon. Therefore, the causes of delays in construction projects have been investigated in many countries, and have been extensively studied in the literature over the years (Arditi et al., 2017). Some of these studies will be briefly explained below. This study focuses primarily on the factors that may cause delays in construction projects regardless of the type of project.

Baldwin and Mantei (1971) investigated the causes of delays in building projects in the United States through a questionnaire survey in which respondents were engineers, architects, and contractors. It was concluded that a substantial agreement was reached among the three groups on the causes of the delays. The results revealed that weather, change orders, labor supply, and subcontractors were the main factors causing delays in building projects in the United States.

Arditi et al. (1985) examined the causes of delays in Turkish public construction projects undertaken between 1970 and 1980. The results noticed that the most common factors leading to delays were difficulties in obtaining construction materials, contractors' difficulties in receiving a monthly payment from public agencies, contractor's financial difficulties, deficiencies in contractor's organization, and deficiencies in public agencies organization.

Sullivan and Harris (1986) conducted a research on the problems experienced by contractors and the performance of large-scale construction projects in the United Kingdom construction industry through a questionnaire survey. The results demonstrated that the main problems in the construction projects undertaken in the United Kingdom were waiting for information, variation orders, ground problems, bad weather, and design complexity. On the other hand, the most common causes of problems in the construction projects under overseas contracts were variation orders, materials procurement, waiting for information, mechanical and electrical procurement, and laborers/tradesmen shortage.

Okpala and Aniekwu (1988) carried out a study on the key factors causing delays and cost overruns in Nigerian construction industry via a questionnaire survey in which respondents were architects, civil engineers, and contractors. Respondents were asked to rate the level of importance of causes of delays. The survey results revealed that the most important causes of delays were a shortage of materials, finance and payment for completed works, and poor contract management.

Semple et al. (1994) analyzed the causes of claims, delays, and cost overruns in 24 construction projects in Western Canada, which include civil, industrial, high-rise apartment building, and petrochemical projects. The quantitative analysis applied in the study revealed that contract durations were exceeded by more than 100% due to delays. The results of the study emphasized that delays often lead to additional costs due to reasons such as extended site overhead, attempts to accelerate or mitigate delays, and loss of productivity. In addition, the results concluded that the most frequent delays related to claims were an increase in the scope of the work, weather, restricted areas, and acceleration.

Assaf et al. (1995) examined the causes of delays in large building projects in Saudi Arabia via a questionnaire survey. Design errors made by designers (due to unfamiliarity with local conditions and environment), excessive bureaucracy in project-owner operation, shortage of manpower, shortage of skilled labor, and difficulties of financing projects by the contractor during construction were the most important causes of delays according to the owners. On the other hand, the most important ones according to the contractors were the preparation and approval of shop drawings, delays in contractors' progress payment by the owner, design changes by owner or agent during construction, and delay in special equipment out of abroad. In addition, cash problems during construction, difficulties of financing projects by the contractor during construction, the relationship among different subcontractors, schedules in the execution of a project, slowness of owner's decision-making process, and delays in contractors' progress payments by the owner were considered as the most important causes of delays according to architectural/engineering firms.

Ogunlana et al. (1996) studied the causes of delays in high-rise building projects in Thailand. The results indicated that the shortage of construction materials, shortage of site workers, incomplete drawings, materials management problems, and deficiencies in the organization were the major factors leading to delays in high-rise building projects in Thailand.

Chan and Kumaraswamy (1997) designed a survey to evaluate the relative importance of 83 potential factors causing delays in construction projects in Hong Kong from the point of view of clients, contractors, and consultants. The survey results concluded that the five main causes of delays were poor site management and supervision, unforeseen ground conditions, low speed of decision making involving all project teams, client-initiated variations, and necessary variations of works. In addition, the findings were compared to previous similar studies conducted in Saudi Arabia and Nigeria. The comparison findings revealed that the opinions of the respondents on the causes of delays and their level of importance were different.

Kaming et al. (1997) conducted a questionnaire survey on the factors causing delays and cost overruns in 31 high-rise building projects in Indonesia. Respondents were asked to rate the frequency of occurrence and the level of importance of causes of delays. The survey results noticed that design changes, poor labor productivity, inadequate planning, materials shortage, and inaccuracy of materials estimate were the most significant causes of delays.

Mezher and Tawil (1998) examined the causes of delays in the Lebanese construction industry from the perspective of owners, contractors, and architectural/engineering firms. Cash problems during construction, scheduling of sub-contractors, permits from the municipality, bureaucracy in government agencies, and contractor financing problems were the most important causes of delays according to the owners. On the other hand, the most important ones according to the contractors were the design change by the owner, owner’s slow decision, shop drawings, schedule of sub-contractors, uncooperative owner, and permits from the municipality. Moreover, shop drawings, preparation of scheduling work, lack of personnel training and management support, design change by the owner, and cash problems during construction were considered to be the most important causes of delays according to architectural/engineering firms.

Al-Momani (2000) conducted a quantitative analysis of construction delays by investigating a random selection of 130 public projects constructed in different regions of Jordan between 1990 and 1997. The results of the analysis stressed that the main causes of delays were related to designers, user changes (change orders), weather, site conditions, late deliveries, economic conditions, and an increase in quantity.

Ahmed et al. (2002) prepared a report to identify the most important factors causing delays in the Florida construction industry, based on their likelihood of occurrence. Based on the results of the questionnaire survey, the 10 most important causes of delays were building permits approval, change order, changes in drawings, incomplete documents, inspections, changes in specifications, decision during the development stage, shop drawings approval, design development, and change laws and regulations.

Odeh and Battaineh (2002) carried out a study on the causes of delays in construction projects, including large public and private buildings, roads, and water and sewer projects, with traditional type contracts in the Jordanian construction industry via a questionnaire survey. The survey results concluded that inadequate contractor experience, financing and progress payments, labor productivity, slow decision making, improper planning, owner interference, and subcontractors were considered to be the most critical factors causing delays.

Frimpong et al. (2003) identified and evaluated the factors leading to cost overruns and delays in groundwater construction projects in Ghana. The questionnaire survey was designed based on preliminary investigations conducted on groundwater drilling projects in Ghana between 1970 and 1999. The results revealed that there was a substantial agreement among consultants, owners and contractors in terms of ranking of factors. The results also noted that the main causes of delays and cost overruns in the construction of groundwater projects were monthly payment difficulties from agencies, poor contractor management, poor technical performance, material procurement, and escalation of material prices.

Long et al. (2004) designed a questionnaire survey to identify problems with their occurrence and impact on performance in large construction projects in Vietnam. 62 problems were identified through literature review and interviews with professionals in the Vietnam construction industry. The survey results emphasized that the most prominent problems were inaccurate time estimating, slow site clearance, excessive change orders, slow government permits, and severe overtime had a high degree of occurrence, and slow site clearance, slow government permits, inaccurate time estimating, lack of capable representatives, and contractor's financial difficulties.

Lo et al. (2006) explored the perceptions of construction practitioners in Hong Kong on the importance of 30 causes of delays, and effectiveness of mitigation measures recommended by the report of Construction Industry Review Committee, via a questionnaire survey. The results pointed out that inadequate resources due to contractor/lack of capital, unforeseen ground conditions, exceptionally low bids, and inexperienced contractors were the five most crucial causes of delays.

Assaf and Al-Hejji (2006) conducted a questionnaire survey on-time performance of large construction projects in Saudi Arabia. The shortage of labors, unqualified workforce, ineffective planning and scheduling of project by the contractor, the low productivity level of labors, hot weather effects on construction activities, change orders by the owner during construction were the most significant causes of delays according to the owners. On the other hand, the contractors argued that the delay in progress payments by the owner, late in reviewing and approving design documents by the owner, change orders by the owner during construction, delays in producing design documents, and late in reviewing and approving design document by the consultant were the most important reasons for the delays. Moreover, type of project bidding and award, shortage of labors, delay in progress payments by the owner, ineffective planning and scheduling of project by the contractor, change orders by the owner during construction were the most important causes of delays according to consultants. Change order was the most common cause of delays identified by each of the three parties.

Sambasivan and Soon (2007) studied the causes and effects of delays in construction projects in Malaysia in order to identify the delay factors and their impact on project completion. The level of importance of 28 causes of delays and 6 effects of delays were asked to respondents, (i.e., clients or owners, consultants, and contractors) via a questionnaire survey. The results concluded that contractor's improper planning, contractor's poor site management, inadequate contractor experience, inadequate client's finance and payments for completed work, problems with sub-contractors, shortage in material, labor supply, equipment availability and failure, lack of communication between parties, and mistakes during the construction stage were the most significant causes of delays.

Toor and Ogunlana (2008) addressed the problems causing delays in construction projects in Thailand through a questionnaire survey and interviews. The questionnaire survey and interviews were conducted at the Suvarnabhumi International Airport project site, the largest construction project in the history of Thailand. The results demonstrated that the lack of standardization in design, lack of contractor's experience and control over a project, inadequate experience of staff, lack of competent subcontractors/supplier, and unrealistic project schedule were the five most important problems causing delays.

Enshassi et al. (2009) investigated 110 factors leading to time overruns and 42 factors leading to cost overruns in Gazza Strip. The results concluded that the main five delay factors/causes in Gazza Strip included strikes, external or internal military action and border closures, lack of materials in markets, shortage of construction materials at the site, delay of material delivery to site, and cash problem during construction.

Kaliba et al. (2009) identified the causes and effects of delays and cost overruns in road construction projects in Zambia. Delayed payments, financial processes, financial difficulties, contract modification, economic problems, materials procurement, changes in drawings, staffing problems, equipment unavailability, poor supervision, construction mistakes, poor coordination on-site, changes in specifications, and labor disputes and strikes were considered to be the major causes of schedule delays in road construction projects.

Fugar and Agyakwah-Baah (2010) examined the causes of delays in building projects in Ghana. The results indicated that delay in honoring payment certificates, underestimation of the cost of the projects, underestimation of the complexity of projects, difficulty in accessing bank credit, and poor supervision were the most substantial causes of delays.

Doloi et al. (2012) identified 45 factors affecting delays in the Indian construction industry and established a relationship between the critical attributes for the development of prediction models for assessing the impacts of these factors on delays. Lack of commitment, inefficient site management, poor site coordination, improper planning, lack of clarity in project scope, lack of communication, and substandard contracts were identified as the most critical factors.

Kazaz et al. (2012) studied the causes of delay, and their level of importance in construction projects in Turkey. 34 factors causing time overruns in construction projects were evaluated through a questionnaire survey applied to 71 Turkish construction companies. According to the results, design and material changes, delay of payments, cash flow problems, contractor's financial problem, poor labor productivity, estimation problems, lack of feasibility studies, construction defects, an unbalanced number of workers, and fluctuation in material prices were the top 10 causes of delays.

Mahamid et al. (2012) explored the time performance of road construction projects in the West Bank in Palestine through a questionnaire survey conducted towards the contract and consultants. Political situation, segmentation of the West Bank and limited movement between areas, award project to the lowest bid price, progress payment delay by the owner, and shortage of equipment were the top five severe causes of delays.

Akogbe et al. (2013) analyzed the factors causing delays in construction projects in Benin. The top 10 important factors were identified as financial capability, financial difficulties, poor subcontractor performance, materials procurement, changes in drawings, inadequate planning and scheduling, slow inspection of completed works, equipment availability, preparation, and approval of drawings, and accepting inadequate design drawings.

Alinaitwe et al. (2013) surveyed 22 factors that cause delays and cost overruns in public sector construction projects in Uganda. According to the results, the five most prominent causes of delays were changes to the scope of work, delayed payments, poor monitoring and control, the high cost of capital and political insecurity, and instability.

Fallahnejad (2013) determined the causes of delays in the construction of 24 gas pipeline projects in Iran. Imported materials, unrealistic project duration, client-related materials, land expropriation, change orders, contractor selection methods, payments to the contractor, obtaining permits, late delivery of ordered materials by suppliers, and contractors' cash flows were the 10 major factors causing delays.

Gunduz et al. (2013) identified and analyzed the 83 delay factors for construction projects in Turkey. Based on the results, inadequate contractor experience, ineffective project planning, and scheduling, poor site management and supervision, design changes by the owner or his agent during construction, late delivery of materials, delay in performing inspection and testing, unqualified/inexperienced workers, change orders, and delay in site delivery were the most important delay factors. A further study by Gunduz et al. (2015) proposed a decision support tool for contractors before the bidding phase to quantify the likelihood of delays in construction projects in Turkey by using the relative importance index incorporated in the fuzzy logic. The results of the study were exactly the same as the results of the previous study carried out by the same researchers.

Ruqaishi and Bashir (2013) assessed the factors causing delays in construction of oil and gas processing facilities in Oman. According to the results of the statistical analysis of the data obtained from the questionnaire survey, poor site management and supervision by contractors, problems with subcontractors, inadequate planning and scheduling of the project by contractors, poor management of contractor's schedules, delay in delivery of materials, lack of effective communication among project stakeholders, and poor interaction with vendors in the engineering and procurement stages were the primary factors causing delays.

Marzouk and El-Rasas (2014) surveyed and analyzed 43 delay causes of construction projects in Egypt. Finance and payments of completed work by owners, variation orders/changes of the scope by the owner during construction, effects of subsurface conditions, the low productivity level of labors, ineffective planning, and scheduling of project were the top 10 delay causes based on their importance index.

Kim et al. (2015) investigated the factors causing delays in hospital projects in Vietnam. The results indicated that the main reasons for delays were financial difficulties to the owner, lack of supervisor's responsibilities, change the design by the owner, incompetence contractor, and inadequate contractor experience.

McCord et al. (2015) evaluated the 75 delay factors for housing construction projects in Northern Ireland. The results revealed that finance-related issues, mistakes, and discrepancies in design documents/drawings, owners' slow decision making, delay in providing services from utilizes, and delay in obtaining permits from the municipality were the key delay factors.

Arditi et al. (2017) examined the relationship between delay and organizational culture of a construction company via a questionnaire survey in which the respondents were construction companies in the United States and India. The primary causes of delays in the construction industry was summarized by the review of 39 journal papers in 23 different countries. The results noticed that the most common causes of delays were delays in owner payments to the contractor, design changes during construction, incomplete or improper design, and shortage of materials/equipment/manpower, whereas, the least common causes of delays were weather conditions, poor labor productivity, and poor contract management.

Vacanas and Danezis (2018) identified the most important causes of delays in construction projects in Cyprus through a questionnaire survey. The results noted that variations requested by the client, mistakes and missing information from consultants' drawings, low productivity, difficulties in financing of the works by the contractor, and inadequate programming of works were the major causes of delays perceived by the respondents.

Hossain et al. (2019) investigated the 55 causes of delays in Kazakhstan construction industry and analyzed the impact of these causes on various types of construction projects. The results concluded that the most prominent causes of delays were incomplete/improper design, delay in materials' delivery, financial difficulties of the client, slow decision-making process, lack of quality control/mistakes during construction, poor labour productivity, quality of materials, shortage of manpower (skilled, semi-skilled or unskilled), poor planning and scheduling of project, and shortage of equipment.

Bajjou and Chafi (2020) evaluated the causes of delays in the Moroccan construction industry by means of a questionnaire survey. According to the results of the statistical analysis of the data collected from the respondents, the delay of progress payment, lack of training for employees, lack of waste management strategy, unrealistic contract duration imposed by clients, rework due to the construction errors, excessive subcontracting, delay in obtaining permits from governmental agencies, ineffective planning and scheduling, lack of collective planning, and unskilled workforce were the top 10 most important causes of delays.

Results and Discussion

A comprehensive literature review on the causes of delays in construction projects was carried out in this study. In this context, 37 studies focusing on the causes of delays in construction projects in 27 different countries were reviewed. Most of these studies used the questionnaire survey and relative importance index in order to identify the most important factors causing delays in construction projects. In addition, almost all of these studies have identified the causes of delays on the basis of previous studies. On the other hand, several studies such as Long et al. (2004) used the interview, in addition to the literature review, to determine the causes of delays.

According to the results of the literature review, the most cited causes of delays are:

- Change orders and/or uncertainity in the project's scope,
- Errors, discrepancies, and deficiencies in design documents and specifications and/or incomplete design documents and specifications,
- Deficiencies in the owner's decision and/or approval process,
- Owner's financial difficulties and delays in the contractor's progress payments,
- Deficiencies in the contractor's management skills and poor site management,

- Inadequate or improper budgeting and planning conducted by the contractor,
- Problems in supplying labor and technical personnel,
- Problems in the procurement of the equipment,
- Problems in material procurement,
- Communication and coordination problems among the parties,
- Unforeseen or unexpected weather conditions.

The causes of delays in construction projects in different countries are presented in Table 1, based on the results of the literature review.

Table 1. Causes of delays in construction projects.

No.	Cause of Delay
1	Complex nature of the project
2	Change orders and/or uncertainty in the project's scope
3	Errors, discrepancies, and deficiencies in design documents and specifications
4	Incomplete design documents and specifications
5	Unrealistic contract conditions
6	Late site delivery and problems/difficulties in obtaining required permits and licenses
7	Deficiencies in the owner's decision and/or approval process
8	Owner's financial difficulties and delays in the contractor's progress payments
9	Deficient, inadequate and late inspection, test, control by the consultant
10	Consultant's inadequate supervision skills
11	Deficiencies in the contractor's management skills and poor site management
12	Inadequate or improper budgeting and planning conducted by the contractor
13	Contractor's deficiencies in the required knowledge for construction methods
14	Inadequate contractor experience
15	Contractor's financial difficulties and cash flow problems
16	Renovations and reworks due to errors and defective works during the construction
17	Problems in supplying labor and technical personnel
18	Low labor production rate
19	Problems in the procurement of the equipment
20	Low equipment efficiency and/or equipment failures
21	Problems in material procurement
22	Low subcontractor performance and/or subcontractor related problems
23	Communication and coordination problems among the parties
24	Problems in providing services from utilities (water, electricity, telephone)
25	Unforeseen or unexpected ground conditions
26	Unforeseen or unexpected weather condition
27	Economic problems (currency losses, inflation, escalation, price increases, fluctuations, etc.)
28	Problems among the labors and/or technical staff and/or strikes
29	Acts of God
30	Political fluctuations and/or conflicts, civil war, war, terrorism
31	Legislative amendments
32	Occupational accidents and/or insufficient site safety considerations

The results of this study revealed that there is no consensus on this issue in the literature, since the identification of the causes of delays is highly subjective. Moreover, since the researchers have examined this issue from different perspectives, there is no consensus even on the classification of the causes of delays. For example, Assaf et al. (1995) classified causes of delays into nine categories (i.e. material, manpower, equipment, financing, changes, government relations, scheduling and controlling, environment, contractual relationships), whereas Arditi et al. (1985) did not classify causes of delays. Since the obligations and responsibilities of the parties may vary depending on the project delivery method and the type of contract, the causes of delays can be classified according to these variables. The results of this study also noted that the factors affecting the delays in the construction projects and their degree of importance vary from one country to another. The differences in the causes of delays may arise from the variations in the socio-economic, socio-cultural, political, geographical and climatic attributes of each country or region, as well as the type of project. For instance, Enhassi et al. (2009) stated that strikes, external and internal military action, and border closures were the main causes of delays in the politically unstable Gaza Strip. Furthermore, almost all of the previous studies carried out a questionnaire survey and represented the perspectives of the different project stakeholders. Respondents' perspectives on the causes of delays could be affected by their roles in the project. Finally, the differences in the results of the previous studies may originated from the differences in the types of construction projects. While some studies were carried out using data from a very specific type of construction project, such as airport projects (Toor and Ogunlana (2008)), gas pipeline projects (Fallahnejad (2013)), hospital projects (Kim et al. (2015)), others reflected a holistic view (Sullivan and Harris (1986), Chan and Kumaraswamy (1997), Mezher and Tawil (1998)).

Conclusion

Delays are common and one of the most important problems in construction projects. Delays have several adverse effects on project success such as time extensions, cost overruns, reduction in productivity, disputes, and bankruptcies. In view of the importance and complexity of the delays in construction projects, it is essential to identify the causes of the delays to take the necessary precautions to minimize the negative effects of the delays.

A great number of studies, which focus on the causes of delays in construction projects, have been carried out by many researchers. The main objective of this study is to identify and better understand the causes of delays in construction projects. For this reason, 37 studies focusing on the causes of delays in construction projects in 27 different countries were reviewed. According to the results of the literature review, the most cited causes of delays are: (1) change orders and/or uncertainty in the project's scope, (2) errors, discrepancies, and deficiencies in design documents and specifications and/or incomplete design documents and specifications, (3) deficiencies in the owner's decision and/or approval process, (4) owner's financial difficulties and delays in the contractor's progress payments, (5) deficiencies in the contractor's management skills and poor site management, (6) inadequate or improper budgeting and planning conducted by the contractor, (7) problems in supplying labor and technical personnel, (8) problems in the procurement of the equipment, (9) problems in material procurement, (10) communication and coordination problems among the parties, and (11) unforeseen or unexpected weather conditions.

Identifying the causes of delays in the early phase of construction projects may help to improve the performance of these projects by taking pro-active actions against these causes. Moreover, early detection of causes of delays may help to ensure that construction projects are completed on time, within budgeted cost and at the required quality standards. This study forms the basis for further studies on the causes of delays in construction projects.

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A Comparative Case Study on Investigation of Volatile Organic Compounds (VOCs) in Higher Education Buildings

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Abstract

Many health issues can be seen on occupants of buildings depending on poor indoor air quality (IAQ). Many factors lead to the pollution of indoor air. Volatile organic compounds (VOCs) which can occur from building materials, office equipment like printers and photocopy machines, cleaning materials and cosmetics, cigarette smoke etc., are one of the most important indoor air contaminants. Poor IAQ in a building can cause sick building syndrome (SBS) which is a threat to occupants' health. Therefore, the management of IAQ is very important in buildings. Besides many materials used indoor, some parameters such as design, application, and technology affect the VOC level in the indoor environment. This makes VOC management difficult. People spend most of their time in closed spaces. For students, they spend a considerable amount of time in their schools, so education buildings must be designed with high IAQ to prevent negative effects on students' health and productivity. This study aims to investigate the VOCs in higher education buildings by comparing two different faculty buildings. For the case study, the Faculty of Architecture and the Faculty of Engineering buildings of Trakya University were chosen. For each building, measurements were performed during November and December on school days. VOCs were analyzed by using the GC-MS/MS. For tube analysis, air samples were collected by Tenax® and the samples were analyzed by using the thermal desorption method in GC-MS. The results were examined statistically and were compared with the limit levels in the literature.

Keywords: *education buildings, indoor air quality, IAQ, volatile organic compounds, VOC.*

Introduction

Nowadays, outdoor air pollution gradually increases based on dense housing and heavy traffic in cities. However, the concentration of outdoor pollution is not as much as it is in indoor spaces. The Environmental Protection Agency (EPA) reported that pollution is consistently two to five times higher indoors than outdoors (Hess-Kosa, 2011). Therefore, it is very important that indoor air quality (IAQ) must meet human health and comfort conditions. A healthy IAQ is defined as the air in which the pollutants known in it are not at the levels of harmful concentrations determined by the authorities and at least 80% of the people in the environment do not feel any dissatisfaction with the quality of the air (ASHRAE, 2013). Based on a building's function, there are acceptable limits to the pollutants such as carbon dioxide (CO_2), carbon monoxide (CO), volatile organic compounds (VOCs), and any other particulates. In sum, the concentration of these gases determines the IAQ of a space.

Poor IAQ in a building can cause health problems on the occupants of buildings. These building-related health problems, which are a threat to occupants' health and productivity, are called Sick Buildings Syndrome (SBS) (Redlich et al., 1997). Therefore, considering the length of the operation phase in the building life cycle, it is very important to manage the IAQ without negatively affecting the user's health. It is even more difficult to manage IAQ in public spaces, such as educational buildings, where occupants in different profiles come together. However, proper comfort and IAQ conditions must be provided for students, who spend most of their time in an indoor environment, to be healthy and productive. Recently, many studies on IAQ are conducted actively (Wolkoff & Nielsen, 2001; Panagiotaras et al., 2014). It has been seen that some of these studies discuss the effects of IAQ on the performances of students and as well as teachers (Mendel & Heath, 2005; Vesitara & Surahman, 2019). Moreover, the studies examining SBS resulting from poor IAQ in educational buildings are also quite common today (Keskin et al., 2005; Vesitara & Surahman, 2019; Gawande et al., 2020).

VOCs, which can occur from building materials such as paint, polish, carpet covering, composite wood panels, some insulation materials, and various decoration materials and household products such as household textile and cleaners, furniture and also some cosmetics, are one of the most influential factors for IAQ (Güney et al., 2011). VOCs with a high level of emission from these materials used in the buildings cause poor IAQ. It has resulted in many studies that VOCs cause various diseases such as respiratory diseases and cancer (Sofuoglu et al., 2011). Especially for education buildings, apart from building itself, many potential sources for VOCs exist inside of the buildings. So that many materials which students use in workshops and laboratories, particularly printers and photocopy machines cause VOC emissions. By considering the importance of VOCs in education buildings, there are many studies on the effects of VOC in IAQ of education buildings. Some of these studies are summarized in Table 1. It is seen that the common parameter in IAQ studies is VOC. Besides, the intersection season of these researches are winter. Moreover, apart from one of the studies, it was determined that most of them were conducted for PS and SS (Table 1). It can be said that this is a result of the impact of VOC emissions on students in this age group. Because students at these ages are more affected during their development periods. In Turkey, various studies, especially for PS, were conducted in different years (Aydoğdu et al., 2005; Sofuoglu et al., 2011; Demirel et al., 2014; Babayiğit et al., 2014). However, Yurdakul et al. (2013), Can et al. (2015), and Yurdakul et al. (2017) examined IAQ and VOCs in higher education buildings.

Although some studies are examining higher education buildings, they are more limited than the others. Therefore, it is very important to examine these educational buildings to contribute to the literature. This is especially significant for faculties, where the tools, equipment, and materials used in their education such as architecture and engineering, lead to VOCs. Thus, this study aims to investigate the VOCs in higher education buildings by comparing two different faculty buildings. For the case study, the Faculty of Architecture and the Faculty of Engineering buildings of Trakya University were chosen. The investigation was done with the help of measurement in each faculty buildings at the same time during the course time in winter.

Table 1. Indoor air quality studies on education buildings in different countries.

Country	Education Degree[1]	Investigated Parameters[2]	Scope[3]	Date and Season	Reference
Australia	PS	AT, FA, PM_{10}, RH, VOCs	4 Sch.	2002 From winter to summer	Zhang et al. (2006)
China	PS	AA, AT, CO_2, FA, PM, RH, VOCs	1 Sch.	2013 Fall and winter	Cai et al. (2015)
Germany	n/a	A, CO_2, E, VOCs,	92 Cr. 75 Cr.	2004 and 2005 Winter 2005 Summer	Fromme et al. (2008)
Greece	KG and PS	AT, CO, CO_2, FA, NO_2, O, R, RH	3 Sch.	2011 and 2012 Fall and winter	Kalimeri et al. (2016)
Korea	KG, PS, SS and HS	CO, CO_2, FA, PM_{10}, TBC, VOCs	55 Sch.	2004 From winter to summer	Yang et al. (2009)
Poland	KG	B, BA, CO_2, F, FA, PM, VOCs	2 Sch.	2013 and 2014 Winter	Mainka et al. (2015)
Portugal	PS	AT, B, CO, CO_2, F, RH, VOCs	14 Sch.	2009 From spring to summer	Pegas et al. (2011)
Serbia	PS	CO_2, FA, NO_2, O, PAH, PM, VOCs	1 Sch. (5 Cr.)	2012 Spring	Jovanovi et al. (2014)
Switzerland	PS and SS	AT, B, CO_2, D, FA, RH, VOCs	39 Sch.	1992	Smedje et al. (1997)
USA (California)	PS	VOCs	25 Sch.	2010 - 2012 From fall to summer	Mishra et al. (2015)
USA (Michigan)	PS and SS	AT, AB, CO_2, RH, VOCs	9 Sch. (64 Cr.)	2003 Spring and Summer	Godwin and Batterman (2007)
USA (Minnesota)	PS	VOCs	2 Sch.	2000 Winter and Spring	Adgate et al. (2004)

[1] ***Education Degrees:*** *KG: Kindergarten, PS: Primary School, SS: Secondary School, HS: High School*
[2]***Investigated Parameters: A:*** *Aldehydes, AA: Acetaldehyde, AT: Ambient Temperature, B: Bacteria, BA: Bio Aerosols, CO: Carbon monoxide,* CO_2*: Carbon dioxide, D: Dust, E: Endotoxin, F: Fungi, FA: Formaldehyde,* NO_2*: Nitrogen dioxide, O: Ozone, PAH: Polycyclic Aromatic Hydrocarbon, PM: Particulate Matter, R: Radon, RH: Relative Humidity, TBC: Total Bacteria Counts, VOC: Volatile Organic Compound*
[3]***Scope:*** *Cr.: Classroom, Sch.: School*

Materials and Methods

The study was carried out in Edirne which is located 41°40' N and 26°33' E. It has a humid temperate climate which is temperate in summer and cold in winter. The hottest months are from June to September. By obtaining the settlement, location, plans, and sections and any other drawn documents of the investigated education buildings, properties of building components (roof, window, wall, floor, etc.) that make up the characteristics of the building envelope, were determined. Figure 1 shows the location of the investigated buildings in Edirne. The Faculty of Architecture building is located in the city center and was built by

Sultan Abdulaziz in 1871. The building has two floors and was built in a masonry structure system. The second case building is the Faculty of Engineering building, which is located outside of the city center of Edirne between the City Bus Station and the belt highway connection, has three floors and was built in a reinforced concrete frame system (Figure 1). In summer seasons, both buildings can be cooled by natural ventilation. The spaces that are examined in two buildings have different locations, sizes, and activities (such as classrooms, workshops, and/or laboratories). The physical properties of each investigated space in the buildings are given in Table 2 and Table 3.

By considering the existing conditions of the buildings, air measurements were taken in the spaces in Table 2. Measurements were taken between November and December 2015 during the education period on weekdays. Although many VOCs exist in the literature, the study focused on the most hazardous six VOCs such as Benzene, Formaldehyde, Toluene, Ethylbenzene, Xylene, and Styrene (Koistinen et al., 2008). Gas chromatography/mass spectrometry (GC/MS), which is one of the most common analytical methods to analyze VOCs (Panagiotaras et al., 2014), was used with the help of the Trakya University Technology Research Development Application and Research Center. For tube analysis, air samples were collected by Tenax TA sorbents and these samples were analyzed by using the thermal desorption method in GC/MS. After all data were transferred to the computer, the obtained results were given graphically. Since there is a statistically significant difference between the data between the two examined buildings, t-test (Independent Sample Test) was performed, and the results were evaluated statistically. Finally, the results were compared the data obtained from the literature.

Figure 1: The location, buildings, and classrooms of the selected faculties.

Table 2. Physical properties of the classrooms in the faculty buildings.

Faculty	Classroom ID	Floor	Activity	Direction	Area (m^2)	Volume (m^3)	Capacity (Pers.)
Architecture	MIMA104	Ground	Workshop	West	89,20	382,66	60
	MIMD204	First	Classroom	East	58,90	265,05	40
	MIMA201	First	Workshop	North	138,98	638,48	90

Engineering	MUHD102	Ground	Classroom	South	90,50	301,36	78
	MUHD206	First	Workshop	North	90,50	301,36	40
	MUHL304	Second	Classroom	Northwest	90,33	293,58	104

Table 3. Interior space finishing materials of the classrooms.

			Cladding Properties		**Area of The Components (m^2)**		
Faculty	**Classroom ID**	**Floor**	**Wall**	**Ceiling**	**Window[1]**	**Wall[2]**	**Door[3]**
Architecture	MIMA104	Ceramic	Gypsum Plaster & Plastic Paint + 23 m^2*	Gypsum Plaster & Plastic Paint	17,85	161,47	2,93
	MIMD204	Ceramic	Gypsum Plaster & Plastic Paint	Gypsum Plaster & Plastic Paint	6,62	123,75	2,52
	MIMA201	Ceramic	Gypsum Plaster & Plastic Paint + 32 m^2*	Gypsum Plaster & Plastic Paint	5,45	198,53	2,93
Engineering	MUHD102	Ceramic	Gypsum Plaster & Plastic Paint	Gypsum Plaster & Plastic Paint	14,58	101,73	8,40
	MUHD206	Ceramic	Gypsum Plaster & Plastic Paint	Gypsum Plaster & Plastic Paint	14,58	101,73	8,40
	MUHL304	Ceramic	Gypsum Plaster & Plastic Paint	Gypsum Plaster & Plastic Paint	10,08	101,62	3,36

** Wall boards with XPS and textile covering.*
Components Materials: (1) PVC Frame, (2) Masonry, (3) Chipboard

Results and Discussion

The active air samples, obtained by the selected spaces in the buildings, were analyzed by using the thermal desorption technique in GC/MS. Then, VOCs determined at different sampling points with active sampling were given in $\mu g/m^3$ concentration. Data are presented as mean ± standard error in all of the graphs (Figure 2). In the study, to determine the effects of students in the emission of VOCs and show the differences, the measurements were conducted twice for each space. Accordingly, the highest values of Benzene, Formaldehyde, Toluene, and Styrene were obtained by the spaces in the Faculty of Architecture building while Ethylbenzene and Xylene were in the Engineering. It is seen that in the faculty buildings the values of VOCs in the measurements when the spaces are empty and full vary in a wide range. In fact, some of the highest results of VOCs were measured when no students exist in the spaces. This results from the highest level of emission concentration at the end of the lesson and cleaning activities in the spaces. The chemical properties of cleaning materials are influential in VOC emission (Bonnet et al., 2018). For example, after each lecture in the Faculty of Architecture, the classroom is prepared for the next lecture by cleaning the floor and the surfaces of the desk/tables. Therefore, the ventilation of the spaces is necessary to remove the harmful effects of these activities. Nevertheless, sometimes the time between two lessons may not be enough to achieve this. In the Faculty of Architecture, almost all highest results belong to MIMA104 while MUHL304 is the only space having the highest value in six VOCs in the Engineering (Figure 2). These two spaces are the workshops and laboratories that architecture and engineering students use extensively in their applied courses. This is an expected result considering both the user density and the materials and equipment used in MIMA104 and MUHL304.

Moreover, the significance of the difference between the results obtained was statistically evaluated by independent sample t-test. In this analysis, whether the space is full or empty, it is accepted as an independent variable, the measured values are the dependent variables. The investigation was carried out in two different ways, namely for the selected spaces in each building and for the results that overall sum of the separate spaces in the buildings (Figure 2).

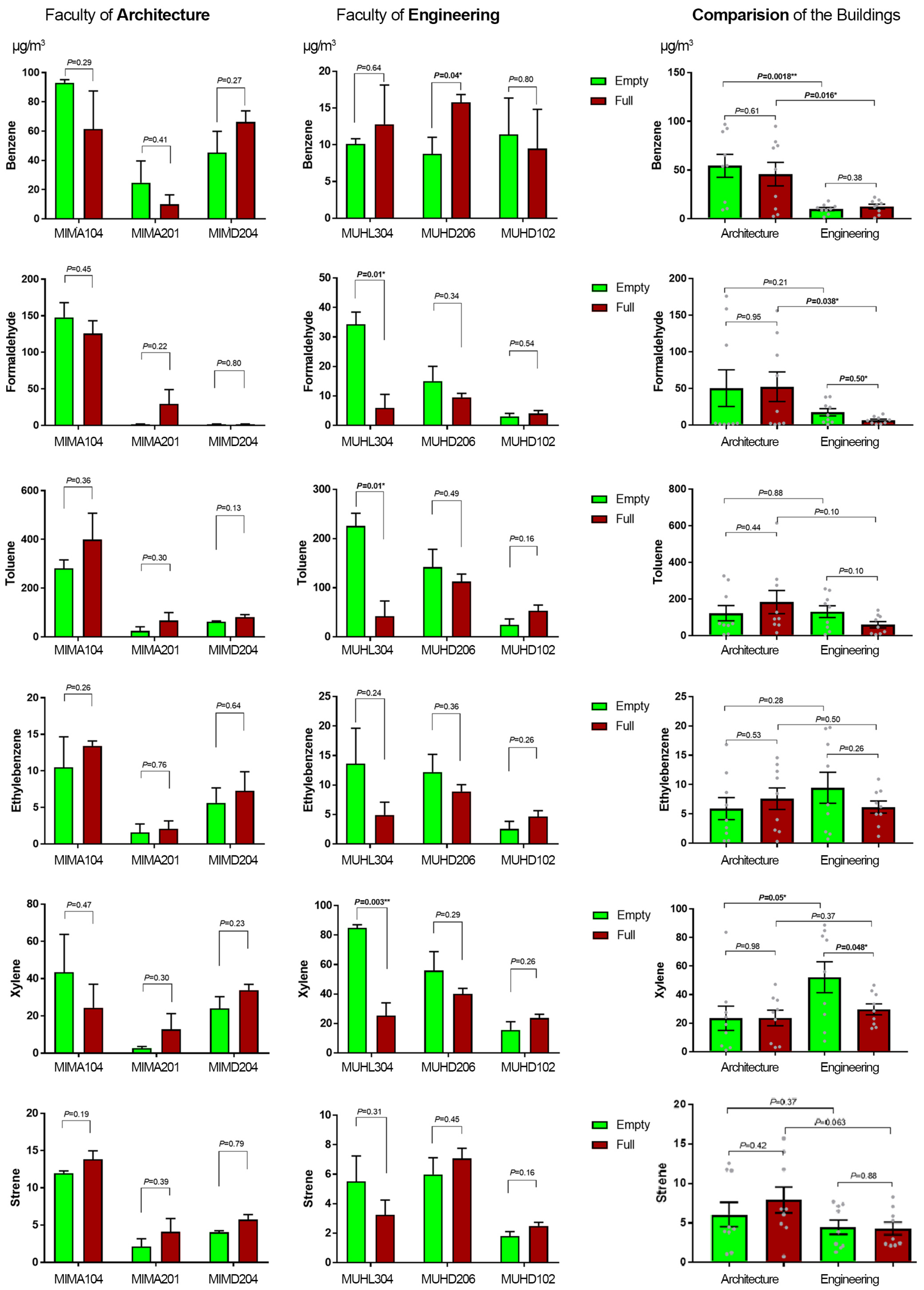

Figure 2: Measured values of VOCs in the buildings.

Firstly, data for the Faculty of Architecture show that statistically no significant difference was found ($p>0.05$). However, the differences in the Formaldehyde, Toluene, and Xylene are significant in MUHL304 (respectively $p=0.01$, $p=0.01$, and $p=0.003$ where $p<0.05$) while only MUHD206 has statistically significant difference for Benzene ($p=0.04$) in the Faculty of Engineering. Secondly, much more significant differences were obtained in the comparison of the buildings. Accordingly, only for Benzene the differences in both empty and full buildings is significant ($p=0.0018$ and $p=0.016$). Besides, when occupied the buildings, only Formaldehyde has a significant difference between two faculty buildings ($p=0.038$) while Xylene is for the empty buildings ($p=0.05$).

In addition to the statistical evaluation given according to the measurement results, comparing these data with the results in the literature is very important for making more comprehensive inferences. In Table 4, measured values are given with values in the literature together such as minimum (min), mean, and maximum (max) values. If the reference study does not highlight one or more of these values, it is stated as not available data (n/a).

As Table 4 shows that, the values in the Faculty of Architecture, especially in terms of Benzene, Formaldehyde, Toluene, and Ethylbenzene, are above in the literature. The data of the Faculty of Engineering are close to the results in the literature, particularly for Benzene and Formaldehyde. For only Xylene, both results in the building are below the literature.

According to literature review results, the value of Benzene is (mean) 0,09 and (max) 1,6 $\mu g/m^3$ in the PS and the SS in the USA during spring and summer (Godwin & Batterman, 2007). In Turkey, this value is determined as 16,4 $\mu g/m^3$ by obtained results of the KG and the PS analysis during fall, winter, and spring (Sofuoglu et al., 2011). In another study, Yurdakul et al. measured Benzene in the university building (in the classrooms, offices and corridors) as (min) 1,1 $\mu g/m^3$, (max) 29 $\mu g/m^3$, and (mean) 3.2 $\mu g/m^3$ (2017). In the measurements taken in the workshops of the paint shop and the glasshouse of the Faculty of Fine Arts of one of the Anadolu University, Benzene 2,86 $\mu g/m^3$, Toluene 418,94 $\mu g/m^3$, Ethylbenzene 25,01 $\mu g/m^3$, Xylene 26,33-46,39 $\mu g/m^3$ was measured averagely (Can et al., 2015). The results are expected to be parallel since the Faculty of Architecture is similar to the educational activities in the Faculty of Fine Arts. However, the similarity exists in only the Xylene values between the Faculty of Architecture of Trakya University and the Faculty of Fine Arts of Anadolu University. Besides, the Faculty of Architecture has lower values about Toluene and Ethylbenzene while Benzene is high in the Faculty of Fine Arts.

To sum up, some factors can lead to these differences in the study. One of the important factors, which has an impact on the results, is the different location of two faculty buildings. Because the Faculty of Architecture building is located in the city center while the Engineering building is located in uptown. Another reason for the difference arisen can be considered as the total amount of interior finishing materials. Although the building finishing materials of spaces are the same in both buildings, their area and volume ratio and the number of occupants quietly differ from each other. However, it is noteworthy that the VOC results in the Faculty of Architecture building are higher than the Faculty of Engineering building although the spaces, where measurements were taken in the Faculty of Architecture, have higher area and volume ratio. This is the consequence of the limited area of the windows used for ventilation in the Architecture building. Moreover, the equipment (mockup materials and various glues, etc.) that the architecture students bring with to use in the class works have an important role in these differences. Furthermore, due to being an old building, the Faculty of Architecture building needs to be painted frequently. It can be said that this activity has also one of the significant effects on high results.

Table 4. Comparison between measured values in the study and the literature.

	Measured Values in the Study (µg/m³)						Values in the Literature (µg/m³)			
	Faculty of Architecture			Faculty of Engineering						
VOCs	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**	
Benzene	9,93	48,52	93,04	8,77	11,39	15,00	n/a	0,09	1,60	[1]
							6,30	n/a	8,90	[2]
							10,60	n/a	16,40	[3]
							n/a	3,80	n/a	[4]
							n/a	1,60	n/a	[5]
							1,50	n/a	9,40	[6]
							1,10	3,20	29,00	[7]
Formaldehyde	1,20	44,23	147,80	3,10	12,01	34,37	n/a	86,68	n/a	[8]
							8,00	n/a	14,00	[3]
							2,30	n/a	28,50	[6]
Toluene	24,49	145,73	399,24	24,62	100,06	225,89	n/a	2,81	74,60	[1]
							15,50	n/a	19,70	[2]
							25,70	n/a	26,60	[3]
							n/a	31,40	n/a	[4]
							n/a	26,20	n/a	[5]
							10,00	37,00	408,00	[7]
Ethylbenzene	1,58	9,96	29,27	4,60	7,81	13,61	n/a	0,24	2,80	[1]
							0,42	n/a	1,40	[2]
							n/a	0,70	n/a	[5]
							n/a	n/a	17,00	[7]
Xylene	2,73	29,80	67,29	15,68	40,93	84,84	n/a	46,39	n/a	[9]
							0,72	1,45	5,28	[10]
							0,25	n/a	21,03	[11]
Styrene	2,14	7,71	13,82	1,80	4,35	7,07	n/a	0,04	1,40	[1]
							0,36	n/a	0,65	[2]

[1]: Godwin & Batterman, 2007; [2]: Aslan et al., 2009; [3]: Sofuoglu, 2011; [4]: Güney et al., 2011; [5]: Demirel et al., 2014; [6]: Kalimeri et al., 2016; [7]: Yurdakul et al., 2017; [8]: Istrate et al., 2016; [9]: Can et al., 2015; [10]: Scheepers et al., 2010; [11]: De Gennaro et al., 2013

Conclusion

In this study, VOC measurements were examined in the education buildings where adult students study at and spend most of their time in. According to the results, which were obtained in two different faculty buildings of a higher education, Ethylbenzene, Styrene and Xylene show the similar values to each other. However, some VOC values are different. Especially Benzene, Formaldehyde, Toluene, Ethylbenzene, and Styrene are higher in the Faculty of Architecture building than the Engineering. The empty space measurements of Ethylbenzene and Xylene are highest in the Faculty of Engineering. Moreover, statistically significant difference was found for Benzene, Formaldehyde, and Xylene between two faculty buildings.

To sum up, as a result of the investigation, it was determined that the location and natural ventilation properties of the buildings are effective in determining the IAQ in terms of VOCs if the indoor finishing materials are the same. The amount of VOC in the indoor environment is also increasing in city centers where the indoor air does not sufficiently ventilate the indoor. In addition, the limited ventilation possibilities also affect this situation negatively. Moreover, spaces such as workshops and laboratories are the places with the highest VOC emission considering the course materials used in the indoor environment.

The measurements were conducted only for winter conditions in the study. If measurements are taken for spring and summer conditions in future studies, seasonal comparison can be made. Thus, with adding a survey for students, a detailed examination of the symptoms that may occur on students in case of long-term exposure to VOCs can be determined.

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Pandemics As Force Majeure in Construction Contracts: Key Considerations, Implications and Recommendations

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Abstract

The World Health Organization declared the novel coronavirus to be a pandemic on March 11,2020, about six weeks after the outbreak of the disease in Wuhan, China. The disease impacted the supply chain across all industries, including the construction sector. Both public and private projects have been and will be heavily affected by the pandemic. The potential impacts of the novel coronavirus include shortages of inputs, delays, disruptions, financial difficulties, and termination. The present paper shall undertake an examination of the concept of force majeure in different jurisdictions and focus on the operation of a force majeure clause in construction contracts. Procedural requirements for relying on the clause, notice requirements, documentation and mitigation obligations of the contractor shall be discussed by comparing standard construction contracts including AIA, ConsensusDOCS, EJCDC, FIDIC, the World Bank, JCT, and NEC forms. The question of whether the contractor is entitled to relief is a complex issue and depends largely on the wording of the clause as well as other relevant clauses, defining the risk philosophy of the contract. On this basis, the paper shall formulate recommendations for elements to be taken into account in drafting a force majeure clause relating to pandemics.

Keywords: *force majeure, pandemics, risk philosophy.*

Introduction

The outbreak and the rapid spread of the coronavirus has negatively affected construction work, causing delays, work stoppages, quarantines, travel bans, limitations on transportation, site closures, lockdowns, disruptions. Many contractors attempted to invoke force majeure clauses that address exceptional circumstances excusing performance. These clauses define events qualifying as force majeure, allocate the risks between the contracting parties and describe the parties' rights and obligations.

The present paper aims to examine force majeure clauses under the most widely used standard forms, focusing particularly on the infectious disease as an exceptional event. The analysis shall be limited to time and cost entitlement under major forms.

The first section shall define the term "force majeure" and its coverage. The second section shall focus on the anatomy of the force majeure clause. The qualification of an infectious disease as an event excusing performance shall be examined in the third section. A comparison of standard major forms shall follow under the fourth section. The paper shall conclude by reviewing key considerations and offering recommendations in the drafting of force majeure provisions in the post-pandemic era.

The Term

"Force Majeure" is a legal term borrowed from the Napoleonic Code of 1804 and derived from the Roman term *vis major* (superior force) or *casus fortuitous* (an accident against which prudence could not have provided). "Force Majeure" is defined as "an event or effect that can be neither anticipated nor controlled. It is a contractual provision allocating the risk of loss if performance becomes impossible or impracticable, especially as a result of an event that the parties could not have anticipated or controlled."(Black's Law Dictionary, 2014). Although force majeure is not a common law concept, it is used in contracts governed by both civil law and common law jurisdictions.

The term refers to an exceptional event that relieves a party from its obligations under the contract. The essential elements of the exceptional event are unforeseeability, unavoidability, externality and impossibility of performance: the event must be unforeseeable at the time of contracting, beyond the control of the party invoking the clause, an objective condition "existing externally" (Li Jin, 2014, p.61) and must render performance impossible.

The exceptional events may typically include exceptional natural and manmade occurrences that relieve a party from its contractual obligations. Natural events cover earthquakes, hurricanes, floods, fire, plague, and other natural disasters. Manmade events or political events may include terrorism, riots or civil disturbances, war, acts of civil or military authority, national emergencies, strikes (usually excluding strikes which are by the contractor's personnel or any of its subcontractors), nuclear or chemical contamination, pressure waves from devices travelling at supersonic speeds, failure of public infrastructure, depending on the wording of the clause or the list that follows the definition of the term.

The Clause

Not all construction contracts contain a force majeure clause, which is essentially an "excuse clause" relieving a party of its obligations under the contract (Katsivela, 2007, p.101). If there is one, the clause may be structured in two sections. The first section defines the term and the criteria that need to be fulfilled for qualification. FIDIC 1999 editions, for example, require the fulfillment of five criteria: Force Majeure is defined as an exceptional event,

(a) which is beyond a Party's control,
(b) which such Party could not have reasonably provided against before entering into the Contract,
(c) which, having arisen, such Party could not reasonably have avoided or overcome, and
(d) which is not substantially attributable to the other Party. (Sub-Clause 19.1).

The second section of the typical clause sets out a list of events that could constitute force majeure. There are basically two approaches to the design of the second section: (1) an exhaustive list approach (2) a non-exhaustive list approach. If there is an exhaustive list of events, force majeure relief will be available only for the events specifically covered by the list. If the approach is non-exhaustive, a blanket phrase like “any other cause whatsoever beyond the control of the respective party”, “but not limited to”, “such as” or “any event of a similar nature” precedes or follows the list of qualifying events. (Berger, 2010, p. 280). In the latter case, an event not specifically listed bears the potential of triggering the force majeure clause, provided it satisfies the fulfillment criteria.

The clause is generally supplemented by a number of related clauses which set out the requirements for invoking the clause (proof of causation, timing and form of notices, prevention and mitigation duties) and the consequences of force majeure (entitlement to time extension, cost, suspension and termination).

The Disease as Force Majeure

Whether an infectious or contagious disease qualifies as an event triggering the force majeure clause depends on the wording of the relevant provision. The entitlement is another matter. In Roman law, “when a crop was eaten by a plague of mice or starlings, the jurists decided that when the enjoyment was lost as the result of vis mayor, then the lessee was excused from paying his rent in hire contracts” (Watson, 1991, p.64).

But would any infectious or contagious disease qualify as force majeure? When the WHO declared the coronavirus as a “pandemic” on 12 March 2020, we became aware of a hierarchy of diseases we were not concerned of previously. For the sake of clarification, a comparison between the types of diseases is provided below.

According to Chakraborty (2015), the difference between disease outbreaks is dependent on “the intensity of the pathogen, its mode of transmission, herd immunity, and prevalence and incidence of the illness and disease in the community.” (Chakraborty, 2015, p.1) “Endemic” means the constant presence of a disease in a community, which may be defined by a geographic area or population group (Porta, 2008). An “epidemic” has been defined as `` the occurrence in a community or region of cases of an illness, specified health behavior, or other health-related events clearly in excess of normal expectancy; the community or region, and the time period in which cases occur, are specified precisely" (Green et.al, 2002, p.3). A “pandemic”, on the other hand, is an outbreak that affects a broad geographical area, e.g. a region or the world (Kirch, 2008, p. 1459). The Centers for Disease Control (CDC) define an epidemic as “an increase, often sudden, in the number of cases of a disease, above what is normally expected in that population in that area.” and a pandemic as “an epidemic that has spread over several countries or continents, usually affecting a large number of people” (CDC, 2012).

In fact, the term “pandemic” never appeared in force majeure clauses prior to the outbreak. A Westlaw search returned zero force majeure clauses containing the term (Schwartz, 2020, p.56) and only 74 cases including “epidemics”.

The distinction between the categories is important because of a few potential issues. First, the disease may not be covered as a force majeure event under the contract if there is an exhaustive list that does not make an express reference to the disease. Even if the disease is expressly referred to, the exact wording used in the list would have legal implications. Under an exhaustive list that makes a specific reference to a "pandemic", an epidemic or endemic may not qualify as a force majeure event. Reference to an epidemic would, on the other hand, qualify pandemic as a force majeure event, as the latter is higher in the hierarchy.

Another key issue is the authoritative role of the World Health Organization in the official classification of the disease. Thus, if the clause covers an epidemic, WHO's official declaration of an outbreak as an epidemic would be of utmost importance for the party which seeks relief under the force majeure clause. In addition, the timing of the official declaration may be critical in terms of notice time limits. If a party wants to invoke the force majeure clause, it would be required to notify the other party within a contractually predetermined time after the party became aware or should have become aware of the relevant event constituting force majeure. The virus was declared a Public Health Emergency of International Concern on January 30, 2020 and declared a pandemic on 12 March 2020. A potential issue here would be the interpretation of the claim lapse period, in other words the base date for being held responsible for awareness.

Finally, the impact of COVID-19 pandemic may be classified as an excusable delay or depending on the contract, a compensable delay event. If the disease does qualify as a force majeure event or an exceptional event entitling the contractor to time extension only, alternative routes of cost recovery might be possible under alternative provisions of the contract.

Comparison of Major Forms

This section shall compare the responses of major forms to the infectious disease either as a force majeure event or an exceptional circumstance entitling the contractor to time extension and/or cost. The major forms chosen for analysis are AIA A201-2017: General Conditions of the Contract for Construction; ConsensusDocs 200:Standard Agreement and General Conditions Between Owner and Constructor; FIDIC 1999 editions; FIDIC 2017 editions; FIDIC Multilateral Development Bank Harmonised Edition 2010 (for World Bank contracts) ; NEC 4 Suite of Contracts 2017; JCT Design and Build 2016 and EJCDC Standard General Conditions (Document C-700).

Table 1 summarizes the results of the analysis with the following considerations:

Existence of a clause under the heading "Force Majeure" (Column 1: FM Clause)
Existence of a relevant or alternative clause that covers exceptional events (Column 2: Relevant Clause)
Specific reference to an infectious disease (e.g. "epidemics") under the Force majeure Clause or Relevant Clause (Column 3: Reference to Disease)
Entitlement to time extension (Column 4: Time Extension)
Entitlement to cost (Column 5: Cost)

Table 1: Results of the analysis.

	1.FM clause	2.Relevant clause	3. Reference to Disease	4. Time Extension	5. Cost
AIA A201-2017	No	8.3.1: Delays and Extensions of Time	No	Yes	8.3.3[1]
Consensus Docs 200	No	200.1: Time and Price Impacted Materials[2]	Yes 6.3 Delays and Extensions of Time (6.3.1. (j)epidemics)	Yes	200.1
FIDIC 1999	Yes 19		No	Yes	13.7[3]
FIDIC 2017	No	18: Exceptional Events	No	Yes	13.6[4]
FIDIC MDB 2010	Yes		No	Yes	13.7[3]
NEC 4	No	60.1(19)[5]	No	Yes	60.1 (19)[5]
JCT D&B2016	Yes 2.26.14 [6]		No	Yes	4.21[7] 4.21.4[8] 4.21.2.1[9] 4.21.5[10]
ECJDC	No	4.05. Delays in Contractor's Progress 7.15 Emergencies	4.05.C.1(epidemics)	Yes	

Notes:

[1] "*This section 8.3.3 does not preclude recovery of damages for delay by either party under other provisions of the Contract Documents.*"

[2] Amendment 1, revised 2011. Potentially Time and Price-Impacted Materials Amendment is a standardized, three-page Amendment that provides an Owner and Contractor a baseline price and calculation method for potential adjustments to material prices.

[3] Adjustments for Changes in Legislation: The Contract Price to be adjusted for any change in the Laws of the Country or in the interpretation of such Laws, made after the Base Date.

[4] Adjustments for Changes in the Laws: The Contract Price to be adjusted for any change in the Laws of the Country or in the interpretation of such Laws, made and/or officially published after the Base Date.

[5] Compensation Event. 60.1 (19) "*an event which - stops the Contractor completing the whole of the works or - stops the Contractor completing the whole of the works by the date for planned Completion shown on the Accepted Programme, and which - neither party could prevent, - an experienced contractor would have judged at the Contract Date to have such a*

small change of occurring that it would have been unreasonable to have allowed for it and - is not one of the other compensation events stated in the contract."
[6] Force Majeure is a Relevant Event entitling the Contractor to an extension of time. Under JCT, entitlement to compensation is restricted to events resulting from a 'Relevant Matter'.
[7] 4.21 There may be an entitlement to additional payment if the employer postpones any of the works under Sub-Clause 3.10.
[8] "*Delay in receipt of any permission or approval*" (Relevant Matter).
[9] Employer's instruction to postpone work (Relevant Matter).
[10] Impediment, prevention, or default by Employer (Relevant Matter).

Assuming that all procedural requirements (e.g. notices) are met, obligations (e.g. mitigation efforts) fulfilled and that the governing law does not limit the application of the Force Majeure clause or the relevant clause, the standard forms listed in Table 1 allow for an extension of time. Compensation, however, is a more complicated issue. The sub-clauses listed under column 5 indicate potential alternative routes for cost recovery under other provisions of the specific form. Under AIA, for instance, Sub-Clause 8.3.3. does not preclude recovery of damages for delay under other provisions of the Contract Documents. These are the owner's failure to provide evidence of financial arrangements; discovery of concealed/ unknown conditions; the owner's rejection of a proposed subcontractor; change orders and construction change directives; work stoppage caused by the owner's failure of payment; discovery of hazardous materials; suspension by the owner for convenience; and emergencies. The language of the Sub-Clause might be negotiated by the parties.

ConsensusDocs 200.1, Time and Price Impacted Materials Amendment and Schedule A may be used as an addendum to a contract. The parties may agree upon a method for establishing the market price as of the date of the Amendment and a method for calculating an adjustment in prices.

FIDIC forms (1999 editions, 2017 editions and MDB 2010) allow for time extension under the Force Majeure clause and the Exceptional Events clause, but restrict the recovery of cost to manmade events in the Country (defined as the Country in which the Site or most of it is located). Provided actions by the local authorities or government are considered as Changes in Legislation (1999 editions, MDB 2010) or Changes in Laws of the Country (2017 editions), the Contractor may be entitled to recovery of cost under Sub-Clause 13.7 under the 1999 editions and MDB 2010 or under 13.6 of the 2017 editions.

By contrast, the disease is expressly a compensation event under clause 60.1(19) in NEC forms (NEC3 and NEC4) as:

An event which stops the Contractor completing the works or stops the Contractor completing the works by the date shown on the Accepted Programme and which neither Party could prevent, an experienced contractor would have judged at the Contract Date to have such a small chance of occurring that it would have been unreasonable for him to have allowed for it and is not one of the other compensation events stated in this contract.

Under JCT a contractor is entitled to time extension but has to establish a "Relevant Matter" for recovery of costs. Sub-Clause 4.21 lists the Relevant Matters, but the infectious disease is not contained in the list. However, indirect routes might be available under if a permission or approval required by a statutory authority is delayed (Sub-Clause 4.21.4), the Employer issues an instruction to postpone any of the works to be done under the contract (Sub-Clause 4.21.2.1), the Employer or any Employer's person impedes or prevents the contractor from doing the works (Sub-Clause 4.21.5).

Finally, although the EJCDC forms expressly mention epidemics under Sub-Clause 4.05 (Delays in Contractor's Progress), the contractor is entitled to time extension but "Such an adjustment shall be Contractor's sole and exclusive remedy for the delays, disruption, and interference described in this paragraph". The disease under EJCDC remains an excusable, but non compensable delay.

Contractors are required to serve notices under varying time limits in all of the major forms considered. Under AIA, the notice period is 21 days from where the condition was first discovered or 21 days after the occurrence of the event, whichever comes first. ConsensusDocs require prompt written notice after the Contractor first recognizes the delay. Under the FIDIC forms, the notice period is 14 days after the party became aware (or should have become aware) of the event. In the 2017 editions, there is a continuing notice requirement (every 28 days). NEC requires a notice to the Project Manager within eight weeks of becoming aware that the event has happened. Under the JCT forms, the contractor is obliged to notify the Architect/Contract Administrator if and whenever it becomes reasonably apparent that progress is being or likely to be delayed. Written notice to the Engineer is required no later than 30 days after the start of the event under the ECJDC forms.

Key Considerations, Implications and Recommendations

This section shall address several issues that should be considered in drafting a force majeure clause in the post-pandemic era. The first issue is whether the outbreak of an infectious disease satisfies the requirement of unforeseeability from now on. It has been argued that "due to their seasonal and recurrent nature as well as the increased frequency of serious outbreaks, pandemics became foreseeable." (Tsekhanska, 2020, p.12). Whether the consequences of an outbreak of this magnitude (e.g. state measures, lockdowns) are also foreseeable is another question that deserves consideration.

So, the relevant question is "Does a force majeure event have to be unforeseeable?" According to Brunner (2009), the foreseeability of the extent and time of the impediment, like a long-lasting earthquake or a general strike are important factors (Brunner, 2009, p.158). However, governing law may make a difference in the interpretation of foreseeability. Kokorin and Weide (2015) discuss the relativity of the concept, in terms of the courts' definition of the average man: "Should the foreseeability be absolute (so as 'to escape the bounds of all human foresight'), or is it enough for it to be relative (normally foreseeable)?" (Kokorin &Weide, 2015 p.71). The UK Court of Appeal has questioned the "*over-refinement of the concept of foreseeability'* (McKendrick, 2018, p.703) because some risks (e.g. earthquakes) are more foreseeable in some parts of the world than in others.

The same can be said, for example, of projects carried out in well-known seismic zones (e.g. Turkey, Japan). In Istanbul, an earthquake of a considerable magnitude is foreseeable, given its close proximity to the North Anatolian fault, which was ruptured in 1999. Yet, the earthquake is a force majeure event in almost all contracts due to its inevitability and unavoidability, provided the contractor demonstrates the seismic performance of temporary and permanent structures on the site. The seismic performance of temporary and permanent structures is specified in annexures of the contracts, most notably under the document titled Employer's Requirements.

Employers might consider specifying processes for dealing with infectious diseases and requirements in the same manner in future contracts under a similar document describing pre-access testing for personnel and equipment, in addition to periodic health controls and methods of assessing fitness for work.

The second major issue is the impossibility element. To rely on the force majeure clause, a party must show that the event rendered contractual performance impossible. On the other hand, considering the recent effects of the pandemic, specifically within the context of construction projects we can hardly say that performance of the contract was absolutely impossible. The impact was gradual on many construction sites unless the site was shut down by governmental order. There were material shortages, logistics breakdowns, delays in receipt of permission, lack of specialty staff or contractors, quarantines, travel restrictions and changes in legislation. In some projects, performance was disrupted but was partly possible. In other words, impossibility was not absolute. According to Schwartz (2020), courts will be called on to make difficult judgments concerning "where the line for Impossibility will lie" (Schwartz, 2020, p.53). The interpretation of the impossibility element depends largely on governing law. However, the requirement has been relaxed in England and the U.S. in favour of "impracticability" (Augenblick & Rousseau, 2012).

The force majeure clause should address the contractor's rights for partial and absolute impossibility due to the effects of the disease (governmental directives, shutdowns, closure of borders, travel bans). Impossibility may likewise be temporary, and performance may be resumed after the aggrieved party ceases to be affected by the event (Samerezeldin & Abu Hemr, 2017, p. 21).

A third issue is one of definition. As noted earlier, the differences between the categories of infectious diseases have contractual implications. If, for instance, the list of events following the definition of force majeure includes "pandemics", the occurrence of an epidemic might not qualify as a triggering event. The inclusion of "communicable disease outbreak", on the other hand, could capture diseases that do not qualify as epidemics. Consideration should also be given to the institution authorized for official declaration (e.g., "epidemic as declared by the WHO").

Conclusion

The outbreak of the pandemic has refined our understanding of the force majeure concept. It has also led us to reconsider the essential elements of an event that qualifies as force majeure.

The interpretation of a force majeure clause will certainly vary across jurisdictions and it will take some time before civil codes and laws adjust to the post pandemic era. It is, however, likely that contracting parties shall respond faster to the changing circumstances by re-drafting and/or negotiating force majeure clauses in their contracts. Employers and contractors shall certainly take different approaches, as employers prefer narrower definitions and contractors prefer wider definitions.

This paper has attempted to shed some light into the new issues contracting parties shall have to consider. Two elements that shall deserve particular consideration are "foreseeability" and "absolute impossibility". The language and wording of the qualifying events under the clause and the designation of the authorized institution are other important issues that parties shall have to deal with in drafting new provisions.

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Literature Review on BIM-based Building Energy Performance Optimization

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Abstract

Buildings comprise a large part of global energy consumption and make a significant contribution to overall CO2 emissions in the world. Therefore, increasing the energy efficiency of buildings becomes a priority to reduce these undesirable effects. Building energy performance assessments are complex multi-criteria problems as the energy performance is affected by many factors such as building orientation, envelope design, climate conditions, daylighting levels, and HVAC system usage schedules. This complicated situation makes it difficult to accurately predict building energy consumption. BIM (Building Information Modeling) has started to be used to calculate the energy consumption of buildings, as its use is increasing in many areas of the construction industry. BIM not only aids in estimating the energy performance but also has the capacity to provide the necessary data for optimizing the energy use of a building by changing parameters that affect the energy usage. This study aims to do a literature review on BIM-based building energy performance optimization. As a result, it will provide a review of the methods that can be leveraged in building energy optimization, which can help designers more easily assess energy efficiency when making design decisions.

Keywords: *building energy performance, building information modeling, energy analysis, energy optimization, BIM.*

Introduction

Around the world, buildings use 30–40% of all primary energy, and they constitute 40-50% of greenhouse gas emissions (Ramesh et al., 2010). As buildings have such a significant impact on the environment, there is a huge attempt to increase energy efficiency. It is not possible to increase the efficiency of this without measuring the amount of energy consumption. Therefore, the prediction of building energy usage has a crucial role in increasing energy performance to reduce energy use and environmental impact. Building performance analysis is a good way to predict the energy usage profile and cost of energy consumption in buildings to provide improvement opportunities (Egwunatum et al., 2016). However, building energy systems are quite complex since they are affected by many factors such as building geometry (surface, opening), building orientation, space composition (space, zone), HVAC (heating, ventilating, and air-conditioning) system type and operating characteristics, building construction (construction, layer, material, window type), building usage (functional use), weather conditions (U.S. General Service Administration, 2009; Moon et al., 2011). Due to this complexity, it is difficult to accurately predict building energy consumption. BIM (Building Information Modeling) has been serving to estimate the energy consumption of buildings. Optimizing energy consumption is another issue that is as important and difficult as predicting energy consumption. BIM's optimization capability also uses it for this purpose. Although the use of BIM brings considerable conveniences compared to traditional methods, as in many fields in the construction industry, and provides more accurate estimations in a shorter time, it is unfortunately not possible to optimize the consumption results directly. Therefore, there is a considerable attempt to optimize energy consumption and process. This study aims to reviews the literature on BIM-based building energy performance optimization.

Building Energy Performance Assessment

Energy consumption of buildings primarily ensures that the indoor environment is comfortable and livable; these include space heating, cooling, domestic water heating, lighting, ventilation, and appliances. However, the energy use of buildings is not always the same, because many factors have an impact on it, such as type, size, weather, and seasonal variations, as well as the behavior patterns of the residents (Egwunatum et al., 2016). Building performance analysis includes some contextual analyses such as solar and thermal energy, ventilation, daylighting, building massing, site orientation, and HVAC systems. (U.S. General Service Administration, 2009) The aim of building energy analysis is the prediction of the usage profile and cost of energy consumption buildings to provide improvement opportunities. As building energy performance depends on many parameters and includes some analyses, its assessment is a very time-consuming and complicated process. To improve this challenging process, some technological advances are used like building information modelling.

Building Information Modeling

Building Information Modeling (BIM) is the most promising development in the construction industry (Azhar, 2011). BIM digitally represents the building components by computable graphic and data attributes that define them into software applications, and also building components can be manipulated intelligently with parametric rules. Data in the components describe how they behave during analyses and work processes, for example, quantity takeoff, and energy analysis (Eastman et al., 2018). BIM has been commonly using in the construction industry and serving many different purposes like design coordination, visualization, facility management, building energy analysis. BIM makes it possible to work with what-if scenarios to get the best design option by enabling the collaboration of multiple disciplines. Therefore, it has been commonly using for building performance assessments. Building information modeling provides opportunities to overcome the limitations of traditional building energy modeling, such as tedious model preparation, model inconsistency, and costly implementation, and also promotes building energy modeling to the digital building design process (Gao et al., 2019; Yuan & Yuan, 2011).

Literature Review

Optimization is the method of finding optimal solutions that have better quality than other solutions (Pezeshki et al., 2019). Building energy performance optimization is a challenging task since they are multi-criteria complex problems as they depend on many factors. BIM-based building energy optimization is a promising technique to design buildings with higher energy efficiency and better overall performance. Although using BIM for building energy modeling brings many advantages and overcomes many limitations, there some technical constraints created by particular problems posed by building simulation and optimization tools. For example, the lack of automated comparisons between different conditions and the sharing of geometry and boundaries with ease of operability are major constraints (Yi & Malkawi, 2009). Gourlis and Kovacic (2017) stated that currently, only one-way BIM is possible, which means that it is not possible to return the building performance simulation or optimization information. Therefore, there are considerable efforts to optimize BIM-based building energy performance. When the literature is reviewed, it is seen that most of the studies are conducted energy optimization by using parametric tools or optimization algorithms. In the following sections, relevant studies are gathered under these main headings.

Parametric Analysis Tools

Parametric modeling provides generative modeling by using building parameters and rules. Objects are automatically updated according to changing contexts with parametric modeling. (Aish & Woodbury, 2005; Qian, 2007). Parametric design tools allow designers to discover all possible alternative solutions and make decisions based on the performance of the building. (Lara et al., 2017; Dautremont et al., 2019; Menzel & Shetty, 2019). The energy performance data obtained through BIM is not enough to provide building optimization directly; it is easier to perform this optimization in the BIM within the parametric modeling section or with extra tools. Studies related to parametric analysis indicate that they have a significant potential for optimization of building energy performance (Naboni et al., 2012). In this section, studies, which use a parametric analysis tool for building energy performance optimization, are collected.

BIM-based parametric simulations are a commonly used technique for different optimization purposes for building energy performance. Abanda and Byers (2016) optimized the building orientation, whereas Sadeghifam et al. (2019) determined the best combinations of building-envelope components. Amani and Reza Soroush (2020) investigated and optimized the parameters affecting energy consumption by using BIM-based parametric analysis. Konis et al. (2016) developed a simulation-based parametric modeling workflow was for evaluating the performance of multiple passive design alternatives in the early stages of design. Menzel and Shetty (2019) conducted a case study to improve the daylighting performance of the predefined building. Thus, the performance of the façade of the building is optimized by parametric analysis. Another study, which performs a facade optimization considering daylight, solar heat gains, and thermal losses is performed by Baker (2018).

Welle et al. (2011) developed a methodology called ThermalOpt for thermal simulation and optimization. ThermalOpt integrates and automates workflow from a parametric BIM model to an energy simulation engine and a daylighting simulation engine using Industry Foundation Classes (IFC). Asl and Zarrinmehr (2015) conducted a case study to evaluate the

Revit2GBSOpt (Revit to Green Building Studio Optimization) application, which automatically links Autodesk Revit and Autodesk Green Building Studio and also enables to optimize building energy performance at the early phase of design parametrically. The case study revealed the potential for complex parametric simulation and optimization seamlessly integrated with architectural modeling (Asl & Zarrinmehr, 2015). Shi et al. (2016) proposed BIM-based building energy simulation and optimization tool, which helps to optimize the building form, building orientation, and window to wall ratio based on building energy performance. Schlueter and Geyer (2018) introduced an integrated design workflow combining BIM and the Design Performance Viewer (DPV) toolset, which links bi-directionality from the design model to simulation and back.

Optimization Algorithms

Optimization algorithms are another widely used method to achieve building energy performance optimization. Algorithms are crucial to generate new designs and guide the design optimization process. (Si et al., 2016) Generally, algorithms are used to optimize the data obtained from BIM. As BIM is compatible with many data exchange formats and tools, algorithms can be easily used. Optimization algorithms can be grouped into three categories: direct search algorithms, intelligent optimization algorithms, and hybrid algorithms. (Si et al., 2019) According to Shi et al. (2016), intelligent optimization algorithms are the most widely used. In this section, studies that use the algorithms to optimize building energy performance are collected.

Genetic algorithm(GA) is one of the intelligent optimization methods that can solve nonlinear optimization problems (Ooka & Komamura, 2009). Hong et al. (2017) used the GA method to increase the similarity between the target facility and the building energy simulation model. GA is performed in the generic optimization platforms after obtaining a BIM-based model. Yi and Malkawi (2009) developed a new representation for building geometry by using GA as the optimization algorithm for performance-based form-making. This was used as a base to integrate modeling software with GA. Nagpal et al. (2019) proposed a simulation workflow with a GA that automatically estimates the properties of several unknown building performance characteristics. Arida et al. (2016) presented an optimization process that uses a genetic algorithm to determine the best model parameters by minimizing the model errors.

Rahmani Asl et al. (2015) integrated parametric BIM-based building energy performance simulation system and daylighting tools to optimize building energy performance using non-sorting genetic algorithm NSGA-II algorithms (one of the commonly used genetic algorithms) through a case study, which aims to optimize daylighting and energy use of a residential building. This integrated system allows designers to explore design alternatives and optimize multiple objectives in the early design process. Chardon et al. (2016) used the NSGA-II to carry out multi-objective optimization through a case study. Xu et al. (2016) also employed the NSGA-II algorithm to optimize building envelope systems, electrical systems, and HVAC systems of a case study-office building. After evaluating the building performance via a BIM-based energy simulation tool, NSGA-II multi-objective optimization algorithm was used for getting the best design combinations. Petri et al. (2017) optimized the building energy in with the NSGA-II algorithm.

Artificial intelligence algorithms can also be used for the prediction and optimization of buildings' energy consumption. Banihashemi et al. (2017) developed a hybrid energy objective function that integrates two well-known Artificial Neural Network (ANN) and Decision Tree (DT) algorithms to obtain the best solution for energy optimization functions and enhance the accuracy of data-driven energy modeling and prediction.

Si et al. (2016) compared three commonly used optimization algorithms, one direct search algorithm (HookeeJeeves) and two evolutionary algorithms (MOGA-I Iand MOPSO) through a case study that optimizes different design variables like positions of the windows, orientation, thermal conductivity. Generic optimization platforms were linked with BIM-based building energy simulation software, and these three algorithms are compared considering different performance indices like stability, robustness, validity, speed, coverage. It is concluded that no algorithm performs best in all areas; therefore, the algorithm must be carefully selected according to the nature of the problem and design variables.

Conclusions

This study reviewed the literature on BIM-based building energy performance optimization. BIM's ability to interact with many software and tools, and to easily exchange data, makes it possible to use it with different methods and optimization techniques. It is seen that most of the studies in the literature use parametric analysis tools and optimization algorithms after obtaining a BIM-based energy assessment. There is no method that takes into account and optimizes all parameters and works effectively in several different case studies. Although each method has its minuses and pros, it is seen that it provides optimization for that case. In the progress of time, it is highly probable that these optimization techniques will develop or different optimization techniques will emerge, and it is certain that BIM is going to be actively involved in the improvement of this optimization process.

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Interaction of Building Information Modelling (BIM) and Lean Construction: A Bibliometric Analysis

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Abstract

Both Building information Modelling (BIM) and Lean Construction (LC) represent new paradigms within the Architectural, Engineering and Construction (AEC) industry. BIM as a transformative information technology provides the basis for integrated construction processes. LC as a management approach introduces minimal waste and value generation. Even though these are originally different concepts, the synergy between them can allow continuous improvement. This paper aims to provide a holistic map of BIM and LC interaction by carrying out a bibliometric analysis of existing literature on related researches. VOSviewer tool is employed to conduct a range of network analysis. The main goal is to gain a snapshot of the worldwide status of this research area including top research fields of BIM and LC, network of regions, network of publishing journals, co-authorship network, citation of articles and network of co-occurring keywords. A total of 201 papers focusing on BIM and LC synergies are identified from the Scopus database. Region-based network visualisation tells us that the USA has published the greatest number of articles about BIM and LC. Journal of Construction Engineering and Management, and Automation in Construction are the most dominant journals publishing about BIM and LC interaction. Last Planner System (LPS), Integrated Project Delivery (IPD), visual management, collaboration and waste are the core components in this field.

Keywords: *bibliometric analysis, building information modelling, lean construction, VOSviewer.*

Introduction

Managing the information of a facility during its lifecycle is becoming an arduous task due to the complex and data intensive nature of the construction industry. The traditional exchange of information in physical blueprint on paper or narrow digital format lead loss of consequential information during the entire building lifecycle, especially, between handovers of design, construction and operation (Borrmann et al., 2018). Building Information Modelling (BIM) which is defined as “a modeling technology and associated set of processes to produce, communicate and analyse building models” (Sacks et al., 2018), suggests a new method for management and coordinated exchange of information among disciplines and stakeholders in order to hinder this information loss. On the other hand, the construction industry is considered as having high levels of waste (Bølviken and Koskela, 2016). A meta-analysis of construction between 1970 to 2000 by Horman and Kenley (2005) reported that almost 49.6% of construction workers spent on non-value adding activities. Lean Construction (LC), the counterpart of lean production, aims to reduce the waste and increase the value (Gao and Low, 2014). As a new management approach, LC is a way to design production systems to minimise waste of materials, time and effort in order to generate the maximum possible amount of value (Koskela et al., 2002). Despite the benefits from their independent implementations, the synergies between BIM and LC can bolster the entire building lifecycle from design phase to handover and facility management (Dave et al., 2011) if all potentials are exploited (Sacks et al., 2010). Since the industry is pushed towards a more collaborative working environment, the acceptance of both BIM and LC, which collaboration is at their cores, should increase. Engaging these two concepts provides improved design and construction processes, and increased productivity. By aiming to understand the current status, this study focuses on illustrating a holistic synopsis of BIM and LC interaction researches through VOSviewer tool. Based on the Scopus database, the researches are analysed from different perspectives including co-authorship, region, journal, citation and keyword co-occurrence.

Research Method and Data Analysis

BIM and lean construction related studies were acquired from the Scopus database, which consists of comprehensive and substantial journals. The retrieval was conducted using the following code: TITLE-ABS-KEY ((“Building Information Model*” OR BIM) AND (“Lean Construction” OR LC)) AND (EXCLUDE (SUBJAREA, “BIOC”) OR EXCLUDE (SUBJAREA, “MEDI”) OR EXCLUDE (SUBJAREA, “NEUR”) OR EXCLUDE (SUBJAREA, “IMMU”) OR EXCLUDE (SUBJAREA, “PHAR”) OR EXCLUDE (SUBJAREA, “AGRI”)). In order to see the interests of the research community, all types of articles including journal papers, conference papers, reviews, book chapters and short surveys were included. A total of 201 articles were examined. Figure 1 illustrates the published records by year. The VOSviewer tool is employed for constructing and visualizing the bibliometric networks. In the VOSviewer, the “node” represents the publications, journals, researchers or keywords, and the “edge” indicates the relation and strength of the relation between two nodes. The minimum number of articles and citations of an author are set to a number that gives us the graph, which is neither very congested nor very empty. For each network analysis, the total link strength indicates the total strength of the links of an item with other items. The analyses of co-authorship, country/region, published journal, co-citation and co-occurring keyword were respectively performed.

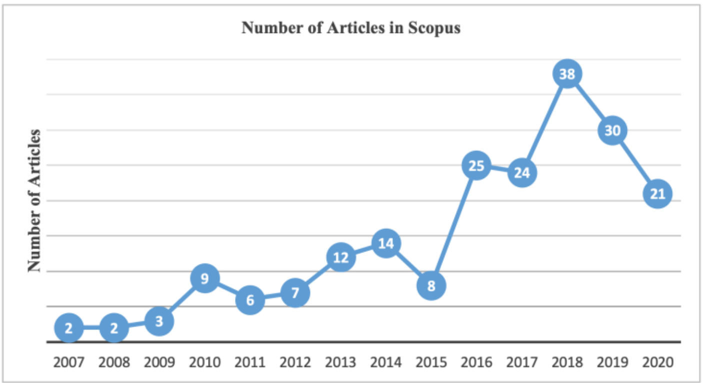

Figure 1: The number of articles in Scopus between 2007–2020 (It covers the first quarter of 2020).

Results and Discussion

Co-authorship Analysis

The co-authorship analysis reveals the collaboration and cooperation among the authors in BIM and LC integration. In the VOSviewer, the minimum number of published articles is determined as three and the minimum citations of an author is set at 20. 12 out of 475 authors met these criteria. After a detailed assessment, only nine authors were analysed since some of the authors were not connected to each other. Each colour represents a different cluster. The size of nodes is the number of articles by an author. The edges show the relationships between the authors. The closer the distance, the stronger the relationship. Having the largest node, Koskela L. has a great significance in BIM and LC interaction (Figure 2).

Figure 2: Co-authorship network.

Table 1 presents the details of co-authorship network. Sacks R. stands first with 621 citations, followed by Koskela L. and Dave B. with 415 and 130 citations respectively. Tezel A. is among the rising academics with recent studies. Sacks R. has the highest average normalised citations, indicating 222% higher citations than the average citations among these articles. The total link strength shows the total number of links of an author collaboration with all other authors. For instance, 15 total link strength for Koskela L. indicates that Koskela L. has co-authored 15 times with other authours.

Table 1. Details of co-authorship network.

Author	Number of Documents	Citations	Avg. Norm. Citations	Avg. Pub. Year	Total Link Strength
Koskela L.	9	415	2.27	2013	15
Dave B.	8	130	1.95	2015	12
Sacks R.	6	621	3.22	2011	2
Alarcón L.F.	5	30	0.79	2016	6
Främling K.	3	83	2.91	2015	9
Kubler S.	3	83	2.91	2015	9
Mandujano M.G.	3	26	0.95	2015	6
Mourgues C.	3	26	0.95	2015	6
Tezel A.	3	26	1.2	2018	1

Network of Countries/Regions

For this analysis, the minimum number of articles and the minimum citations of an author are both set at four in the VOSviewer. 16 countries/regions met the criteria; however, Canada and Spain were excluded as they were not linked to the others. Whereas Figure 3 demonstrates the network of these 14 countries, Table 2 presents the details of country/region network. The US with 48 articles and accounting for 25.94%, has the highest performance, followed by the UK.

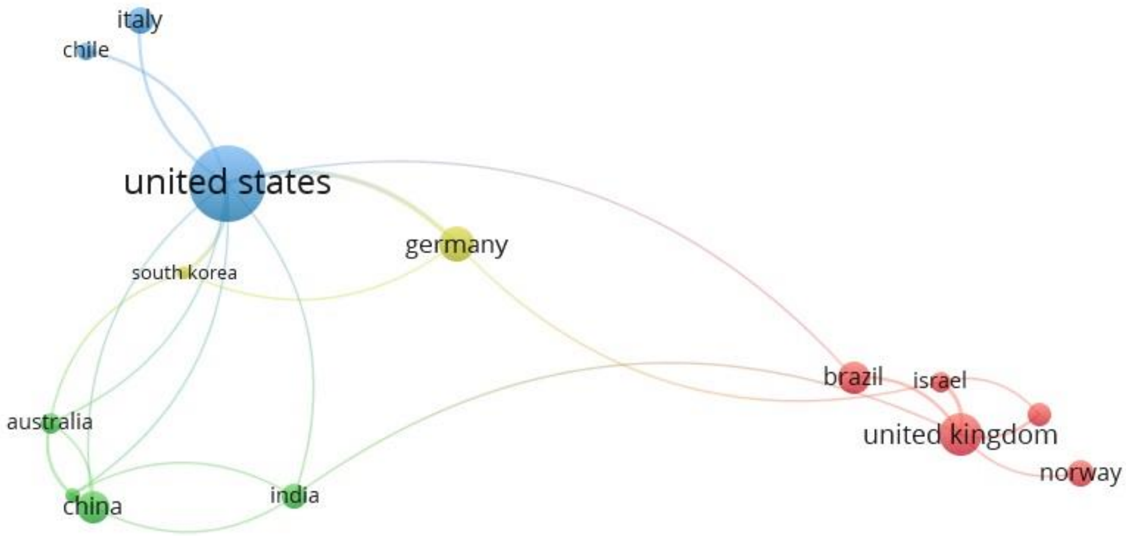

Figure 3: Network of countries/regions.

Hong Kong obtained the highest value in the average normalized citations, which indicates its influence in this area. The US with the greatest number of articles remains behind Israel and the UK in terms of the number of citations. For Israel, the greatest number of citations can be justified with its average publication year is 2012 and having an early and seminal article in this field.

Table 2. Details of countries/regions network.

Country/Region	Documents	Citations	Avg. Pub. Year	Avg. Norm. Citations	Total Link Strength
United States	48	412	2015	1.2	16
United Kingdom	21	574	2016	1.54	9
Germany	16	211	2016	1.08	6
Brazil	14	74	2017	1.17	3
China	14	45	2017	0.87	6
Italy	11	46	2018	1.7	2
Norway	11	13	2018	0.64	1
India	10	40	2018	0.38	4
Finland	9	123	2016	1.52	3
Australia	8	127	2016	2.45	5
Israel	8	631	2012	2.62	5
Chile	6	36	2016	0.76	2
Hong Kong	5	88	2017	3.12	7
South Korea	4	57	2016	1.72	5

Network of Published Journals

Journals that published articles on LC and BIM synergies are given in Figure 4. The minimum number of documents and the minimum number of citations were chosen as two and five respectively. Of 31 sources, 7 met the threshold. *International Journal of Managing Projects in Business* was excluded due to dysconnectivity with the others. *Automation in Construction* and *Journal of Construction Engineering and Management* being at the centre show their significance in the BIM and LC field.

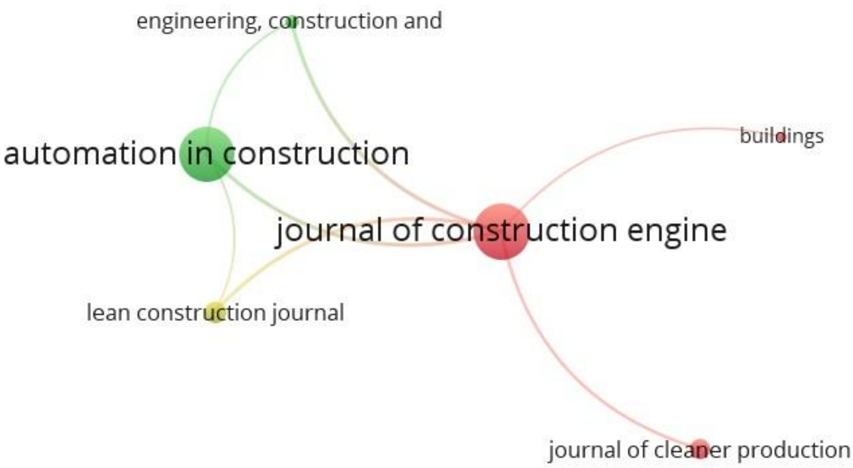

Figure 4: Network of published journals.

Journal of Construction Engineering and Management and *Automation in Construction* have top citations. The average normalized citation for *Journal of Cleaner Production* is the highest despite having only two journal papers (Table 4).

Table 2. Details of published journals.

Full Name of Journal Sources	Documents	Citations	Total Link Strength	Avg. Citations	Avg. Norm. Citations
Automation in Construction	6	385	10	64.17	1.83
Lean Construction Journal	6	58	4	9.67	0.81
Journal of Construction Engineering and Management	5	414	12	82.8	1.60
Engineering, Construction and Architectural Management	3	27	4	9	1.18
Journal of Cleaner Production	2	51	2	25.5	2.76
Buildings	2	6	2	3	0.67

Network of Article Citations

The citation analysis in the bibliometric analysis reveals the most momentous and pivotal papers in BIM and LC integration. The minimum number of 25 citations for each article were selected in the VOSviewer. Out of 201 articles, 16 met the threshold, later narrowed down to 11 since five of them were not connected to each other. Sacks R. (2010a) and (2010b) being the most cited papers, have strong connections with others (Figure 5).

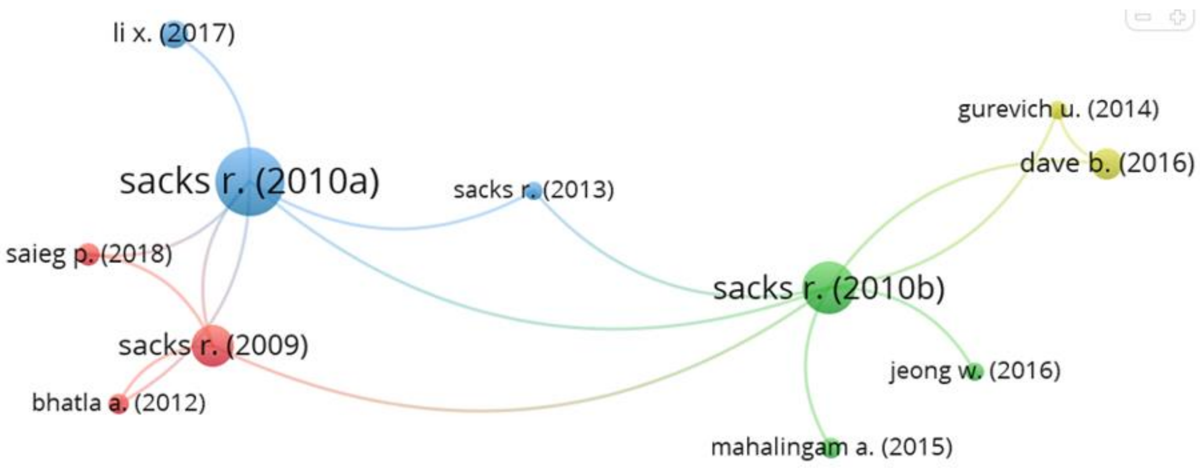

Figure 5: Citation of articles.

Sustainability and Internet of Things (IoT) related studies are also present among the most cited articles along with the main BIM and LC interaction researches (Table 5).

Table 5. Details of articles citations.

Article	Title	Citations	Norm. Citations
Sacks R. (2010a)	Interaction of lean and building information modeling in construction	262	4.35
Sacks R. (2010b)	Requirements for building information modeling based lean production management systems for construction	169	2.81
Sacks R. (2009)	Visualization of work flow to support lean construction	112	2.47
Dave B. (2016)	Opportunities for enhanced lean construction management using Internet of Things standards	66	6.81
Li X. (2017)	Mapping the knowledge domains of building information modeling (BIM): A bibliometric approach	56	7.78
Saieg P. (2018)	Interactions of building information modeling, lean and sustainability on the architectural, engineering and construction industry: A systematic review	40	11.18
Bhatla A. (2012)	Integration framework of BIM with the last planner systemTM	34	2.94
Mahalingam A. (2015)	Investigating the role of lean practices in enabling BIM adoption: Evidence from two Indian cases	32	1.6
Jeong W. (2016)	BIM-integrated construction operation simulation for Just-in-Time production management	28	2.89
Sacks R. (2013)	KanBIM workflow management system: Prototype implementation and field testing	28	4.6
Gurevich U. (2014)	Examination of the effects of a KanBIM production control system on subcontractors' task selections in interior works	27	4.55

Network of Co-occurring Keywords

The keywords co-occurrence analysis shows the recent research trends and the core of research in this area. It can help spot new BIM-LC related research topics. A standardisation approach was adopted to merge variant terms (e.g. “BIM”, “building information modeling”, “building information models” are merged into “building information modelling”). The frequency of keywords co-occurrence was set at three. 29 out of 467 keywords matched the threshold (Figure 6). Being BIM an LC the basis of visualisation, BIM (green) and LC (orange) are the largest nodes, 128 and 102 respectively. Other co-occurring keywords are “collaboration”, “IPD”, “last planner system”, “lean”, “visual design construction”, “augmented reality” and “waste”.

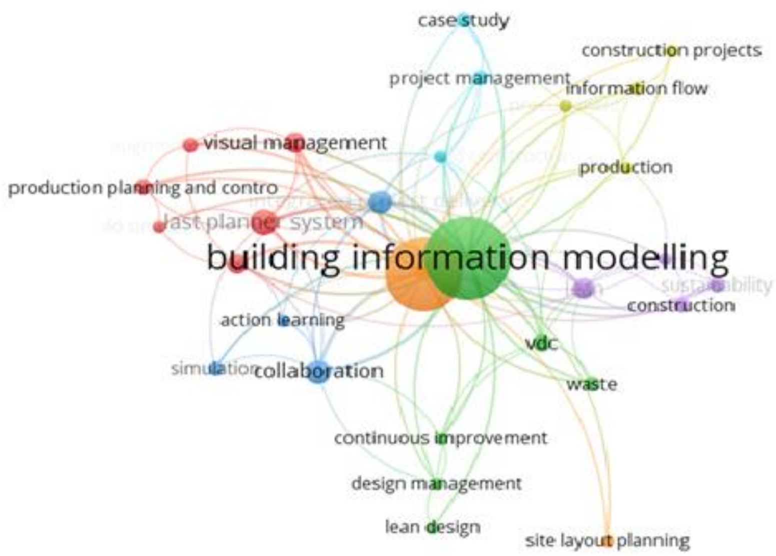

Figure 6: Network of co-occurrence keywords.

Conclusion

By evaluating the research trends on BIM and LC, which are the focal points of researchers in the last two decades, this paper outlines the status quo of BIM and LC studies statistically. It highlights the influential articles, authors, journals, countries and relevant research areas focusing on BIM and LC synergy. Beyond the overview of BIM and LC interaction, this work also suggests new research areas such as IoT and sustainability in alignment with BIM and LC. Since BIM fulfils some LC principles greatly through the new way of producing and managing the information as well as the improvement of the workflows for many stakeholders; exploring BIM and LC studies and their possible integration with other technologies is of great importance for enhancing the design and construction processes.

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From social networking to social distance: How did architects react to the pandemic? Evidence from social media accounts

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Abstract

The crisis caused by the covid-19 pandemic is still being experienced by the first wave of effects, and more is expected until an unforeseen future. Each industry is discussing the change predicted for the near future but everyone seems to agree on the idea that things will definitely be different for a prolonged period, and it appears that AEC industry is not far from this argument. While the first reaction all over the industry was to increase the health and safety measures, site and office workers are affected by different practices. While site work was either suspended or went on with strict measures, most of the office workers are sent home and expected to work online. Although the global work environment was encouraging architects to communicate and work online for some time now, a change in such a scale was not something expected this abruptly. While discussing the expected change for architectural practice, this study attempts to identify the reactions of architects and architectural companies to this compulsory work environment change using the data taken from their social media accounts and social networking service (SNS) practices.

Key Words: *architect, architectural office, content analysis, covid-19, ICT, pandemic, social media, social networking services, SNS.*

Introduction

Economic crises are becoming more prominent with an increasing pace over the last decades. Although political and economic conflicts are more common for a cause, the crises triggered by the covid-19 virus, in the first weeks of 2020 was unexpected for most of the world. The unexpected halt to people's mobility caused a total silence for most of the industries. Inevitably, depending on the extent of the precautions countries took into effect to slow down the spreading of the virus, architecture, engineering and construction (AEC) industry took its share. While some countries imposed a total lock-down, some others choose to imply a mixed set of limitations. As an example, Turkey imposed a partial lock-down for different age groups while total lock-downs are imposed for weekends. However, while most of the construction sites stayed operational, majority of technical offices preferred to send their staff home and asked them work from their homes. Almost suddenly, people woke up into a new world where any kind of physical contact with 'other' people became almost offensive and our isolated homes became the only possible place that we can eat, sleep, work if possible socialize in a limited and mostly digital way. The work environment unavoidably shifted into digital mediums. However, it was not just office programs that were considered to keep business world operational. Online meetings became a daily routine and people found one of the easiest and practical ways to reach their clients as using social networking services (SNS). Sales, marketing and customer relations works operated majorly on those channels. One the main reasons for the SNS use is the wide spread use of these applications through smart phones. In our daily lives, smart phones are ubiquitous devices that are even becoming a standard for public works. And although they are mostly privately owned devices, due to their practicality they became an inseparable office equipment for businesses including the AEC industry. SNSs that enable instant messaging and live group video conferencing increased their popularity that are well suited to the isolation period.

ICT technologies have implemented a revolutionary infrastructure into the human civilization such that it seems somewhat impossible to think our future apart from it. New media technologies built over them are changing the way we communicate and do our businesses with an increasing pace. On the other hand, the concept of social media is literally young and its implications are yet to be further discussed but it is becoming more apparent each day that, what social media changed so far seems to be only "a scratch on the surface of what is coming and what is possible" (Aral et al., 2013).

Most of the SNSs were designed to be used on web browser interfaces and afterwards adopted to mobile devices by dedicated software or 'apps' in short. Facebook, Instagram, Pinterest, and LinkedIn are among the most popular SNSs according to the renowned architecture web site Archdaily (Abdallah, 2020). Each SNS presents its own way of interaction for the people by their constantly changing interface and ease of use. In this context, Instagram has a more specialized property that is also pointed out by researchers. According to Miles (2014), Instagram is a breakout social network, which is the first SNS that was 'born mobile'. Use of Instagram among the architects and architectural offices are also booming, not just on using its social aspects but also using it as a tool for improving their business (Lee, 2014). Moreover it is not limited to tech-savvy new generations that are using ICT innovations since their birth but it is already part of some renowned senior architects. Architect Norman Foster of London based Foster+Partners architecture office have started a personal as well as a corporate Instagram account in 2017 at age 82. Today he is being pointed out to be one of the best Instagrammers of the architecture world by many, such as Furman (2019) who criticizes the state of architectural mediation over his Instagram posts' popularity.

Institutions of the AEC sector are releasing guidelines to overcome the present and predicted difficulties of the future. However, it seems that we have just started to understand the repercussions of the crisis caused by the covid-19 corona virus and we are far from predicting how our daily lives and the way businesses flow will change in the near future yet. Discussion over the future of public spaces is a hot topic such as what this crisis brings into another already debated issue, the future of the architectural education. Architecture is a profession deeply interested in society and human behavior. This interest tackles with any kind of threat whether it is referring to a positive change or the opposite. In this context, social media can be considered as a strategic management tool for an architect to build an identity both for their personal character and their business. Therefore, SNSs seem to be a practical way for the architects to express and discuss opinions about the predicted change and future implications that will affect the society and the profession.

As the main research interest for this paper was the reactions of the architects approximately during the lockdown period, three research questions of qualitative and quantitative units of analysis are set as follows:

Q1: How is the performance of architects/architecture offices' Instagram accounts? (Quantitative & Qualitative implications)
Q2: Did Architects respond to the Covid-19 pandemic by their Instagram posts? (Quantitative implications)
Q3: How did the architects react to the pandemic? (Qualitative implications)

The approach trying to identify these research questions as well as scope and limitations are explained in the next section. Sections over details about the data collected and a discussion over the outcomes of the data provided and validity of the research questions tries to finalize the paper.

Methodology, Scope and Limitations

This research paper tries to identify reactions of architects against the covid-19 pandemic using their social media traffic, in particular Instagram posts. Instagram became one of the 'most important new tool for architects' in the last couple of years (Abdallah, 2020) especially for design oriented professionals and businesses by the advantage of its visuals based interface. As the needed data was present as a digital media content, content analysis method is selected make the necessary analysis.

Content analysis is a research method for analyzing the content of various documents, such as visual and verbal data (Harwood and Garry, 2003), not necessarily from an author's or user's perspective (Krippendorff, 2018). It is often used to decide the occurrence of certain words, themes or concepts within the data provided. This method can be used to quantify the presence meaning and relationship of such words, themes or concepts. As a distinction from many other social sciences research methods, content analysis method does not require data collection directly from people. It uses data from recorded information in forms of text, media, or other such articles. In this context, content analysis suits well for analyzing social media data. Codes of the content analysis are formed by the keywords that we out of a sudden began to frequently hear. These codes included the name of the virus, 'covid-19' and varied through more contextual indicators such as 'stay safe and healthy' or 'difficult times'. Starting with a quantitative analysis, the number of times these codes are used is recorded. After that, a qualitative search for the stress caused by this global crisis that may be skipped by these pre-determined codes are looked for. Text and visuals are checked for possible implicit or explicit ties relative to the research questions. Some of the findings of this qualitative search which are indicating an implicit relation to the research theme are also added as 'other' to the table of codes.

In a local versus global context, Turkish architects are selected from the members of Freelance Architects Association and their global counter parts from a selection of world's best architects. Instagram accounts of architects/architectural offices in this group are eliminated according to the amount of activity and seven of the busy ones are selected from each group. Posts of these accounts between the last week of February 2020 to the end of first week of June 2020, covering roughly 70 calendar days on average, are analyzed according to a content analysis structure. This structure is shown in Table 1.

Due to these research variables selected for this study, this research has many limitations. The decision to use the selected architects and architectural offices depends on an ongoing research by the author that is not yet published, that studies global and local architects' social media use in a time-dependent context. Reviewed social media accounts representing an architect or an architectural office are among the most active ones compared to others that are selected for this research. Another issue is to separate the corporate accounts with the personal ones, since some of the architects leading architecture firms also have personal accounts. Although many of the personal accounts' shared content are parallel to corporate ones, only the corporate accounts are preferred as the data source. However, selecting corporate accounts can also be tricky. Some of the architects/offices have side accounts besides their official business accounts that even have more followers than the business account. As an example, the Instagram account 'Zaha Hadid Architecture' has 1.1 million followers, where the official business account 'Zaha Hadid Design' has roughly 111.000 followers. Only business accounts are taken into account for this research to avoid any confusion.

The performance of individual Instagram accounts can be measured in different ways. The first measures and the most easily accessible ones are the number of the followers of the account, number of the accounts being followed by and number of media uploads (posts) shared by the users. However, these numbers are not enough to predict the performance of an account if the research focuses on a relevant time period or some other basic comparisons between the account and that particular social networking population. In order to maintain a more in-depth performance analysis of the architects / architectural offices, a web site dedicated to make basic statistical analysis for social networking sites is employed. Quantitative analysis made for the first research question of this research depends on the data taken from the dedicated social media analysis web site socialblade.com. Social media is a relatively new-established research area and the social networking platforms that are being explored are in a constant change of popularity. Instagram is selected as a preferred social networking platform frequently used by designers at the time of the research. However, other social networks in combination with different architect selection can offer a diverse perspective.

Any Clue on Architects Reactions over the Social Networks?

As stated in the methodology section, seven local and seven global architects are selected as the research population for this study. The local ones, representing Turkish architects/architecture firms are 1-Çinici Architects/Can Çinici, 2-Emre Arolat Architects (EAA), 3-Erginoğlu&Çalışlar Architects, 4-Tabanlıoğlu Architects 5-Autoban, 6- Gökhan Avcıoğlu Architects (GAD), 7-Toner Architecture. Global architects/architecture offices inspected in the research are 1-BIG-Bjarke Ingels Group, 2-Foster + Partners, 3-MAD Architects, 4-MVRDV, 5-OMA, 6-Studio Gang and 7-Zaha Hadid Architects.

Performance of Architects/Architecture Offices' on Instagram

In order to answer the first research question, a mixed way of analysis is selected that is both quantitative and qualitative implications: In order to find quantitative answers to "Q1: How is the performance of architects/architecture offices' Instagram accounts" and interpret the findings, a social media analysis web site, socialmedia.com is used to analyze these accounts. Instagram performance analysis summary of the selected architects/architecture offices Instagram accounts are shown on Table 1. The architects are sorted according to their media uploads during the time period selected for the research. As the data retrieved from SocialBlade is weekly, there is a slight shift in start and end times of the time period analyzed. Due to this shift, the period analyzed starts between February 24-29th and ends at June 6-7th. As the start of this period cover the period of when the outbreak turned into a pandemic and restrictions and lock-downs took place all over the world and the end date complies with the ease of these restrictions globally this slight shift is acknowledged as reliable. The metrics shown on the table include the overall numbers of media shared by the account, total number of followers, and number of accounts followed by the account as basic indicators. Average likes and average comments are means of the responses for the shared content. 'Rank' and 'Engagement Rates' are calculated by the site depending on their analysis. Rank is calculated based on a variety of metrics including average view count, comments and likes. Engagement rate is the total number of interactions on a post such as likes, comments and saves, divided by the total number of followers of the account based on the latest 20 pictures uploaded to Instagram.

Besides the current status of the accounts using the overall ratings explained so far, historical data showing the number of posts, number of followers and number of followed at the end of February is also added to state any meaningful changes that happened during the period of the pandemic restrictions. As the architects are sorted according to their media uploads during the time period subject to this research, there seems to be different relations between number of posts and followers gained for the two groups. While the global seven does not show a correlation between these two variables, Turkish seven tend to show a strong relation with the exclusion of Emre Arolat Architects. Although Emre Arolat Architecture account gains more followers despite relatively low number of uploads GAD Architecture's number of uploads and gained followers are in the context. First three Local accounts' media uploads are above the global group for the period of analysis. Emre Arolat Architecture's Instagram account is the only B- rated architecture office between the local group. EAA account has more total uploads and engagement rate than any of the global architects.

As a result, Table 1 shows that each group has members with low number of media uploads or followed accounts. Global architects have huge numbers of followers and getting considerably more comments and likes for their posts. On the other hand, the local architects have more engagement rates as the total response of likes and comments in proportion with the total followers are quite higher. Also, there seems to be a direct correlation between their number of uploaded media and gained followers. Average total media and number of followed accounts of this group is higher than their global counterparts. However, a more in depth analysis is needed to identify if these architects, who are in a way social media leaders of their scale, have responded to the pandemic during the crisis period or not.

Traces of Response to the Pandemic by Instagram Posts

Architecture extends beyond designing spaces but also in some ways shape the lives of people. So, the second research question of the study tackled with the idea that architects would have been reacting for the unexpected and traumatic situation created by the pandemic. In order to examine the 'Q2: Did Architects respond to the Covid-19

Table 1- Instagram Performance Summary of / Global and 7 Local Architects/Architecture offices (Analysis by Social Blade.com)

			Grade	Media Uploads		diff.	Followers		diff.	Following		diff.	Engage. Rate %	Avg. Likes	Avg. Comments
			J 6-7	F 24-29	J 6-7		F 24-29	J 6-7		F 24-29	J 6-7		J 6-7	J 6-7	J 6-7
	GLOBAL 7														
1	MAD Architects	@madarchitects	B	908	952	44	383.515	395.089	11.574	530	530	0	0,86	3.399,88	16,92
2	MVRDV	@mvrdv	B	704	743	39	466.355	510.753	44.398	207	216	9	2,26	11.476,20	54,36
3	Studio Gang	@studiogang	B-	458	491	33	67.823	73.084	5.261	312	345	33	1,46	1.054,96	9,16
4	Foster + Partners	@fosterandpartners	B	285	307	22	293.946	311.447	17.501	55	60	5	1,23	3.808,40	31,24
5	OMA	@oma.eu	B	582	599	17	387.704	419.017	31.313	192	195	3	1,97	8.194,28	53,48
6	ZAHA HADID DESIGN	@zahahadiddesign	B-	88	105	17	87.898	111.571	23.673	3	3	0	2,89	3.207,32	19,20
7	BIG - Bjarke Ingels Group	@big_builds	B	309	322	13	404.765	439.985	35.220	251	255	4	1,94	8.461,64	50,24
	LOCAL 7 (Turkish)														
1	GAD Architecture	@gadarchitecture	C+	388	460	72	12.265	14.292	2.027	965	970	5	2,18	305,00	7,00
2	Emre Arolat	@emrearolat	B-	1432	1501	69	44.739	48.460	3.721	611	691	80	3,24	1.553,96	15,20
3	Autoban	@autoban212	C+	471	530	59	22.670	23.723	1.053	849	894	45	1,55	364,36	2,92
4	Erginoglu&Calislar Architects	@ecarchitects	C+	516	526	10	10.970	11.532	562	2	2	0	1,98	227,04	1,08
5	TA_	@tabanliogluarchitects	C+	172	175	3	17.902	18.381	479	167	167	0	2,71	493,32	4,00
6	Cinici Architects / Can Cinici	@ciniciarchitects	C+	508	509	1	9.842	9.934	92	342	340	-2	2,50	246,84	1,64
7	TONER	@tonerarchitects	C+	41	41	0	4.934	4.960	26	368	391	23	5,20	253,60	4,48

F 24-29: February 24-29th

J 6-7: June 6-7th

pandemic by their Instagram posts?' all 14 architects' Instagram posts during the period of late February to June are observed according to the content analysis framework formed. Keywords selected for this framework are checked in the descriptions under the visuals or on the visuals, including hashtags related to these keywords. Video clips are checked for its content as well as the history parts, if they are attached to the account page which would otherwise be deleted automatically by the system in a couple of days. Results of this scan is shown on Table 2. The numbers shown on Table-2 shows different number of reactions expressed by the architects/architecture offices. These responses bring us to the our third research question: 'Q3: How did the architects react to the pandemic?'.

The response frequency is not parallel to the number of posts made by the architects in the research period. In the global architects section, Studio Gang and Foster+Partners are the most profound firms to the pandemic with seven different shared medium each. While Foster+Partners have 7 posts referencing the crisis, Studio Gang has 6 posts and a permanent link under their bio that consists an announcement for a mask design invitation dedicated to the by the pandemic. In these posts, Foster+Partners mentions their work to transform a central courtyard of a university building into a covid-19 emergency ward. Some of their posts refer designing visors for the medical workers and the campaign in the UK with the '#clapforcarers' hashtag that aims to thank and motivate health workers. Studiogang posts tackle with the popular expression 'social distancing' which is frequently used as a single most powerful measure to avoid the virus. These messages underline the importance of being social for the human kind and it should be 'physical distance' instead of being socially distant. The earliest but indirect response from the global architects also comes from Studio Gang. Within their post, dating March 20th, they mention "…staying safe and healthy through this challenging and uncertain time".

However, the most Instagram active architecture companies in this section, MAD Architects and MVRDV seem to be muted except a few shared documents each. MVRDV's shared documents are being reached by a link in bio, that include an update on Corona virus and a 'post-Corona capacity study'. MAD Architects, which is a Bejing and USA based country founded by a Chinese architect Ma Yansong, released only 2 posts related to their office closure and re-opening. The date for MAD Architects office closure is April 20th. When most popular keywords used in the global architects group are checked the first one is covid-19/corona virus followed by face shield/visor and mask combination. Some of the architects show their interest to design face shields and 3D print them voluntarily to help the medical staff on the frontlines of the fight against the virus. Third place for the most frequent used keyword is shared by 'social distancing', 'lockdown' and 'difficult times'.

In the local group, the earliest response came from somewhat 'Instagram shy' Tabanlıoğlu Architects as they have only 3 Instagram posts during the period. Announcement of their office closure and home office transformation dates on March 18th. This post is Tabanlıoğlu Architects' only related post through their Instagram account aside a link attached to their bio that gives more information about this shift. Some of the other offices followed Tabanlıoğlu, as office closures of Autoban is announced on March 20th, Emre Arolat on March 25th and GAD on March26th. Most Instagram active architects GAD Architecture has 8 and Emre Arolat Architecture has 7 posts related to the pandemic and its outcomes. In their posts, GAD Architecture announces their office closure on March 26th. Other posts include an online discussion

Table-2: Shared documents by the architects and traces of pandemic under the selected keywords for the period of late February to early June 2020.

			Posts Total	**Total evidence**	Posts related	History attached	Link attached	**Used Keywords**	covid-19 /corona	stayhome / evde kal	social distancing / sosyal mesafe	faceshield / vis(z)or / siperlik	mask / maske	lockdown /eve kapanma	quarantine / karantina	crisis / kriz	difficult times / zor zamanlar	remote work / uzaktan çalış.	stay safe&healthy/sağlıklı ve güvende kal	other	
	GLOBAL 7								---------- keywords expanded ----------												
1	MAD Architects	@madarchitects	44	**2**	2			**2**						1						1	office return
2	MVRDV	@mvrdv	39	**2**			2	**0**													
3	Studio Gang	@studiogang	33	**7**	6		1	**12**	5		1		1			1	2	1	1		
4	Foster + Partners	@fosterandpartners	22	**7**	7			**10**	5		1	2		1						1	NHS #clapforcarerers
5	OMA	@oma.eu	17	**0**				**0**													
6	ZAHA HADID DESIGN	@zahahadiddesign	17	**0**				**0**													
7	BIG - Bjarke Ingels Group	@big_builds	13	**3**	1	1	1	**2**		1		1									
									10	1	2	3	1	2	0	1	2	1	1	2	
	LOCAL 7 (Turkish)																				
1	GAD Architecture	@gadarchitecture	72	**8**	8			**19**	9						2	5			2	1	missed construction sites'
2	Emre Arolat	@emrearolat	69	**7**	7			**11**	8	3											
3	Autoban	@autoban212	59	**1**	1			**2**		1									1		
4	Erginoglu&Calislar Architects	@ecarchitects	10	**0**				**0**													
5	TA_	@tabanliogluarchitects	3	**1**	1			**3**	1		1								1		
6	Cinici Architects / Can Cinici	@ciniciarchitects	1	**0**				**0**													
7	TONER	@tonerarchitects	0	**0**				**0**													

series of “Covid Crisis and Education” that put forward the need for a new perspective for architectural education in the post-covid era, and promotion of some of their previous architectural designs with regard to social facilities these projects have. Autoban and Tabanlıoğlu have only one posts each announcing their office status as mentioned above. No traces about the pandemic have been found in Çinici, Toner and Ergionoğlu&Çalışlar Architecture offices Instagram accounts during this period. Despite other indirect or more superficial responses, Emre Arolat Architecture’s message from the very first response is quite predicting:

> *Corona days...This unforeseen plague flattened the whole world. It does not discriminate, distill or extricate. It does not distinguish social classes, does not care richness. The world will be different after all.#coronadays*

Discussion and Conclusion

This research started with three main questions to identify the reactions of the architects during the lockdown period. First, assessing the performance of the two selected group of architects in a certain timeframe, we looked for the architects’ reactions towards the covid-19 pandemic in their official Instagram accounts. The content analysis of the Instagram posts show that architects showed different reactions against the period of lockdown. Apart from their origin or Instagram performance in general, some of the architects shared some implications on the unexpected effects of the pandemic in their Instagram accounts. In most cases it started with the announcement of their office closure (@madarchitects, @mvrdv, @gadarchitecture), and shift to the home-office work arrangements (@big_builds, @studiogang). Further, most of them reflected their concerns (@studiogang, @gadarchitecture) and some of them tried to motivate their followers to monitor the guidance being made by the authorities (@big_builds, @emrearolat, @autoban212, @tabanlıoğlu) or showing solidarity with the health care providers. Some of the architects showed their support for the efforts to provide supplies such as producing face shields (@fosterandpartners, @studiogang, @big_builds). However, there were also 2 global and 3 Turkish architects who did not respond to the crisis at all (@oma.eu, @zahahadiddesign, @ecarchitects, @ciniciarchitects, @tonerarchitects). In this unresponsive group, @tonerarchitects did not share any posts and @ciniciarchitects had only one post during the lockdown period which may make sense. But, both @oma.eu and @zahahadiddesign shared 17 and @ecarchitects shared 10 posts during the same period without any clue about the pandemic or the crisis caused by the pandemic.

One of the significant discussions captured by this study is the one that is put forward by Studio Gang (@studiogang). Is ‘social distance’ the correct expression to identify the needed distance between individuals to avoid the infectious particles, or is it the ‘physical distance’ that we are looking for? This gripping viewpoint has a considerable amount of startling connections with the discussion of architecture and built environment. Another discussion is about the future of architectural education. Global Architectural Development (@gadarchitecture) is promoting the discussion on this hot debate adding the uncertainties of the post-covid era. The sudden and compulsory shift towards the digital mediums in this lockdown period created an inevitable leap for the online education efforts. Moreover, it seems we will be facing more online education challenges in the near future and the distinct characteristics of the architectural design education will escalate the pressure on this already hot debate.

Although it is a relatively new digital medium, this research shows that, both global and Turkish architects seem to make an effort to gain ground in the digital mediums such as Instagram. Turkish architects' performance does not fall short of and have higher engagement rates than their global counterparts, but the Global 7 have more followers resulting higher interaction outcomes such as comment and likes. As the number of followers in total increase like a snowball in SNS world, the followers of the Global 7 are soaring more significantly during the period of pandemic compared to the followers of the Turkish 7. This difference may be linked to the scale of the architectural firms and rather low presence of the Turkish architects in global markets, compared to their local existence despite their increasing efforts. In that sense SNS seem to be the right platform to reach the globe. Moreover, the performance of the Turkish 7 is not the same for all the architects just as the global group. Emre Arolat Architecture (@emrearolat) seems quite close to the Global 7 in most performance measures. Again, that can also be associated with the increasing presence of the firm in global markets with their latest work.

As we are entering the third decade of the 21st century, SNSs are starting to come more and more forward both on our personal and business lives. World leaders are putting forward important issues in their personal social network accounts before official announcements, universities are putting forward their SNS popularity as a criteria boasting their popularity. Ironically, we are more into our social networks in the days of so-called 'social distancing'. On the other hand, SNSs are constantly evolving and their popularity is also fluctuating. The findings of this study may be different under a different SNS or another selection of architects in a different timeframe. However, it becomes evident that, social media use in AEC will be worth considering for further research in the near future.

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Introducing Sustainable and Innovative Materials to Construction Industry: Lessons Learned from a Research Project

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Abstract

The waste created as well as natural resources and energy used by the construction industry in comparison to other industries are of the main issues being tackled under the concept of sustainability, both in amount and effect. Its amount of production makes natural aggregates one of the main resources used in construction projects. During the production of such a high demanded material, a significant amount of land and interrelated resources are being lost causing a significant environmental impact. Because of this environmental impact, research is on progress to change natural aggregate with a more sustainable material. An alternative material that fits this purpose is steelmaking slag which is a byproduct of steel production. Steelmaking slag is a sustainable and innovative material for road construction and Turkey has the potential of 5,5 million tons per year. Apparently, technical and legal aspects should be tailored to fit current legislation in order to use this innovative material in road construction. Within this scope, a research project titled "Utilization of steel slag in highway construction, its performance and regulation proposal" has been conducted with the General Directorate of Highways in Turkey. This study aims to summarize the research process with a focus on faced drivers and barriers to adopt such an innovative material for highway construction in the context of project management as a case study.

Keywords: *aggregate, construction industry, drivers and barriers, highway construction, innovation, legislation sustainability.*

Introduction

Resource consumption has gained a new momentum in our era by the effect of rising needs, parallel to population growth and technological advances. In this period with the effects of disasters mankind have understood that our resources are not unlimited, and posterity have the right to live. In this context recycling approaches have been adopted. With the beginning of

21st century, sustainability has been an irreplaceable condition of production. Energy and raw materials consumption have started to decrease day by day with the researches about sustainability. Alongside conventional recycling approaches, recycling of composite products has been provided. In addition to these, waste of an industry has started to be evaluated as the raw material of another industry. In line with these developments, to reduce the environmental impact of raw material production and consumption of natural resources in Turkey, alternatives should be taken into consideration as have been in many developed countries. Accordingly, steel industry attracts attention with developments in recent years.

Turkey is the 8th biggest steel producer in the world and 75% of annual steel production is obtained from electric arc furnaces. However just 1% of steel slag occurred from total steel production is used for manufacturing interlocking paving stones. Other high-volume areas of utilization should be specified to reduce the environmental impact. In this context construction industry attracts attention as the highest consumer of raw materials and leader sector in Turkey.

Steel slag has been removed from waste category and accepted as a by-product in developed countries. It is used as an artificial aggregate in many countries especially in highway construction. International researches about the utilization of steel slag in highway construction are given in Literature chapter. Moreover national academic studies conducted though involve a limited number of samples which is also given in Literature chapter. Based on international examples a research project titled "Utilization of steel slag in highway construction, its performance and regulation proposal" has been conducted with the General Directorate of Highways (GDH) in Turkey to define the utilization probabilities, performance of steel slag as an artificial aggregate in flexible highway superstructure and its regulations.

Literature

Steel slags, including EAF, have mostly been used in surface layers of road pavements, in order to exploit their high resistance to polishing (Fontini, 2009; Huang et al., 2007) a property that allows the necessary roughness characteristics of the road surface to be maintained for longer and therefore guarantee the skid resistance that is indispensable for road safety (Pasetto & Baldo, 2010).

Based on high level of strength, high binder adhesion as well as high frictional and abrasion resistance, steel slag can be used as an aggregate not only in surface layers of the pavement but also in unbound bases and subbases, especially in asphaltic surface layers (Motz & Geiseler, 2001). Approximately 60% of slag is used for road engineering in Japan and European countries, and even 98% of that is utilized as aggregates of cement and bituminous pavement in UK. More than 25 years ago in Germany, test roads were built using steel slag as an aggregate for unbound and bituminous bound mixtures (Motz & Geiseler, 2001). Ahmedzade and Şengöz (2009) investigated the influences of the utilization of steel slag as a coarse aggregate on the properties of hot mix asphalt. The results showed that steel slag used as a coarse aggregate improved the mechanical properties of asphalt mixtures. Moreover, volume resistivity values demonstrated that the electrical conductivity of steel slag asphalt mixtures were better than that of limestone asphalt mixtures. Asi (2007) observed that asphalt concrete mixes containing 30% steel slag had the highest skid number followed by Superpave, SMA (Stone Mastic Asphalt), and Marshall mixes, respectively. Ameri and Behnood (2012) evaluated the effectiveness of steel slag as a substitute for virgin aggregates on mechanical properties of cold mix recycling asphalt pavement. The results showed that the use of steel slag could enhance Marshall stability, resilient modulus, tensile strength, resistance to moisture damage and resistance to permanent deformation of CIR (Cold in Place Recycling) mixes.

Volume instability and heavy metal leaching are two considerable unsafe factors for steel slag using as aggregates in road and hydraulic engineering. In contact with water, free CaO and MgO in steel slag will react to hydroxides. Depending on the rate of free lime and/or free MgO this reaction causes a volume increase of the slag mostly combined with a disintegration of the slag pieces and a loss of strength (Motz & Geiseler, 2001). Therefore, the volume stability is a key criterion for using steel slags as a construction material. Immersion expansion ratio is used to evaluate the volume stability of steel slag in USA and Japan, while in Germany, steam test is taken to measure that of steel slag used for road construction and boiling test for hydraulic construction. In China, the national standard 'Steel slag Stability test Method' was published in 2009 with immersion expansion test as evaluation method. The immersion expansion ratio is limited to 2% for road construction according to the specifications of relative standards. In Germany, experience has found that steel slags with a free lime content up to 7% may be used in unbound layers and up to 4% in asphaltic layers (Motz & Geiseler, 2001).

The heavy metal leaching is mostly related to the stainless slag because it contains a higher amount of Cr and Ni than the ordinary. In Germany steel slag processed to aggregates for road construction and hydraulic structures must be analyzed by leaching tests twice a year. The concentration of Cr_{total} is limited to 3 mg/L (Motz & Geiseler, 2001). Zhang and Hong (2011) insisted that the pollution risks of the heavy metals in the stainless-steel slag were very low and could only treat as the common wastes, not the hazardous through the leaching test. Manso et al. (2006) also performed the leaching test of the concrete with EAF as aggregates and found that Cr_{total} concentration was under the maximum limits stipulated by local legislation (Yi et al., 2012). Furthermore, the leachate from steel slag has been investigated in several studies and compared to the standards of the country in which the slag was tested. The use of slag in environmental applications were found to not pose a hazard in most situations to the health of people or the ecology according to reviewed studies (Geiseler, 1996; NSA, 1998; Proctor et al., 2000; Proctor et al., 2002; Manso et al., 2006; Expoenent, 2007; Pellegrino & Gaddo, 2009; Sofilic et al., 2010).

Methodology

In this paper basic management issues of "Utilization of steel slag in highway construction, its performance and regulation proposal" university-public-nongovernmental organization project is analyzed. In following chapter, generation of research organization with important decisions are given in chronologic order. Origin, generation and main characteristics of steel slag are given in Materials chapter. Planned tests and aim of testing procedures are given in Test Period chapter. Obtained results and conclusions of these results are given in Test Results chapter. Drawbacks of the project are highlighted in these chapters. These drawbacks, emergent problems and solution proposals for all are defined in Problems and Proposed Solutions chapter. Lastly results and conclusions defined.

Research Organization

Çolakoğlu Metallurgy started a project to define the utilization probabilities of steel slag in November 2011 by TechnoBee Academic Firm. TechnoBee Academic Firm directed the investigation of technical properties of steel slag to Istanbul Technical University (ITU), Faculty of Civil Engineering. Conformity of steel slag is investigated according to Highway Technical Specifications 2006 by ITU Transportation Laboratory and according to TS EN 13242-1 by ITU Construction Materials Laboratory. According to sufficient results obtained from the tests, a research meeting conducted with the participation of GDH, Çolakoğlu Metallurgy, TechnoBee and ITU in 2012 to start a nation-wide study and format existing regulations.

In April 2012, research and development projects which are going to be supported by GDH declared to public. Project, with the name of "Utilization of electric arc furnace steel slag in highway construction, its performance and regulation proposal" proposed to GDH within the topic of "Recycling" which is declared between research and development projects. Project is presented to GDH in November 2012. Participation of Turkish Steel Producers Association (TSPA) has been advised to produce a national effect and the project is revised with the participation of TSPA. All the steel producer's contribution including integrated steel plants is enabled. Positive feedback is obtained from 20 steel producers nation-wide.

Project name is also revised as "Utilization of steel slag in highway construction, its performance and regulation proposal" and is signed on 8^{th} of April 2013. Official research period started. In the meantime, new highway specifications are presented to public with the name Highway Technical Specifications 2013. Çolakoğlu Metallurgy and TSPA financially supported the project. The project is also considered as a guide model that provides cooperation of university, industry and public to solve an industry problem. Especially participation of non-governmental organizations in such cases has an important role in terms of project's sustainability.

Materials

Steel slag is a byproduct from either the conversion of iron to steel in a basic oxygen furnace (BOF), or the melting of scrap to make steel in an electric arc furnace (EAF). In the BOF process, hot liquid metal from blast furnace, scrap, and fluxes, which consist of lime and dolomitic lime, are charged to a furnace. A lance is lowered into the converter and high-pressure oxygen is injected. The oxygen combines with and removes the impurities in the charge. These impurities consist of carbon as gaseous carbon monoxide, and silicon, manganese, phosphorus, and some iron as liquid oxides, which combine with lime and dolomitic lime to form the steel slag. At the end of the refining operation, the liquid steel is poured into a ladle while the steel slag is retained in the vessel and subsequently tapped into a separate slag pot (Shi, 2004).

Unlike the BOF process, the EAF does not use hot metal, but uses "cold" steel scraps, which would otherwise be unsightly and environmentally damaging. It can be charged with limited amounts of iron scrap, pig iron, and direct reduced iron. The EAF is a kettle-shaped structure with a removable lid. The three graphite electrodes that heat the furnace pass through the lid. An electric current is passed through the electrodes to form an arc. The heat generated by this arc melts the scrap. During the melting process, other metals are added to the steel to give it the required chemical composition. Also, oxygen is blown in to the EAF to purify the steel. After samples have been taken to check the chemical composition of the steel, the EAF is tilted to allow the slag, which is floating on the surface of the molten steel, to be poured off. The EAF is then tilted in the other direction and the molten steel poured into a ladle (Shi, 2004).

Most steel slags consist primarily of CaO, MgO, SiO_2, and FeO. In low-phosphorus steel-making practice, the total concentration of these oxides in liquid slags is in the range of 88–92%. Therefore, the steel slag can be simply represented by CaO–MgO–SiO_2– FeO quaternary system. However, the proportions of these oxides and the concentration of other minor components are highly variable and change from batch to batch even in one plant depending on raw materials, type of steel made, furnace conditions, etc. (Shi, 2004).

There are several methods for cooling molten steel slag: natural air cooling, water spray, water quenching, air quenching, and shallow box chilling. Natural air-cooled steel slag is cooled in air naturally after pouring into a pit or on the ground. It consists mainly of big lumps and some powder (Lea, 1974). In the water-spray cooling process, molten steel slag is poured into a pit and cooled in air. Water is sprayed onto the surface of the steel slag after molten steel slag is solidified so the solidified steel slag will break into pieces itself due to the temperature differences, which will make the slag handling and metal recovery much easier (Shi, 2004). However, this process causes the slag particles to become more porous. This situation may be basically explained as gases are trapped in slag when it cools down and generates micro to macro size cells. These cells absorb more water or binder which decreases the economic feasibility of porous aggregate. In Turkey, steel producers generally cool their slag with water spraying. First drawback of the project emerged from porous structure caused by water spray cooling method. Moreover, dolomitic limestone is obtained from Ömerli-Alyans quarry in Istanbul for comparison of chemical, physical, environmental and mechanic test results.

Volume instability of steel slag is defined in Literature chapter. The volume instability of steel slag is emerged as the second drawback of the project. There were no tests determined to measure volume expansion of aggregate in Turkey. Inherently there were no limits for volume expansion of aggregate. Besides applicability of expansion tests in Turkey should be taken into consideration.

The heavy metal leaching of steel slag is defined in Literature chapter. The heavy metal concentration of steel slag is emerged as the third drawback of the project. The project was the first nation-wide study and each specimen should prove that the heavy metal concentration is below national legislation limits.

Test Period

Firstly, components of steel slag and natural aggregate are investigated by X-Ray diffraction method. Main components of steel slag are accepted as total iron, MgO, SiO_2, MnO, total lime (CaO) and Al_2O_3 according to literature. These components are researched in both natural aggregate and steel slag.

To determine physical properties of samples, tests identified in Highway Technical Specifications 2013 are chosen. These tests include unit weight, water absorption, organic material content, Atterberg limits, methylene blue, clay lumps and friable particles, flakiness index, soundness of aggregates with sodium sulfate, resistance to degradation, polishing resistance, and stripping resistance. All tests are performed for both samples. Test results are compared with each other and Highway Technical Specifications 2013 limits. Chemical analyses are performed to determine metallic iron and free lime content of steel slag. These contents are accepted as critical compounds of slag because of oxidation and expansion probability. Oxidation of metallic iron may cause adhesion loss and free lime may cause expansion with hydration by the effect of water.

Ecological analysis of steel slag is investigated from eluate and original material according to national solid waste disposal specifications. Fluoride, sulfate, total dissolved material, dissolved organic carbon, chloride, copper, barium, mercury, nickel, antimony, arsenic, cadmium, total chrome, lead, selenium, molybdenum, zinc, pH, total organic carbon, loss of ignition, BTEX, mineral oil and derivatives and PCB parameters are researched.

Granular layers are examined according to Highway Technical Specifications 2013 granulometry limits. Steel slag is not accepted as a by-product in Turkey. Hence particle distribution differs according to facility's requirements. Therefore, ideal granulometry is used for each granular layer. There are two main types of granular layers in Highway Technical Specifications 2013: subbase and base. Subbase has two different types. Base has two subtypes as granular base and plant mix base which have three and two types, respectively. All granular layers are investigated in this project to determine their properties as well as to choose the worst sample for expansion test. Optimum water content, maximum dry density and California bearing ratios of all granular layers determined for steel slag and natural aggregate.

Sample with the highest maximum dry density is chosen for potential expansion of aggregates from hydration test for the worst scenario case. Test is performed according to ASTM D4792 standard. Four types of bituminous mixtures are produced. These are bituminous base, binder, wearing course and stone mastic asphalt. Mainly used types of these mixtures are produced. As specified above, ideal granulometry is used in mix designs. To decrease optimum bitumen content due to high water absorption, two approaches adopted. Firstly, mixing temperature is decreased to 145 – 150^{o} C range. Through binder would behave more viscous and isolate voids instead of filling them. Secondly experimental approach introduced. In experimental approach, maximum theoretical weight is measured instead of calculation.

Optimum binder contents are determined by both experimental approach in which maximum theoretical weight is measured and conventional approach in which maximum theoretical weight is calculated. Results obtained from both approaches are compared. According to comparison it is decided that the best results are obtained from experimental approach. However, according to experimental approach, design period in laboratory takes triple times longer than conventional approach.

Control mixtures are produced with optimum binder contents obtained from experimental approach. Results obtained from control mixtures are compared with projected data. According to comparison it is observed that the results were close. Performance test specimens are produced according to optimum binder contents obtained from experimental approach. Performance tests are started by Lottman tests for determination of resistance to water damage. Secondly rutting tests are performed according to Hamburg method. Lastly fatigue lives of samples are determined.

In third phase, test results are compared between each other and with the literature. Obtained test results beyond Highway Technical Specifications 2013 limits are criticized. Unit price, economical hauling distance and mixture costs of steel slag are calculated.

Before presentation of final report, test roads are constructed in two sites. These sites are selected according to different climates. 750 tons of steel slag is planned to haul. However steel producers were not able to screen fine particles and test roads' constructions are modified to obtain 50% of steel slag as coarse aggregate and 50% fine natural aggregate. First test road is constructed on northern part of Turkey close to Sakarya on D100 highway. Second test road is constructed on southern part of Turkey in Hatay, Arsuz. Skid resistance and displacement values are measured for 6 months on both highways. Results are presented to GDH.

Fourth drawback of the project emerged from the time-consuming experimental design approach. GDH generally expects a design or control period of hot mix asphalt no longer than five days. This five-day period informally accepted as a rule by all GDH regional directorates. To utilize the steel slag in present porous form, design duration should be extended.

Test Results

As mentioned in Materials chapter; cooling steel slag by water spray is a general process in steel producing facilities in Turkey. In this process, especially the surface of hot slag (1.100 – 1.500 °C) is immediately cooled. Gases are trapped inside the slag in this cooling process. Therefore, steel slag takes a porous structure. Maximum water absorption limit is specified as 2% in Highway Technical Specifications 2013. All samples' water absorption results were beyond this limit.

Besides friable particle values are obtained beyond the limits that specified in Highway Technical Specifications 2013. High friable particle content has determined to be originated from free lime. Free lime originates from purification process of scrap with lime in ladle. It is a small amount of total lime in steel slag and can be removed by weathering. Porous structure problem may be solved by different cooling processes. However, these processes need sizable investment and new infrastructure. Therefore, scope of this project based on the utilization of steel slag with its present physical properties and minimum investment.

According to test results, it is determined that steel slag samples were in inert and non-hazardous waste class. Generally, two parameters of the samples which are determined as non-hazardous waste were above the limits of inert waste class. These parameters were total dissolved material and nickel concentration. It is predicted that the total dissolved material amount is based on free lime content. Therefore, this problem may be solved by weathering. In weathering process, lime hydrates and becomes $Ca(OH)_2$. If the weathering process is long enough, with the effect of CO_2, $Ca(OH)_2$ becomes $CaCO_3$. $CaCO_3$ is a tough structure that have low solubility in water. Formation of $CaCO_3$ is called as armoring process. After armoring process, leaching of metals decreases.

There were no specified tests for expansion rate of aggregates in Turkey. Therefore, ASTM D4792 standard is selected via its applicability. A warm water bath in ITU Transportation Laboratory is modified and surcharge load determined in ASTM D4792 produced. USA states' transportation departments have specified the expansion limit of steel slag as %0,5. This limit is also adopted in project and equivalent limit for EN 1744 is determined as 3,5% according to EN 13242.

According to tests conducted to unbound granular layers; optimum water contents were high relatively to natural aggregate. Porous structure of steel slag increased the optimum water content. Maximum dry density values of steel slag mixes were high due to high metal oxide content of steel slag. Superior California Bearing Ratio (CBR) results are obtained from test.

Higher internal friction angle of steel slag increased the rigidity of unbound granular layers. Considering all the test results of unbound granular layer with respect to higher CBR values, higher optimum water content and maximum dry density values may be eliminated.

According to comparison of two hot mix asphalt design approaches, mentioned in Test Period chapter, best results are obtained from experimental approach. Performance test specimens are produced according to optimum binder contents obtained from experimental approach. Resistance to water damage of specimens were adequate and above the limits. Superior test results are obtained from rutting test and longer fatigue life is obtained from the samples with steel slag relative to the samples produced by natural aggregate.

Skid resistance results were good in test roads. However, displacement values were relatively higher than conventional pavement. This result was different from performance test results conducted in laboratory. Difference was a result of 50% natural aggregate utilization in test roads. Steel slag's density and internal friction angle is higher than natural aggregate consequently steel slag needs more bitumen. In test roads, higher bitumen content decreased the rigidity of pavement.

Fifth drawback of the project emerged from the adoption of experimental design approach. In which firstly mixing temperature should be decreased to 145 – 150^{o} C range and secondly maximum theoretical weight should be measured. These two facts need extra effort and care.

Sixth drawback of the project emerged from the relatively worse test results obtained from test roads. New test roads should be constructed with 100% steel slag and tests should be repeated. However this would take at least six more months and this duration should be added to project schedule.

Problems and Proposed Solutions

Steel slag was a relatively porous aggregate than natural ones. All the samples' water absorption values were beyond the limit specified in Highway Technical Specifications 2013. To decrease the absorption value different cooling processes could be applied. However, these processes need sizable investment and new infrastructure for steel producers. Therefore, utilization of steel slag as obtained from producer is aimed and specification of a new limit for steel slag aggregate is proposed.

Second drawback of the project was the volume instability of steel slag. There were no tests determined to measure volume expansion of aggregate in Turkey. ASTM D4792 standard is selected via its applicability. A warm water bath in ITU Transportation Laboratory is modified and surcharge load determined in ASTM D4792 produced. USA states' transportation departments have specified the expansion limit of steel slag as %0,5. This limit is also adopted in project and equivalent limit for EN 1744 is determined as 3,5% according to EN 13242. These limits are also proposed to GDH. Beyond the measurement of expansion ratio according to sustainability; steel slag should be used in highway construction. Therefore 6-month obligatory weathering period is proposed both to GDH and TSPA.

Third drawback of the project was the heavy metal concentration of steel slag. According to test results, it is determined that steel slag samples were in inert and non-hazardous waste class. In applications, the material used in construction should be inert. Thanks to the armoring process in weathering period, in this period steel slag was able to become inert. Therefore, 6-month obligatory weathering period which was proposed to decrease expansion rate, had also been a solution for leaching of heavy metals from steel slag.

Fourth and fifth drawbacks of the project emerged from the time-consuming and demanding experimental design approach. Adoption of experimental design approach is proposed in addition to this extension of design period for steel slag asphalt is proposed.

Sixth drawback of the project emerged from the relatively worse test results obtained from test roads. New test roads should be constructed with 100% steel slag and tests should be repeated. Second construction and test period would take at least six more months. Construction and new tests proposed to both GDH and TSPA as the financial supporter.

Results and Conclusions

Evaluation meetings for problems and proposed solutions are conducted in Ankara GDH Research and Development Department. All stakeholders contributed to the meetings. Decisions taken in these meetings are given below:

- Proposed new water absorption limit is evaluated separately for unbound granular and hot mix asphalt layers. Adoption of new water absorption value is specified as a tolerable alteration for aggregates that will be used for unbound granular layers. However it is indicated that for hot mix asphalt aggregates, consideration of design procedure and mix performance is required.
- ASTM D4792 and EN 1744 standards are adopted to measure the volume expansion of steel slag. Respectively %0,5 and %3,5 limits are accepted.
- To decrease the expansion rate of steel slag, 6-month obligatory weathering period is accepted both by GDH and TSPA as the producers' representative.
- After 6-month obligatory weathering period, heavy metal concentration of steel slag is considered as low risk and before hauling of the material form producer's stockyard to construction site, it is accepted that the environmental analysis must be repeated.
- Time-consuming experimental design approach is not approved by GDH despite sufficient test results. Long design period and adopting a new procedure accepted as a demanding challenge. Therefore new water absorption value for hot mix asphalt aggregates is not modified.
- Construction of new test roads and new tests are not accepted both by GDH and TSPA. Proposed schedule of project and financial support was over.

In conclusion, steel slag is defined as an artificial aggregate for unbound granular layers and legislation appendix is published. Sustainability is supported in Turkey's biggest two production sectors. However adoption of new procedures in the viewpoint of public institutions is challenging especially in construction sector. Main reason of this challenge may be accepted as the national construction policy for infrastructure works. Recently infrastructures are constructed by contractors generally under build-operate-transfer projects. This situation obligates public institutes to become more rigid in legislations and standards.

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Design Changes in Turkish Construction Industry: Investigation of Applied Competition Projects

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Abstract

Design changes in construction projects affect project performances negatively. Professionals should identify the underlying causes of the design changes to increase performance in construction projects. The purpose of this study is to identify the causes of design changes in the Turkish construction industry and examine the effects of these causes on project performance. The study includes three stages. First, a literature review study was conducted to understand the reasons for design changes and their effects on project performance. In the second stage, Architectural competitions in Turkey were listed. Eight winning and constructed projects were selected. Semi-structured interviews were conducted with the architects about design changes in these projects. In the fieldwork, ten factors causing design changes were identified. The most common factor in design change is errors and inconsistencies in the design. Finally, the literature review study and the field study were compared. In the preliminary literature review search, no recent study on the design change issues in the Turkish construction sector was found. Therefore, this study aims to contribute to the literature review with recent research.

Keywords: *architectural competitions, design changes, design error (flaw), rework.*

Introduction

Design changes make it more difficult to manage already complex construction processes (Love et al., 2000). Design changes are known as additions, omissions and corrections that occur in the terms of the contract in the working conditions of a construction project or in any of the design and construction phases after the contract is signed. Such changes relate not only to the terms of the contract, but also to changes that may arise in working conditions (Burati et al., 1992; Akinsola et al., 1997; Yap et al., 2017;Abdul-Rahman & Wang, 2017). Findings from literature review studies conducted in various parts of the world show that design changes significantly affect the time and cost performance of the construction project (Boon et al., 2018, 2019; Bower, 2000; Chang et al., 2011; Knotten et al., 2015; Love & Li, 2000; Park, 2003; Rahman et al., 2017; Sun & Meng, 2009; Yap & Skitmore, 2017). Many studies have been conducted to examine timeouts, cost overruns and rework due to design changes due to different project types, location of the design and population constraints (Boon et al., 2018, 2019; Bower, 2000; Chang et al., 2011; Knotten et al., 2015; Love & Li, 2000; Muhamad & Mohammad, 2018; Park, 2003; Rahman et al., 2017; Sun & Meng, 2009; Yap & Skitmore, 2017; Yap et al. 2017,; Burati et al., 1992; Love, 2002; Aslam et al., (2019). Rework due to design change causes delays and disruptions in the work flow during construction. When reprocessing increases, project cost and timing are likely to increase. This situation leads to increased demands and disputes. Therefore, it is necessary to understand the dynamics underlying the design changes that started working again. Thus, effective measures can be designed for design change management (Boon et al., 2018).There are many studies in the world that examine the causes of design changes and their effects on project performance and suggestions for solutions to these problems. However, the literature review survey in the construction sector in particular Turkey *"design changes"* the study of the concept has proved to be a small number.

The purpose of this study is to identify the causes of design changes in the Turkish construction industry. The effect of these reasons on project performance is to conduct research on design changes through national architectural competition projects that have been acquired and implemented. To bring solutions to these problems determined by making use of the literature review study in this context.

Literature Review: Design Change

Design changes are a major problem in the construction industry (Bibby, 2003). These changes usually occur at any stage of the project due to various causes from different sources (Abdul-Rahman & Wang, 2017; Motawa et al., 2007). Project managers are responsible for managing change effectively and planning in detail (Love et al., 2000). In order to effectively manage design changes and take necessary measures, it is necessary to understand the dynamics underlying design changes well (Boon et al., 2018). One of the reasons for project changes is the lack of timely and effective communication (Yap et al., (2018). Late approvals from customers, delayed appointments are situations that cause design change (Ballard & Koskela, 2014). Lack of interdisciplinary coordination in the building design process; it affects construction processes, design, and end product. Quality, manpower, materials used, program and cost are problems. (Doğan et al., 2015). Boon et al. (2019), the most important ten reasons for his design; lack of coordination between various professional disciplines, change of specifications, addition or neglect of functions, additional requirements, incorrect or inconsistent state regulations, design negligence, missing drawings, wrong or incomplete decision making, are listed in the design. Yap et al. (2017), stated the lack of coordination among various professional consultants, changing specifications /errors / inconsistencies in design documents and unforeseen ground conditions are the five most important reasons for design change. According to Yap and Skitmore (2017), the negative effects of design changes on project performance resulted in reprocessing, projects with longer project duration resulted in timeouts and cost overruns. A business or activity process is being redone due to faults or errors to design changes. This situation is defined as rework (Abdul-Rahman & Wang, 2017). Rahman et al. (2017), reprocessing caused by design change was expressed as an unnecessary effort to repeat an unnecessary work or activity process due to initial misapplication resulting from design changes. According to Palaneeswaran (2006), most of the rework cases are caused by changes, damages, defects, errors, negligence and other incompatibilities.

In his study Arditi et al. (1985), stated that the delays in construction projects caused the projects not to be completed on time, to wear out and rework. Kuroğlu et al. (2011) stated that, in a construction project, the project being out of the specified period affects the cost and therefore the quality of the product to emerge.

Kazaz et al. (2012) stated that deviating from a planned timeline is one of the most common problems in construction investments. Gündüz et al. (2014) emphasized that construction delays are common in the construction industry and cause concerns for project performance.

Güray (2004) stated that in his thesis study, changes occurring at any stage of building construction processes in the construction industry caused cost increases and rework.

Özgüneş (2016) in his study, proposes a decision support model to manage the project changes related to the changes in the design process in design-construction projects.

In their study, Arditi et al. (2017) stated that delay is one of the most common problems in the construction industry. Irfan et al. (2019) in their study, expand their knowledge area by measuring the impact of cross-stakeholder conflict on project constraints in the construction industry, which is missing in this research area.

An analysis of studies conducted in Turkey, of studies done on the subject of design changes in Turkey were found to be less. In Turkey, with world literature review also shows that there are similar problems. In the context of literature review studies in Turkey it was found to be in front of delays in the project.

Methodology

The study took place in three stages. In the first stage, a literature review study was conducted. The concept of design change, the causes of design changes and their effects on project performance are examined. In the second stage, as a field study, eight projects that received the first prize in the competition and were implemented were reached. The reasons for design changes are examined through these projects. In the third stage, the literature study and the field study were compared. As a field study, free participation national architectural competition projects organized under the title of *'make with competition'* organized by Arkitera Architecture Platform were examined (Annex A). Eight projects that were implemented by winning the first prize from the free participation competition projects between 2005 and 2015 were reached. Semi-structured interviews were held by contacting the architects of the projects. The interviews were held between 23.03.2019 - 15.04.2019. The interviews lasted between 120 and 150 minutes. Interviews and projects conducted are given in Table 1 below. Interview questions are shown in Table 2.

Table 1. Architect-project relationship interviewed.

	P01	P02	P03	P04	P05	P06	P07	P08
G01								
G02								
G03								
G04								
G05								
G06								
G07								
G08								

Table 2 Interview questions.

1	(Abdul-Rahman & Wang, 2017; Bibby, 2003; Boon et al., 2018; Durdyev et al., 2010; Hwang & Low, 2012; Kazaz et al., 2012; Knotten et al., 2017b; Motawa, 2007; Okada et al., 2017; Sun et al., 2006; Sun & Meng, 2009; Yap et al., 2018b; Yap & Skitmore, 2017)	We kindly ask you to evaluate the application process you experienced in the competition in terms of construction quality, cost and duration. - Has the building's quality been the architectural group's wish? - Has the cost remained as planned? -Is it able to be built in the specified time?
2	(Abdul-Rahman & Wang, 2017; Aslam et al., 2019; Boon et al., 2018; Du et al., 2019; Fan & Zhang, 2013; Love et al., 2000; Mohamad et al., 2012; Motawa et al., 2007; Muhamad & Mohammad, 2018; Okada et al., 2017; Sun et al., 2006; Yana et al., 2015; Yap et al., 2017; Yap & Skitmore, 2017)	Could the designed building and the applied building be exactly the same? If not, at what points were the changes and what were the reasons?
3	(Best, 2006; De Blois et al., 2011; Fan & Zhang, 2013; Ibrahim A. Motawa et al., 2006; Savolainen et al., 2018)	Who was the employer? Who was overseeing the project? If the employer supervised, what was the occupation of the person in the supervisory role in the supervising team? Did anyone in the audit team include the design group?
4	(Andersen et al., 2005; Aslam et al., 2019; Emmitt, 2010; Irfan et al., 2019; Koo et al., 2010; Okada et al., 2017)	Have there been interdisciplinary problems in the implementation process of the project? Were there any problems in the coordination of the teams?
5	(Çetinkaya, 2017; Czmoch & Pękala, 2014; Fan & Zhang, 2013; Kagioglou et al., 2000; Koo et al., 2010; Kopuz, 2015; Miettinen & Paavola, 2018; Muratoğlu, 2015; Savolainen et al., 2018; Serin, 2016)	Did you make use of the Building Information Modeling (BIM) system during the design and implementation phase of this project? If BIM systems were used, did other project stakeholders also use this system?

Field Study

Among the factors determined in the field study, the most causing factor in design change is errors / inconsistencies in design (material, detail, manufacturing error). Many of the materials and details written in the specification in P01 have not been applied. Fast production in P03 caused the details quality problems. This situation adversely affected the quality of the final product. There have been some changes in the materials and details related to manufacturing in P02, P04, and P05. Changes such as material changes, detail changes were made in P06 too. There were changes in materials and construction technologies in P07, P08.

There were many problems among stakeholders in the projects reviewed. In P01 and P02, there was no communication between the architectural group and the static team. In P03, there were problems with the mechanical and electrical team in coordination between the stakeholders. The two-headed management system in P01 and P08 caused coordination problems among stakeholders. P02, P03 and P08 projects, it caused business repetitions and time loss. The design process in the construction industry is a complex process in which many experts work together. Information transfer between stakeholders takes time. Each change causes positive progress or changes in the previous stages (Doğan et al., 2015). Lack of interdisciplinary coordination causes design changes (Ballard & Koskela, 2014). The lack of effective coordination among the disciplines in the building design process, not only the design, but also affects the construction processes and the final product, creating problems with the program, quality, manpower, materials used and cost (Doğan et al., 2015). Lack of communication between construction parties causes conflicts among stakeholders (Irfan et al., 2019).

In P01, P04 and P07, equivalent materials were used due to missing recipes in the technical specification stages. This situation caused the use of equivalent materials and deficiencies in the manufacturing details and negatively affected the quality of the final product. Competition specifications are prepared in the most ideal way possible in P08. However, in the specification, many parameters of P08 that actually exist are ignored. Therefore, regulations regarding the legislation / specification have been made. According to these regulations, changes were made regarding the capacity, program and fields of P08. Specification (requirement) change is one of the most important reasons for design changes (Cox et al., 1999; Love & Li, 2000; Chang et al., 2011; Mohamad et al., 2012; Hwang et al., 2014; Yana et al., 2015; Yap & Skitmore, 2017; Yap et al., 2018; Boon et al., 2019). Uncertainties in the specification affect the quality negatively (Irfan et al., 2019). Park (2003), reported that construction changes occurred differently from the original construction plan or the time and methods specified in the specification. Legislation / specification regulations are one of the factors underlying design changes that occur during production (Yap et al., 2018).

Adding / neglecting functions (program / planning / design plugins / negligence) are among the reasons for design changes frequently encountered in projects. The temporary exhibition space in the basement floor in P01 is not included in the competition project, but was later added to the building. Columns that are not at the design stage in P02 were added later due to static necessity. In the process after the competition in P05, the form of the parliament mass changed at the request of the municipality. There have also been changes in the program. In P08, just before the implementation phase, there were changes in its planning, the design of the building was reconstructed and new functions were added. In order to balance the quality-cost pair; compromised on material quality. Low quality of the material has also affected the end product quality. In P01, managing the project with two-headed management caused slow decisions. This situation caused delays in P01 and interruptions in the project from time to time. One of the most important reasons for design changes is making wrong or incomplete decisions (Boon et al., 2019). In order to make efficient profits, it is necessary to stick to the original plan, design, and be fast and determined (Andersen et al., 2005; Ballard & Koskela, 2014; Knotten et al., 2015).

Topographic errors caused by lack of information during design phase in P02 caused design change. Lack of information in contractors and employees in P07 caused problems in detail solutions. In P08, the lack of information has led to the change of the whole planning and the redesign of the project. Design changes; lack of information is related to cost and process (Ballard & Koskela, 2014).One of the reasons for the changes in the designs is the problems with the available information (Emmit, 2014). Repetitive jobs in the Turkish construction industry; It has been accepted as an indication of lack of information and cost calculations related to the subject (Güray, 2004).

In P01, the employer had changing demands, but since the institution that provided the budget is another institution than the employer, quick responses to the changing demands could not be given. This situation caused pauses in the project. In P04, there were some changes in the materials and details related to manufacturing in line with the demands of the architectural group. After the competition in P05, the form of the mass of the parliament was changed based on the requests from the municipal authorities. In P08, a new project design was made from the elements that are too simple to be required by the employer upon the demands of the employer. This has led to repetition and rework of jobs. One of the reasons for the changes in the design is the demands of the customer, the designer and the contractor (Emmit, 2014; Yap et al., 2018).The changes requested by the user are among the design changes during the project process (Okada et al., 2017). The inexperience of the mechanical team in P03 has caused a problem with rainwater in the project. In P04, the management's inexperience with respect to control; it caused coordination problems among stakeholders such as contractor, administration and control group.

Boon et al. (2019), one of the reasons for design change is inability to make the right decision (Boon et al., 2019). One of the factors underlying design changes during production is the competence of the project team (Yap et al., 2018). Labor quality and experience have an impact on projects (Gündüz et al., 2014). Inexperienced contractor (contractor), inadequate field management supervision, poor area management causes delays in projects (Gündüz et al., 2013). The findings from the field study coincide with the literature review. Due to unforeseen conditions in P03 and P06, changes such as material changes and detail changes were made by intervening at necessary points in the field. When there are unexpected changes, planning, organizing, motivating, managing and controlling construction is challenging and problematic (Love et al., 2000). Unexpected weather conditions, disagreements in technical features, difficulties in transportation, unexpected natural events (earthquakes, floods, etc.) and unexpected social events cause delays in design (Arditi et al., 1985).

Workmanship errors occurred in P07 and P08. This negatively affected the quality of the end product. Quality and workmanship are the factors underlying design changes during production (Yap et al., 2018). Labor quality and experience have an impact on projects (Gündüz et al., 2014). One of the other effects that affect the project performance of the design change; poor quality of workmanship (Hanna & Russell, 1999; Arain & Pheng, 2005; Hanna et al., 2005). According to the findings obtained from the field study; the four most important effects of design change on project performance are quality, process, cost and rework.

Design changes require business iterations and rework (Boon et al., 2019). The changes cause project delays and cost overruns (Abdul-Rahman & Wang, 2017). Other effects of design change that affect project performance; poor quality and workmanship (Hanna & Russell, 1999; Arain & Pheng, 2005; Hanna et al., 2005).

After the design phase has ended in P02 and P05, the static team has produced detailed solutions. This situation caused changes due to static necessity. Since disciplines are not working in cooperation with the architectural group in P03, problems occurred in interdisciplinary coordination and in manufacturing details. In P08, business repetitions occurred due to in-house no communication. The budget specified in the specifications in P08 and the budget required for the design overlap. This reasons; caused the designed building and the applied building to differ from each other. It was observed that the findings obtained in the field study coincided with the reasons of design changes in the literature review (Table3).

Table 3. Causes of design changes in the literature review.

	Regulations and missing definitions in the specification (equivalent material, lack of manufacturing detail)	Adding / neglecting functions (program / planning / design plugins / negligence) constantly changing demands	Errors / inconsistencies in design (material, detail, manufacturing error)	Lack of information at the design stage	Lack of coordination among stakeholders	Slow / incomplete decision making	Inexperienced teams / insufficient contractors / lack of expert staff	Unexpected conditions (unpredictable causes)	Workmanship
Boon et al. (2019)	✓	✓			✓	✓			
Yap et al. (2018).	✓				✓		✓		✓
Yap and Skitmore (2017)	✓	✓	✓	✓	✓	✓	✓	✓	
Yana et al. (2015)	✓	✓	✓	✓	✓	✓	✓	✓	
Hwang et al. (2014)	✓	✓				✓			
Emmit (2014).				✓		✓		✓	
Mohamad et al. (2012)	✓	✓	✓	✓	✓				
Chang et al. (2011)	✓	✓	✓		✓	✓	✓	✓	
Love and Li. (2000)	✓	✓	✓	✓					
Cox et al. (1999)	✓	✓						✓	

Conclusion

Research studies in the field of design changes within the scope of architectural design projects carried out with the competition in Turkey were examined. The most common factor in design change is design errors and inconsistencies (material, detail, manufacturing errors). Other factors identified are; arrangements and missing definitions in the specification (equivalent material, lack of manufacturing detail), adding / neglecting functions (add-ons to program and planning), slow decision making, ever-changing demands, lack of coordination between stakeholders, lack of knowledge at design stage, inexperienced teams / inadequate contractor / Lack of expert staff, unexpected conditions (unforeseen causes), and labor. It has been observed that these changes detected in the field study match the definitions in the literature review.

According to the findings obtained in the field study; workmanship factor is a reason for design change. However, the labor factor has not come to the fore in the literature review compared to other factors. In the field study, it was observed that the design change had the most important effects on the project performance. These; quality, time (process), cost and rework. Changes that occurred in the design or implementation phase of the project caused delays in the projects, and the delays caused rework and cost increases. Changes made in the project also affect the end product quality negatively.

These identified design problems are solved by evaluating information input from various sources. For this reason, successful cooperation should enable continuous exchange of information without creating any obstacles (Gray & Hughes, 2001).

Identifying design changes is the first step that needs to be taken to reduce changes. Various measures can be taken at many stages of the project to improve project performance. For example; measures taken at the planning stage, design stage, management and construction phases can eliminate design negligence, unforeseen situations, program changes, changes requested by the user.

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Annex A. Information of applied competition projects.

Project no	Project Year	Project Name	Project Type	Project Location	Competition Start-End Date	Construction Start-Finish Date	Design Team
P01	2005	Istanbul Naval Museum	Cultural Structure	İstanbul	2005-2005	2007-2013	**Hande Köksal (G01), Mehmet V. Kütükçüoğlu (G02),** H. Ertuğ Uçar
P02	2006	Trabzon Municipality Building	Public Structure	Trabzon	2006-2006	2007-2010	**Ozan Öztepe (G03),** Derya Ekim Öztepe
P03	2009	Kadirli Municipality Service Building And Cultural Center	Public Structure	Osmaniye	2009-2010	2012-2013	Deniz Dokgöz, Ferhat Hacıalibeyoğlu, **Orhan Ersan (G04),** Turgut Şakiroğlu
P04	2010	Bornova Municipality Yeşilova Mound Visitor Center	Cultural Structure	İzmir	2010-2010	2012-2014	**Evren Başbuğ (G05),** Umut Başbuğ Ramazan Avcı, Seden Cinasal Avcı
P05	2011	Adana Çukurova Municipality Service Building	Public Structure	Adana	2011-2011	2012-2013	Derya Ekim Öztepe, **Ozan Öztepe (G06)**
P06	2011	Troya Museum	Cultural Structure	Çanakkale	2011-2011	2013-2018	**Ömer Selçuk Baz (G07)**, Okan Bal, Cenk Kurtel, Mehmet Yılmaz Berrin Yavuz
P07	2013	Lüleburgaz Municipality Intercity Bus Terminal	Transporta-tion Structure	Lüleburgaz	2013-2013	2014-2015	Tunahan Koç, Barış Demir, **Sıddık Güvendi (G07),** Oya Eskin Güvendi, Gülşah Örs Demir
P08	2013	Borusan Joy Factory	Education Structure	Many cities	2013-	-	**Hakkı Can Özkan (G08),** Serdar Köroğlu

An Integrated Multi-Attribute-Decision-Making Approach for Wave Energy Site Selection: A Case Study

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Abstract

The selection of the right location for the installation of wave energy converters (WEC) is one of the crucial decisions to ensure the maximum utilization of wave power potential. However, it is a challenging task as there are various conflicting and compromising criteria that need to be considered simultaneously. This study proposes an integrated multi-attribute-decision-making (MADM) approach that can be a useful tool in selection of the right location for the installation of wave energy converters. The proposed model combines the use of the Decision Making Trial and Evaluation Laboratory (DEMATEL) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) methods. DEMATEL is employed to calculate the weights of the criteria, whereas TOPSIS is employed to rank the alternative sites for wave energy converter installation. A case study was carried out to illustrate how the integrated approach can be applied in a real-life problem. Face to face interviews were conducted with decision makers, who are expert in the selection of wave energy site, in order to identify the criteria that may affect the selection of wave energy site and obtain their evaluations on the alternatives according to the criteria. In the light of these interviews and an extensive review of the relevant literature, a total of 4 main criteria and 17 corresponding sub-criteria were determined. It is anticipated that, armed with such a tool, decision makers should be able to select the right location for the installation of wave energy converters effectively.

Keywords: *DEMATEL, MADM problem, site selection, TOPSIS, wave energy, WEC.*

Introduction

Humankind has always needed energy. Although the source, and use of energy has changed over time, the only constant is that the demand for energy is increasing day by day through population growth, industrialization, and technological advances (Chakraborty et al., 2019). While traditional fossil fuels (i.e., coal, oil and natural gas) account for more than 80% of the world's energy generation, they are also responsible for more than two-thirds of total greenhouse gas emissions and over 80% of CO_2 emissions (Shao et al., 2020). As a result, climate change becomes one of the major issues of the 21st century (Akar and Akdoğan, 2018). Increasing environmental concerns have led to the investigation of alternatives to renewable energy sources such as solar energy, wind energy, and wave energy, which have no or little damage to the environment (Kamranzad and Hadadpour, 2020; Shao et al., 2020).

Wave energy is considered as one of the most important renewable energy sources as it is more predictable, more stable, has a lower environmental effect and a higher energy density than other renewable sources (Carballo et al., 2014; Ghosh, 2018; Bertram et al. 2020). The world's wave power reserves are anticipated to be about 2 Terawatts (TW) (Ghosh, 2018), and the European wave energy industry was expected to have 26 Megawatt (MW) of installed capacity by the end of 2018 (Magagna and Uihlein, 2015). Wave power sources vary depending on the location where the wave energy converters are installed, since wave energy is generated using well-designed devices called "wave energy converters" (Chakraborty et al., 2019). Therefore, the selection of right location for the installation of wave energy converters is one of the crucial decisions to ensure the maximum utilization of wave power potential (Carballo et al., 2014). However, it is a difficult task since there are various conflicting and compromising criteria that need to be considered simultaneously. As a result, this selection problem should be regarded as a multi-attribute-decision-making (MADM) problem (Vasileiou et al., 2017; Shao et al., 2020).

The aim of this study is to propose an integrated decision approach that can be a useful tool in selection of the right location for the installation of wave energy converters. For this purpose, first, an extensive literature review was carried out, and face to face interviews were conducted with decision makers to identify the criteria that may affect the selection of wave energy site. After that, an integrated approach was proposed to assist companies interested in wave energy in selecting the right location for the installation of wave energy converters. The proposed approach combines the use of the DEMATEL and TOPSIS methods. DEMATEL is used to calculate the weights of the criteria, while TOPSIS is used to rank the alternative sites for wave energy converter installation. To illustrate how the proposed approach can be applied in a real-life problem, a case study was carried out. The results of this study indicated that the integrated approach can be used as a useful tool in selection of the most suitable wave energy site.

The Proposed Approach

The proposed approach consists of twelve steps, which can be classified into two main phases. In the first phase, the wave energy site selection problem is defined. Then, the decision-making group responsible for the wave energy site selection process is organized. This group identifies the main and sub-criteria that may influence the selection of the wave energy site and develops the hierarchy of the problem. Third, the decision-making group forms direct-influence matrices of the problem. In the final step of the first phase, the weights of the main and sub-criteria of the problem are calculated using the DEMATEL method.

In the second phase, first, the decision matrix, which consists of the evaluations of the decision-making group members on alternative sites for wave energy converter installation, is developed. Then, the items of the decision matrix are normalized, and the weighted normalized decision matrix is generated. Third, positive and negative ideal solutions are determined for each criterion. After that, the distances of each alternative to the positive and negative ideal solution are calculated. Finally, the alternatives for wave energy site are ranked in descending order based on their relative closeness to the ideal solution.

The DEMATEL method, based on pair-wise comparison of various decision-making variables, was developed between 1972 and 1976 by the Science and Human Affairs Program of the Battelle Memorial Institute of the Geneva Research Center to solve complicated and interrelated problems (Gabus and Fontela, 1972; Lin and Tzeng, 2009). The method is a structural modeling technique based on the assumption that the variables depend on each other (Shieh et al., 2010).

In this method, as an important advantage compared to conventional decision-making or ranking algorithms, the interactions between different variables are compared in order to understand the degree of influence between them (Chakraborty et al., 2018). Furthermore, the method helps managers and decision makers visually resolve decision-making problems and categorize variables into cause and effect groups to explain the causal relationships between them via a casual diagram (Jalal and Shoar, 2017). While the criteria that have a greater impact on other criteria are called “cause criteria”, the criteria that are more influenced by other criteria are called “effect criteria” (Sheng-Li et al., 2018). The DEMATEL method has been applied by many researchers in a variety of fields such as marketing strategies, water resources and environment in the literature (Wang and Tzeng, 2012). The calculation steps of the DEMATEL method are explained briefly below (Chakraborty et al., 2018):

Step 1: Generation of the direct-relation matrix (A) using a scale of 0 to 4 (see Table 1).
Step 2: Normalization of the direct-relation matrix (X).
Step 3: Derivation of the total influence matrix (T).
Step 4: Determination of the threshold value (a).
Step 5: Development of the causal diagram.

Table 1. The linguistic scale.

Linguistic Terms	Influence Score
No influence	0
Very low influence	1
Low influence	2
High influence	3
Very high influence	4

The TOPSIS method, one of the most widely used multi-attribute decision-making methods, was developed in 1981 by Hwang and Yoon. The basic principle of the method is that the most appropriate alternative is the one with the shortest Euclidean distance to the positive ideal solution (PIS), and the longest Euclidean distance to the negative ideal solution (NIS) (Tan et al., 2010). PIS is a solution that includes the maximum values of the alternatives for the beneficial criteria, while the minimum values of the alternatives for the cost criteria. On the other hand, NIS is a solution that involves the maximum values of the alternatives for the cost criteria, whereas the minimum values of the alternatives for the beneficial criteria (Dandage et al., 2018). The method has been used in numerous fields by many researchers in the literature, as it does not contain complex mathematical algorithms (Taylan et al., 2014; Polat et al., 2019). The calculation steps of the method are explained briefly below (Kannan et al., 2009):

Step 1: Construction of the initial decision matrix X with n number of alternatives ($n=1,...,i$) and m number of criteria ($m=1, ..., j$).
Step 2: Normalization of the decision matrix items.
Step 3: Formation of the weighted normalization matrix.
Step 4: Determination of PIS (A^+) and NIS (A^-).
Step 5: Calculation of the separation (S_i^+, S_i^-) of each alternative from the PIS and NIS.
Step 6: Computation of the relative closeness (C_i) of each alternative to the ideal solution.
Step 7: Ranking alternatives sorting by C_i values in descending order.

It should be re-noted that in this study, DEMATEL and TOPSIS methods are used as complementary methods to form an integrated MADM approach.

Case Study: Wave Energy Site Selection Using the Proposed Approach

A case study was conducted in order to illustrate how the proposed approach can be used in a real-life problem. Turkey has high wave energy potential due to its geographical location, and also the Black Sea has the highest wave energy potential in Turkey (Akar and Akdoğan, 2018). Therefore, the case study focused on the selection problem of the most appropriate alternative from the two different wave energy sites determined in the Black Sea. The decision model was developed on the basis of the literature review as well as opinions and evaluations of the decision makers, who are experts in the wave energy site selection process.

After conducting interviews with decision makers and carrying out a comprehensive literature review, four main criteria have been identified, which include: locational aspects factors (*LF*), efficiency of the wave energy converter factors (*EF*), cost factors (*CF*), and environmental aspects factors (*EA*). Nine sub-criteria under the main criterion *LF* are: incident wave power (LF_1), incident significant wave height (LF_2), incident wave period (LF_3), water depth (LF_4), maritime transportation density (LF_5), extreme wave height (LF_6), time variation of incident wave power (LF_7), shape parameter of incident wave spectrum (LF_8), and currents (LF_9). Four sub-criteria under the main criterion *CF* include: material cost (CF_1), installation cost (CF_2), operation and maintenance costs (CF_3), and accessibility (CF_4). Three sub-criteria under the main criterion *EA* are: water quality (EA_1), endemic species (i.e., fauna and flora) (EA_2), and migration routes (EA_3). There are two different site alternatives from the Black Sea for the wave energy, which are: (1) Kefken - *41.25°N, 30.20°E* (A_1), and (2) Karaburun - *41.50°N, 28.70°E* (A_2). The decision hierarchy of the wave energy site selection problem is presented in Figure 1.

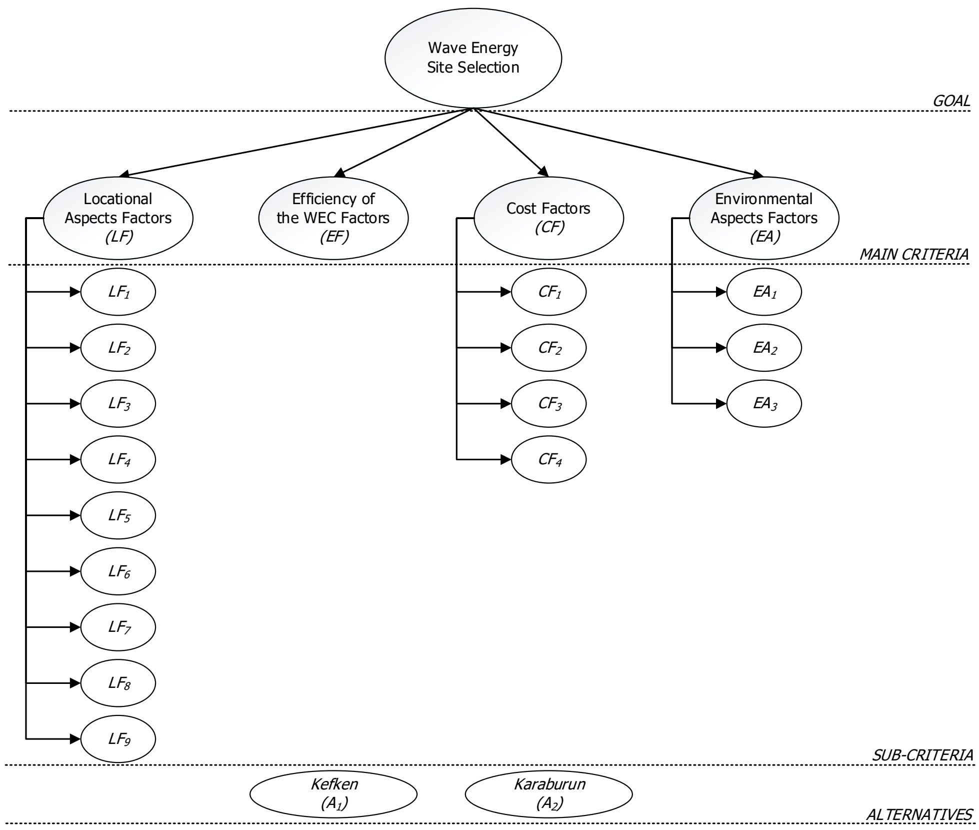

Figure 1: Decision hierarchy of the wave energy site selection problem.

After the development of the decision hierarchy of the wave energy site selection problem, the DEMATEL method is utilized to calculate the weights of the identified main and sub-criteria. For this purpose, three decision makers were asked individually to form pairwise comparison matrices for the main and sub-criteria of the problem. In order to make a group decision, three pairwise comparison matrices were aggregated using the arithmetic means of each preference. Finally, mathematical calculations of the DEMATEL method were implemented to determine the weights of the criteria of the problem. The weights of the criteria of the wave energy site selection problem are presented in Table 2.

Table 2. Aggregated pairwise matrix of criteria for the wave energy site selection problem.

C*	LF_1	LF_2	LF_3	LF_4	LF_5	LF_6	LF_7	LF_8	LF_9	EF	CF_1	CF_2	CF_3	CF_4	EA_1	EA_2	EA_3	W*
LF_1	0.00	1.67	1.67	1.00	0.67	2.00	2.67	2.00	1.67	2.67	3.00	1.00	3.00	1.33	1.67	1.00	1.00	0.083
LF_2	4.00	0.00	2.67	1.00	1.33	3.00	1.00	0.67	0.33	3.33	3.33	3.33	3.33	3.67	2.00	1.33	1.67	0.072
LF_3	3.33	3.00	0.00	0.67	0.67	3.00	1.00	3.00	0.33	3.33	3.00	2.33	2.00	2.00	1.33	0.67	1.00	0.072
LF_4	2.33	2.00	0.33	0.00	2.67	2.00	1.67	2.67	1.67	2.33	3.00	3.33	2.67	3.00	2.00	2.00	1.67	0.071
LF_5	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.67	0.67	1.00	2.00	2.00	3.00	2.67	2.00	2.33	0.070
LF_6	0.67	1.67	1.33	0.00	2.00	0.00	2.00	1.67	0.00	1.67	3.67	2.67	4.00	3.00	0.67	1.33	0.67	0.068
LF_7	0.00	0.00	0.00	0.00	0.33	1.67	0.00	0.33	0.67	3.67	2.67	2.67	2.67	3.00	1.33	1.33	1.33	0.065
LF_8	2.00	1.67	3.00	0.67	1.33	2.00	1.67	0.00	0.33	3.67	1.67	1.67	2.00	2.00	1.00	0.67	0.33	0.064
LF_9	1.00	1.33	1.33	0.33	2.33	1.67	1.00	1.33	0.00	2.00	2.00	3.00	2.33	2.33	2.67	2.00	1.67	0.059
EF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.67	1.33	3.33	1.00	0.00	0.00	0.00	0.056
CF_1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.33	0.00	2.67	3.00	0.67	1.00	0.67	0.67	0.055
CF_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67	2.00	0.00	2.00	2.00	1.00	0.67	0.67	0.054
CF_3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.67	2.33	2.67	0.00	2.00	1.00	1.00	2.00	0.045
CF_4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	2.33	3.67	4.00	0.00	0.67	1.00	1.00	0.044
EA_1	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	1.33	1.00	0.67	1.67	1.00	0.00	3.33	2.67	0.043
EA_2	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	1.33	1.33	1.00	1.33	1.33	1.67	0.00	1.67	0.040
EA_3	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	1.00	0.67	1.67	1.00	1.33	1.00	2.67	0.00	0.037

C: Criterion, W*: Weight*

Based on the findings, the "CF_3 - operation and maintenance costs" has the highest weight among all criteria. It is followed by the "CF_2 - installation cost" and "CF_1 - material cost" with the second higher weight. On the other hand, the "LF_5 - maritime transportation density" is of the least importance to the selection process because it has the lowest weight.

After the calculation of the weights of the criteria of the wave energy site selection problem, the TOPSIS method was used to determine the ranking of two wave energy site alternatives. The first step of the TOPSIS method is to construct the decision matrix when the DEMATEL calculations are over. For this purpose, the decision matrix was first formed with the decision makers. Whereas EA_1 and EA_3 are qualitative, the remaining criteria are quantitative. EA_1 was measured on a scale of 1 to 5 (i.e., 1: Very Bad; 5: Very Good), while EA_3 was measured on a scale of 0 to 1.5 (i.e., 0: not on the migration route, 0.5: only on the migration route of birds of prey, 1: only on the migration route of marine animals; 1.5: on the migration route of both). The data for the LF_2, LF_3, LF_4, LF_6, LF_7, and LF_8 criteria were obtained from an extensive metocean modelling study of Turkish seas titled "Wind and Deep Water Wave Atlas of the Turkish Coast" by Özhan and Abdalla (2002). LF_7 was evaluated as the standard deviation of monthly incident significant wave heights observed in the specified region for one year. LF_8 was assessed from the wave height-wave period scatter diagrams, by taking the reciprocal of the difference between the maximum and minimum periods (*ΔT*) corresponding to the incident significant wave height. The online admiralty (navigation) chart application "Navionics" was utilized to obtain data on the LF_4, LF_5, and CF_4 criteria. LF_5 was calculated using Eq. 1. CF_4 was assessed as the closest distance to the coast from the specified alternative location. While EA_3 was measured using Eq. 2, LF_1 was computed using Eq. 3 (Chakraborty et al., 2019).

$$P_{LF_5} = \sum_{i=1}^{N} \frac{1}{d_i} \tag{1}$$

where d_i = the distance of any maritime facility i, which may cause potential interference (e.g., marine farm, maritime transportation network, anchorage area, military exercise area) to the point where the wave energy converter will be installed, and N = the total number of facilities ($i=1,2,\dots,N$) within a 10 km radius of the specified point.

$$P_{EA_3} = (a+b)\times 0.2 + c\times 1 + d\times 0.6 \tag{2}$$

where a = the number of plant species unique to the region in question, b = the number of animal species unique to the region in question, c = the number of marine species unique to the region in question, and d = the number of amphibian species unique to the region in question.

$$P_w = \left(\frac{\rho\times g^2}{64\pi}\right)\times T_p \times H_s^2 \tag{3}$$

where P_w = average wave power, H_s = incident significant wave height, T_p = peak period, ρ = density of water, and g = gravitational acceleration.

In this selection problem, LF_5, LF_6, LF_7, LF_9, CF_1, CF_2, CF_3, CF_4, EA_1, EA_2, and EA_3 are cost criteria where lower values are desirable. The rest of them are beneficial criteria where higher values are preferable. As a result, LF_5, LF_6, LF_7, LF_9, CF_1, CF_2, CF_3, CF_4, EA_1, EA_2 and EA_3 are minimized, and the rest are maximized. The initial decision matrix of evaluation criteria for the two wave energy site alternatives is presented in Table 3.

Table 3. Initial decision matrix of evaluation criteria for two wave energy site alternatives.

Criterion	Measurement Unit	A_1 (Kefken)	A_2 (Karaburun)	Weight	Optimum Direction
LF_1	kW	3,198.69	4,140.54	0.083	↑
LF_2	m	3.05	3.42	0.072	↑
LF_3	s	7.00	7.20	0.072	↑
LF_4	m	20.00	20.00	0.071	↓
LF_5	point	1.00	0.17	0.070	↓
LF_6	m	9.20	6.40	0.068	↓
LF_7	m	0.84	1.01	0.065	↓
LF_8	s	0.28	0.33	0.064	↑
LF_9	cm/s	10.00	10.00	0.059	↓
EF	%	70.00	70.00	0.056	↑
CF_1	$	3,882,403	4,696,916	0.055	↓
CF_2	$	685,130	828,867	0.054	↓
CF_3	$/year	280,204.91	362,711.51	0.045	↓
CF_4	km	1.40	0.60	0.044	↓
EA_1	1-5 scale	4	3	0.043	↓
EA_2	point	30.00	15.00	0.040	↓
EA_3	0-1.5 scale	1.00	1.50	0.037	↓

The calculation steps of the TOPSIS method were applied after the decision matrix was formed. First, the items of the decision matrix were normalized. Then, the weighted normalized decision matrix was developed. Third, the positive and negative ideal solutions were identified. After that, the separation of each alternative from the positive and negative ideal solution was calculated, respectively. Finally, the relative closeness (C_i) of each alternative to the ideal solution was computed and the alternatives were ranked by C_i values in decreasing order. The results of the TOPSIS method are presented in Table 4.

Table 4. The result matrix of TOPSIS method.

Alternatives	S_i^+	S_i^-	C_i	Ranking
A_1 (Kefken)	0.054	0.024	0.307	2
A_2 (Karaburun)	0.024	0.054	0.693	1

The final ranking of the wave energy site alternatives was determined with the TOPSIS method as $A_2 > A_1$. Based on the ranking results, A_2 (Karaburun) is the best alternative with maximum C_i value. The findings of this study demonstrated that while A_1 (Kefken) becomes the most appropriate alternative if only CF_1, CF_2 and CF_3 criteria for the selection of wave energy converter sites are taken into account, and A_2 (Karaburun) is the most appropriate alternative if all criteria are taken into account.

Conclusion

Wave energy plays an important role in the generation of renewable energy in coastal regions. Wave power sources vary depending on the location where the wave energy converters are installed. Therefore, the selection of right location for the installation of wave energy converters is one of the crucial decisions to ensure the maximum utilization of wave power potential. However, it is a challenging and time-consuming task as there are different conflicting and compromising criteria that need to be considered simultaneously. In this paper, an integrated approach, based on DEMATEL and TOPSIS methods, is proposed. In order to illustrate how the integrated approach can be applied in a real-life problem, a case study was carried out. In the case study, a total of 4 main criteria and 17 corresponding sub-criteria were determined. The weights of these main and sub-criteria were determined with the DEMATEL method. Then the final ranking of the wave energy site alternatives was determined with the TOPSIS method. The results of this study were discussed with decision makers in order to verify the reliability of the proposed approach and its usability in companies interested in wave energy. They stated that the proposed approach can be applied to future wave energy site selection problems in order to make more rational, reasonable, and unbiased decisions. In future studies, (1) different MADM methods such as Analytic Hierarchy Process (AHP) may be employed to determine the weights of the criteria, (2) the decision hierarchy may be re-developed by adding different main or sub-criteria, (3) other MADM methods such as Evaluation Based on Distance from Average Solution (EDAS) may be employed to rank the alternatives, and (4) the obtained results may be compared.

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BIMServerless: A Serverless Development Architecture and Digital Service Model for BIM

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Abstract

Various cloud-based BIM solutions and services are currently available to the construction industry. These solutions involve one or a combination of digital services. Construction professionals who use these systems sometimes face major challenges such as scalability, robustness, and latency for many resource-intensive tasks in large BIM files. These technical issues, as well as subscription fees and/or the cost of licensing of commercial solutions play an important role in a company's digital investment strategy. In addition, the existing solutions provide several functionalities, but many of the functionalities provided are neither needed nor recognized by users. This paper presents the BIMServerless research which investigates the above-mentioned technical, cost/benefit, and usability-related issues in existing cloud-based solutions and proposes a new cloud architecture pattern that makes use of microservices and a serverless architecture for BIM with "Function-as-a-Service" (FaaS) approach that allows end-users to run, manage and compile application functionalities granularly without the cost and limitations of an entire digital service. This research draws a picture of the usability and practices demanded by users of BIM solutions and presents a new computational/development architecture for the next generation of digital offerings for use in the construction industry. It is expected that this research will open further discussions and stimulate interest in BIMserverless as an alternative digital service for the construction industry.

Keywords: *building information modeling, serverless, microservices, function as a service, FaaS.*

Introduction

In today's digitalization solutions, service and resource orientation are widely used for supporting collaboration over distributed environments. In this context, a web service can be defined as a component of a software or an interface designed to support machine-to-machine

(M2M) and/or machine-to-human (M2H) interactions over the Internet. A service-oriented architecture is composed of a set of interacting components which can be invoked, and whose interface descriptions can be published and discovered (MacKenzie et al., 2006). The developments in internet and software technologies has led to the emergence of service-oriented architectures that make it possible for distant applications to inter-operate by making use of their standard web interfaces. The service orientation and the corresponding service/software development frameworks allow a loose coupling of applications over the web, which means several applications can communicate and interact with each other; as well, their components/functions are shared between the applications. Each of these applications (or software components) which take part in such a web interaction is known as a web service.

Building Information Modeling (BIM) has been used in the construction industry for quite some time now. In parallel, a variety of cloud-based digital solutions for BIM have emerged with one, or a combination of multiple digital services (Li et al., 2019). These solutions must often deal with full-size model loading, integration, viewing and data synchronization of large BIM files, which involve resource intensive tasks, requiring large amounts computing and network infrastructure resources. However, most of the time, the performance of these products fails during processing, rendering, querying, or synchronization of large BIM models due to the static design of cloud and network infrastructures (Zibion et al., 2018). Managing these digital infrastructures against rapidly changing data and user requests is a challenging task, requiring extra human and computing resource, and corresponding operational costs.

Besides the technical issues, the high cost of licensing and/or subscription fees for digital services are important factors for a company's digital investment strategy. Despite the variety of such solutions and services, there are certain functionalities needed and utilized for specific phases and/or tasks of the project lifecycle while most of the other functionalities are neither needed nor recognized by the end users. Considering the multi-disciplinary and fragmented nature of AEC-FM industry, this situation ends up either with utilizing multiple digital services which aggregates further the fragmentation problem; or acquiring a more comprehensive solution which does not meet every custom requirement of a lifecycle phase. Therefore, the cost-to-benefit ratio of such digital investments becomes a critical question for an organization (Hong et al., 2019).

Parallel to the developments in the cloud-BIM era, in recent years, the term "serverless computing" has gained momentum. The most prominent implementation of serverless computing is "Function as a Service (FaaS)" offerings. In the context of end user experience, the FaaS approach allows end-users to run, manage and compile application functionalities granularly without the cost and limitations of an entire digital service. From a software developer's perspective, when using the FaaS approach, developers provide the source code of relatively granular functions with a care-free operation effort for servers. The cloud service provider then, on-demand, executes the functions as isolated instances; scales the execution infrastructure dynamically as needed; and bills functions with a pay-as-you-go pricing model (Fox et al., 2017).

This paper presents a research about BIMServerless which aims to achieve the above-mentioned scalability, robustness and cost-to benefit objectives by using the "serverless" computing paradigm. The overall target of this paper is to propose the FaaS concept for the digitalization ecosystem of the AEC-FM industry, and to promote it not only as the backbone of a technological solution, but also as a new business model. This paper also experiments with FaaS as a proof of concept for BIM implementation.

Background

BIM in Cloud and Service Models

Most cloud-based BIM solutions have been built on two distinct approaches. Either the model designed in the BIM modeling application is transferred, processed, and hosted on the cloud; or the model is presented to the user on a standalone BIM (desktop) application which is virtualized on the cloud (Li et al., 2019).

In the former approach to cloud BIM, there are products such as BIMx that are installed and used on a computer. BIMx has functionalities that can enable the sharing of the BIM model on the cloud by uploading the model through a web browser. The BIM model and its files can be viewed through a web browser or through a mobile application. In addition, BIMx applications such as 3D Repo BIM (Fan et al., 2017), Onuma and Davis (2006), VisuaLynk (Yalcinkaya & Singh, 2019a, 2019b) , etc. provide built-in functionalities for specific phases/activities of the construction lifecycle such as design review, asset management, lifecycle data aggregation and management, etc. BIMServer.org (Beetz et al., 2010), IfcWebServer (Ismail et al., 2018), EDM Model Server (Bengtsson, 2005), etc. are open source alternatives that provide data models and viewers for BIM-based models using the Industry Foundation Classes (IFC) standard. They enable users to transform any computer or cloud resource into a BIM server such that the files located in the server will be accessible through a web browser. They mainly intend to transform a computational resource into a file sharing server but with the ability to analyze IFC data and files. They can be installed on a computer with an executable file; or they can be set up as the backbone of a digital service with application programming interface (API) layers. API defines interactions between multiple software intermediaries including the kinds of calls or requests that can be made, how to make them, the data formats that should be used, the conventions to follow, etc. For example, BIM Service interface exchange (BIMsie) (van Berlo, 2015) is the open source effort for the standardization of APIs for BIM web services. It highlights the fact that web-based BIM services develop their own APIs that are different from other application APIs and therefore, many custom interfaces are required to connect BIM applications.

The latter approach to cloud BIM involves the virtualization of the BIM software as a whole. Companies such as Autodesk have developed a whole platform for BIM on the cloud. Their products such as Autodesk 360 and Autodesk Forge combine cloud technologies, BIM and other applications such as project lifecycle management applications. Users have the option of installing the BIM software on their computer or using it through a web browser as a virtualized software platform. Similar to Autodesk products, the Graphisoft BIMcloud (formerly known as BIM Server) is a fully-fledged cloud-based platform solution and provides functionalities (mostly compatible with other Graphisoft products) to visualize, process, and extract BIM models. In addition, Tekla Structures is a standalone product of Trimble and is marketed as a platform on the cloud.

Function as a Service (FaaS) Model

The FaaS model, also mostly known as the backbone of “serverless” computing, is widely known as an event-driven cloud execution model. Individual functions typically describe tiny parts of a larger application. For example, rather than containing a complete web application with an API interface, a single function may only implement one endpoint of such an interface. Functions are expected to execute in a limited amount of time, i.e., a few seconds at most. When this threshold is exceeded, the executions may be automatically retried. Hence, it is important that the logic of the functions be implemented in an idempotent (i.e., making multiple identical requests has the same effect as making a single request) and granular manner (Hummer et al., 2013). Functions can receive input data, which may be required by or may influence the execution of the function. In addition, function executions may result in additional data being produced, such as logs or execution metrics. Function executions are triggered by computational events, which can be diverse in nature. For example, client requests, events produced by other functions of the same application or external systems, data streams, or even complex rules describing a combination of the above can all be configured to trigger a function (Baldini et al., 2017).

Although the benefits of serverless computing and FaaS can be many, they can be summarized from application developers' and end users' perspectives. For any IT project, architecting, provisioning, and maintaining any cloud infrastructure can be huge and resource-intensive steps. In serverless computing, developers have no insights into how their code is being provisioned but assume that enough resources are provided to deal with any workload the service experiences.

FaaS Providers and Developer Tools

All major cloud providers offer FaaS infrastructures. Offerings include AWS Lambda, IBM Cloud Functions, Azure Function, etc. Typically, these FaaS infrastructures provide integrations with other cloud services such as APIs to monitor and assign bills to functions, authorization, and authentication services, etc. Furthermore, there are also open source FaaS offerings such as OpenFaas or Fission (Kaewkasi, 2018). Usually these offerings come with built-in resources for further integrations. These resources are typically billed using a pay-as-you-go pricing model, such as payment per number of function executions, execution times, used memory, etc. Costs generally depend directly on usage, and an idle function which is not invoked usually incurs no cost. Therefore, compared with many monolithic cloud architectures, these systems are quite cost-effective since a server should be up and running in monolithic architecture no matter what the amount of workload and the active users of the service are (Wu et al., 2019). Therefore, the BIMServerless approach for the AEC-FM industry aims to provide a digitalization experience for end-users who want to avoid paying license and/or subscription fees even though the service is not fully utilized.

Architectural Design and Identification of Functions

This section presents the architectural design that is used to develop the prototype of BIMServerless. The utilized cloud services, the granular functions, and the workflow in the prototype design are described. The functions in serverless development can be run individually or as a part of a flow. To create a flow, associated functions should be run in a sequence or asynchronously; the order of this sequence is established by triggers enabled by the FaaS offering. In this step, it is important to identify the base FaaS offering platform. An open source platform, such as OpenFaaS or Fission, could be utilized for this purpose. However, this approach would create extra workload for developers such as establishing the cloud infrastructure, setting up the FaaS platform on the cloud, fine tuning, scalability mechanisms, etc. Therefore, in this study, a commercial FaaS offering was selected called AWS Lambda as the main function deployment service. The following services of AWS are utilized to establish the overall development architecture and set up the triggers for functions (Figure 1).

- **S3 (simple storage service)** is a scalable file storage service through a web interface. In this research, S3 is employed to store the uploaded IFC files and the generated granular 3D models per entity. In addition, it is also used as a mechanism to trigger other functions in the framework.
- **Dynamo DB** is a low-latency, NoSQL-schema-based document database service. In this research, Dynamo DB is employed to store the data generated by the granular functions such as type, name, GUID, geometry (2D/3D), etc. In addition, this service interacts with the relevant functions that are mostly used by end users.
- **Kinesis** is a scalable data aggregating and streaming service. It can achieve a high throughput by forwarding ingress data to a large number of parallel endpoints. In this research, this service is employed as an aggregator and a transmitter for the data generated by the functions in Lambda. In addition, this service triggers corresponding lambda functions in the pipeline.
- **API Gateway** is a management service to create, publish and manage APIs. An endpoint in API Gateway allows other applications to access data or functionality from the back-end services such as Lambda. In this research, API Gateway is used in conjunction with Lambda functions to create a serverless service.

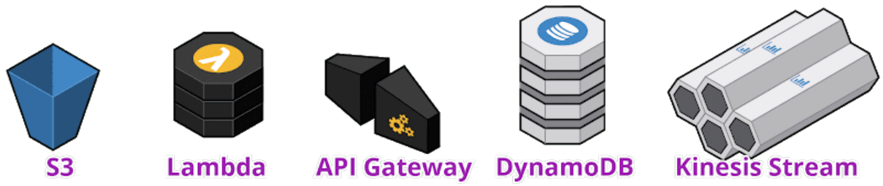

Figure 1: Selected services for BIMServerless architecture.

Minimum Features and Functions of BIMServerless PoC

Identification of the features and associated functionalities for the proposed framework and development is an essential step in this research. Similarly, to identify these kinds of details for other research studies and development projects, an advanced specification research and development has been conducted in BIMSie (i.e., the open source effort for the standardization of APIs for digital BIM-related services) [10-A]. The APIs defined in this standardization effort are organized in different service levels such as *ServiceInterface*, *NotificationInterface*, *AuthInterface*, etc. and associated functional methods. Most of the methods interact with each other in terms of receiving and exporting input/output (I/O) parameters to build a logical chain and serve a specific requirement/scenario. BIMSie is a reliable source for the proposed framework and for the expansive development of the *BIMServerless* prototype. However, it should be pointed out that the integration of all BIMSie service layers and their associated methods in the proposed FaaS is beyond the scope of this paper. Only the minimum viable features are covered in this paper.

Parsing BIM files, and rendering granular 2D/3D models, user and project access management, processing, linking, and exporting the data for case-specific requirements are among the most common practices of BIM data management software. These practices were used as guidance in defining the following functionalities for the proposed *BIMServerless* approach. The proposed application aims to:

- **Register** and **authenticate** the ***user*** with user-defined credentials

- Allow the user to **create** a ***project***
- Allow the user to **upload** an ***IFC file*** for the created project
- **Parse** the uploaded ***IFC file***
- **Create** the basic ***entity data*** such as ***type***, ***name***, ***global unique identification numbers (GUID),*** and ***property sets*** for each element
- **Create** the basic ***geometry data*** such as ***cartesian coordinates***, ***minimum***, ***maximum*** and ***center levels*** of ***bounding boxes***, ***height*** and ***area*** of geometric entities
- **Create** the ***semantic relationship data*** such as ***type***, ***name***, ***GUID*** of each relationship entity in IFC file
- **Semantically link** the ***IFC entities*** between each other with the identified relationships
- **Create** the ***data/file*** for the ***interactive*** and ***granular 2D floor plan*** and ***3D model***
- **Extract** the ***data*** as a response of a query

As mentioned earlier in this paper, the functions running in FaaS offerings are granular, atomic, and typically short-running. On the other hand, the above-mentioned features usually require a decent amount of computational and graphical processing power. In serverless computing, a single function can be concurrently run (hundreds of times) with different input/output parameters. Based on the above-mentioned interactions, it is essential to characterize the functions and parameters of concurrent operations for the proposed development. As it can be seen in Table 1, eight functions are planned for the proposed development. These functions are developed in Python3.5 language, with relevant libraries. For example, the function which ***creates*** entity data, generates the ***name, description,*** and ***property*** sets data of an IFC entity. This function can be concurrently run for each (or a set of) GUID number(s) in the IFC file. Another example can be the function to ***create*** relationship data that extracts the semantic ***relationships*** in IFC file and ***link*** entities accordingly. Like the previous one, this function can also be concurrently run for each, or a set of GUID number(s). The details of the other functions are presented in Table 1.

Table 1. Summary representation of the proposed features and concurrency parameters.

Action	**Function Name**	**Created Data**	**Concurrency**
Uploads IFC file	**uploadIFC.py**	Name, ID (auto generated)	File
Parses IFC file	**parseIFC.py**	Type, GUID, building GUID	GUID(s)
Creates entity data	**updateEntity.py**	Name, description, property sets	GUID(s)
Creates geometry data	**createGeom.py**	Cartesian coordinates, bounding box (min, max, center points), height, area	GUID(s)
Creates relationship and link data	**createRel.py**	Type, name, GUID	GUID(s)
Creates 2D/3D data	**2dGeom.py** **3dModel.py**	Geometry path/file per GUID	GUID(s)
Extracts query data	**query.py**	Query	Varies

Prototype Backend Architecture and Data Flow

The presented services and functions in Table 1 provide the fundamental elements of the proposed development architecture of the BIMServerless prototype. In addition, these elements build the flow of I/O parameters among the web services with relevant triggering events. Figure 2 presents the diagrammatic representation of backend architecture for the BIMServerless prototype with the above specified services and functions. The execution and data flow are described as follows:

1. In the ***first step*** **(1)** the end-user selects an IFC file and click the UPLOAD button in *BIMServerless*. Upon the click of the button, the **uploadIFC.py** function is triggered.
2. **The uploadIFC.py** function does not perform any process on the IFC file but simply saves the file to the cloud environment. The file is saved in *IfcUploadBucket* with the S3 service as shown in ***second step*** **(2)**.
3. When the saving process of the IFC file to *IfcUploadBucket* is completed, S3 triggers the **parseIFC.py** function as shown in the ***third step*** **(3)**.
4. **parseIFC.py** has an IfcFileParser method which parses the file and extracts the data including IfcType and GUID number of each entity. The extracted data is collected in a list and split into small chunks which are sent to the Kinesis stream as shown in the ***fourth step*** **(4)**.
5. After the fourth step, the **parseIFC.py** function generates the base Entity table in DynamoDB and writes the extracted data with IfcType and GUID columns as shown in the ***fifth step*** **(5)**. This table is later updated with the other functions.
6. The Kinesis stream aggregates and distributes the parameters to several parallel endpoints. In this architecture, these endpoints are the other Lambda functions which listen to this stream. As shown in the ***sixth step*** **(6)**, Kinesis asynchronously triggers the following five functions and all of them stream the IfcType and GUID numbers.

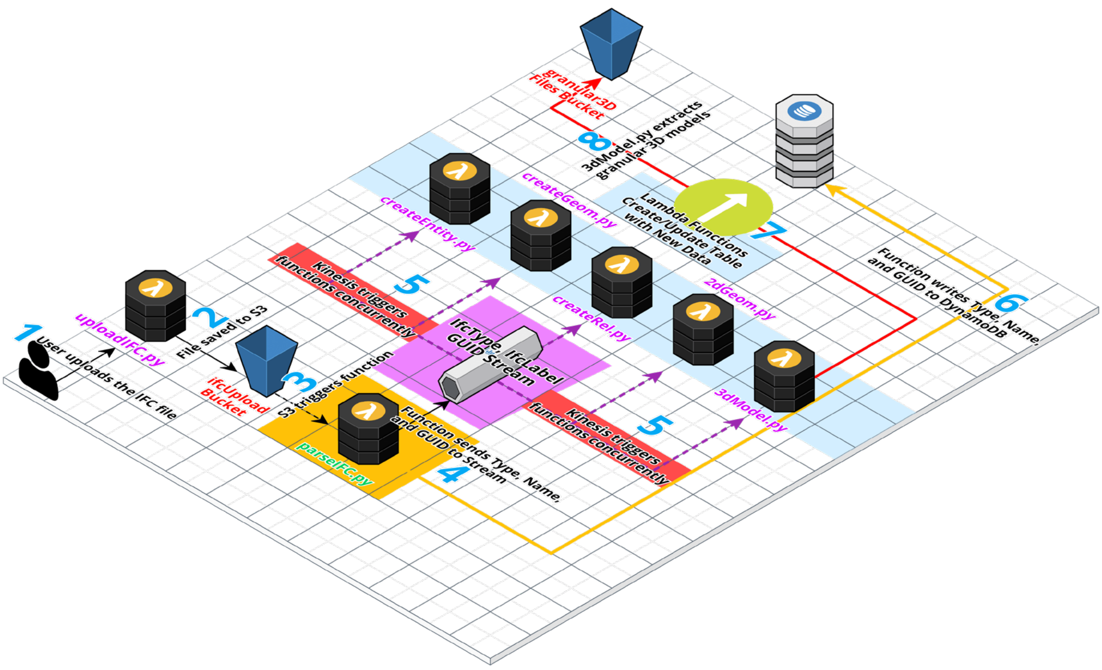

Figure 2: Overall architecture of BIMServerless backend.

7. While the **updateEntity.py** function extracts new data such as Name, PropertySets and Description per entity, the **createGeom.py** function extracts the geometric properties of the entities such as cartesian coordinates, min-max-center points of bounding boxes, area and

volume. In addition, **2dGeom.py** generates the section cut of the building using a user-defined height and the 2D drawing of each geometric entity at that height as a Scalable Vector Graphics (SVG) path. These three functions update the DynamoDB Entity table which was created in the fifth step. To update the table with the new data, IfcType and GUID values of the entities are used as primary keys. In addition to the above functions, the **createRel.py** function retrieves the semantic relationship types and identifies the *related* and *relating* entities for each relationship in the IFC file. This function generates two new tables in Dynamo DB. A RelTypes table stores the extracted relationship types; and the Relations table links the *related* and *relating* entities with the relationship types. The interactions between the Lambda functions and Dynamo DB is presented in the ***seventh step*** (7) in Figure 2

8. **3dModel.py** is an important function in the proposed *BIMServerless* framework. Instead of generating a 3D model of the entire building as one file or a complete process, this function listens to the IfcType and the GUID values from the Kinesis stream generates the granular 3D model of geometric entities. In other words, the 3D model of each geometric entity is stored in a separate file, and each file is saved to a granular3D bucket of the S3 service as shown in the ***eighth step*** **(8)**.

In addition to the above functions and workflow, BIMServerless includes some other granular functions and triggers for the development of the user interface.

Connecting Granular Geometry (2D/3D) to Information Semantics for User Interface

As mentioned in the previous sections, granularity is one of the important keys in BIMServerless. Indeed, the **2dGeom.py** and **3dModel.py** functions create geometry data individually for each entity in a BIM file. However, even if one has access to the granular 2D/3D entities, in order to visualize, it is necessary to load all of the granular models at the same time. This necessity becomes more visible when cross-discipline teams are involved in the work. For example, if one wants to visualize a small part of an air conditioning system that is **connected to** both the **electrical** and **HVAC** models, it is necessary to load and render all models of all related domains and then apply a filtering mechanism to show only the small part of the air conditioning system. The semantic information like material properties, relationships between the entities in multiple BIM files should be semantically linked with each other. The **createRel.py** function in BIMServerless connects the geometric information with the cross-discipline BIM entity data and provides the most important feature of BIMServerless for user interface.

The user interface part of the PoC implementation is mostly about utilization and visualization of the generated data with interactive and granular 2D and 3D models together with interactive charts. The details of the development of the user interface are beyond the scope of this paper. However, the main user benefits of BIMServerless include pay-as-you-go pricing and up to 80% performance improvement in rendering large BIM files (usually larger than 500MB files) due to parallel and granular data retrieval and rendering multiple BIM models (2D/3D) at the same time. Many non-technical users may think that these features are already available in many applications. However, the improved performance, the robust cloud architecture, and the enhanced rendering performance are significant improvements that come with BIMServerless. A proof of concept of the user interface of BIMServerless is presented in Figure 3.

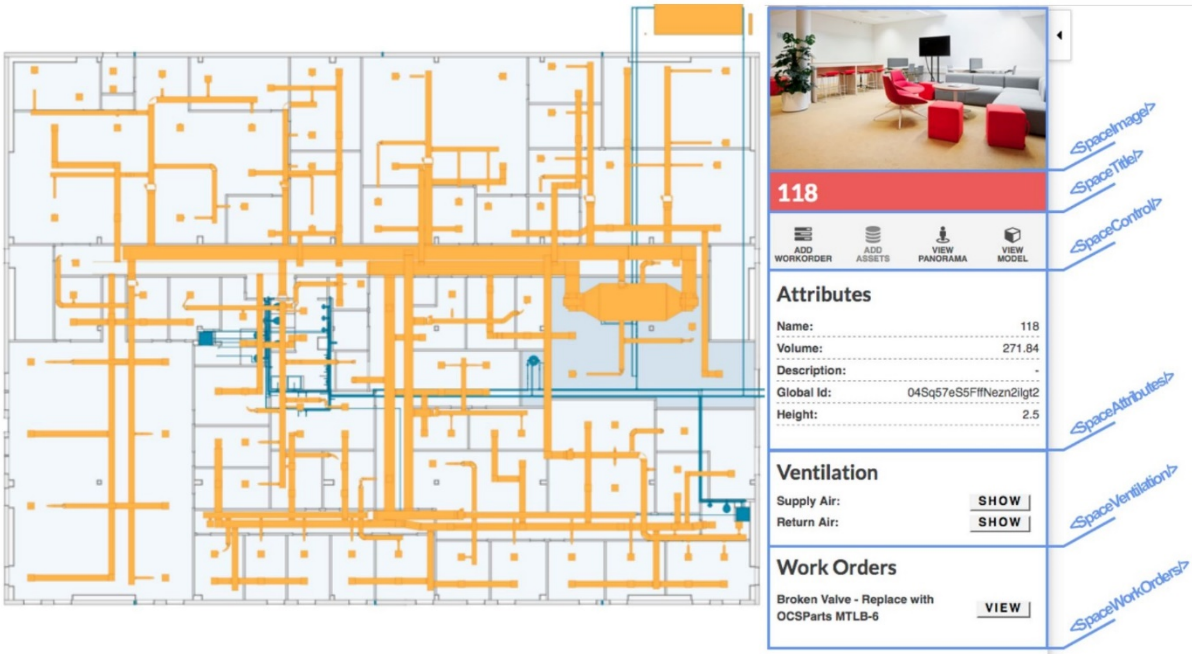

Figure 3: User interface prototype for BIMServerless

Conclusions and Future Research

In this paper, the fundamental parts of the BIMServerless approach is proposed with FaaS, serverless computing, and a pay-as-you-go pricing model. A proof of concept level implementation is also presented with its architectural (computational) design, utilized cloud-services, potential functions and a data flow to simulate a basic user experience with a BIM application. BIMServerless targets the common challenges of many digital services in the AEC-FM industry such as robustness, performance and cost-to-benefit factors. The user interface in Figure 3 is based on an experimental project to test 2D/3D rendering performance of BIMServerless. The initial tests of the granular and semantic information retrieval of BIMServerless provided evidence of a significant performance improvement in rendering large BIM files. It also showed the benefits of a granular platform in which the end-user may choose the exact function(s) for a specific task instead of purchasing an entire application/digital service with many functions that are never utilized.

Although the BIMServerless approach is based on an ongoing research for years, its full consequences are yet to be determined. This paper presented BIMServerless mostly as a proof of concept. The launch of a production-ready digital service based on BIMServerless depends on the answers to research questions such as:

- Development of architectural alternatives in terms of virtualization, digital service network, and granular functionality modeling
- Records of detailed scalability and performance measurements of the digital service offering including functions' execution times, memory consumption, and other relevant computational measures
- Proof of the robustness of BIMServerless obtained by stress testing with gigabyte level BIM models and benchmarking results with available cloud-based BIM services

- Consideration of ideas, discussions, and interest about BIMServerless as a new digital service model in the AEC-FM industry
- Economic feasibility of BIMServerless pay-as-you-go pricing model against existing commercial digital services and BIM platforms with cost benchmarks of multiple use-case scenarios
- Introduction of the "BIM Functions Marketplace" as a digital market in which end-users can purchase individual or a set of functions for AEC-FM lifecycle requirements.

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Analysis of Fall Accidents in Turkey Using Decision Tree Approach

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Abstract

In the construction industry, fall hazards are one of the substantial issues among other hazards. Various prevention methods are used to mitigate fall accidents and decrease the number of serious and fatal injuries for construction workers. As a part of the machine learning approaches, decision tree algorithms have been successfully applied in many areas such as business management and economy, health, social sciences, and construction management. In this study, J48 (C4.5) decision tree analysis was used by employing Weka software to determine and classify the factors associated with fall accidents. The data used in the analysis were obtained from archives of Social Security Institution (SSI) of Turkey. A classification tree model was created in association with parameters (attributes) acquired from data such as unsafe act and condition and construction trade. The model depicts the fatal and non-fatal injury conditions of construction workers related to attributes based on the predictor importance of parameters and accuracy of the model.

Keywords: *fall accidents, decision tree, J48, occupational safety.*

Introduction

6300 people die every day as a result of occupational accidents or work-related diseases according to the International Labor Organization (ILO). Annually, 317 million accidents occur and most of them results prolonged absences from work (ILO, 2015). Turkey ranks the third in fatal accidents of the world and the first for occupational accidents in Europe. Fatal occupational accidents rate in Turkey is about 20.5 employees per 100,000 population

(Altunkaynak, 2018). Among fatal occupational accidents, fall from height stands out as the most reported accident type. Moreover, construction industry is where fall from height accidents occur the most. Therefore, construction and fall hazards are two safety research areas that require further examination (Bayram, 2018).

Construction is one of the most hazardous industries because of its complex nature, labor intense environment and temporary working conditions. Managing safety in construction industry is an intimidating task. According to domino theory, occupational incidents occur due to unsafe acts, unsafe conditions, or both. (Heinrich, 1941). Identification of these factors are important for preventing accidents. Considering the massive human capital and financial losses from injuries, researchers try to gain a better understanding of factors that affect the occurrence and severity of incidents to improve the accuracy of predicting the likelihood of future injuries (Kakhki et al., 2019; Lord & Mannering, 2010).

In recent years, the analysis of incident/accident data using data mining techniques and algorithms became popular among the researchers. Ciarapica and Giacchetta (2009) developed an accident prediction model using artificial neural networks (ANN) and the fuzzy inference system (FIS) for occupational accidents in Italy. Rivas et al. (2011) preferred to use Data-mining techniques (decision rules, Bayesian networks, support vector machines and classification trees) to model accident and incident data compiled from the mining and construction sectors. Cheng et al. (2012) explored the causes and distribution of occupational accidents in the Taiwan construction industry by analyzing a database of 1542 accident cases using classification and regression tree (CART) during the period 2000–2009. Mistikoglu et al. (2015) used the C5.0 and CHAID algorithms to show the associations between attributes of fall accidents for roofers by using OSHA database. Altunkaynak (2018) analyzed the accidents that occurred in the manufacturing sector in Turkey with decision trees and association rule mining. Mutlu and Altuntas (2019) aimed to determine the factors affect the type of accidents by decision tree analysis and association rule mining methods, using the record of 242,537 occupational accidents in the manufacturing industry between 2013 and 2016 which was taken from the Social Security Institution of Turkey. Sarkar et al. (2019a) analyzed the factors of slip-trip-fall (STF) accidents by developing a methodology with decision tree (DT) classifiers, namely C5.0, classification, and random forest (RF). Sarkar et al. (2019b) also focused on predicting the accident outcomes such as injury, near miss, and property damage using occupational accident data in construction sector. The proposed method was based on the optimization of machine learning parameters such as the support vector machine (SVM), artificial neural network (ANN), the genetic algorithm (GA) and particle swarm optimization (PSO) methods to analyze occupational accidents. Ayhan et al. (2020) developed an association rule mining (ARM) model for the assessment of the correlations between the attributes of severe accidents in construction sites.

In this study, it is aimed to determine the factors which affect the fall accidents by using Weka software. A decision tree model was implemented and J48 was chosen as classification algorithm. The decision tree model can depict the association of the attributes and it helps to detect the root cause in accidents. Implementation of prevention methods to the aforementioned causes can decrease the injuries and deaths in fall accidents. Results can be evaluated as mitigation strategies for fall accidents. The data used in the analysis were obtained from archives of Social Security Institution (SSI) of Turkey. Results can be evaluated as mitigation strategies in fall accidents.

Data Demographics

The data involves fall incidents obtained from the Social Security Institution (SSI). 667 construction fall cases were examined and statistically analyzed. The classification and frequencies of data are depicted in Table 1. For instance, the unsafe act attribute is separated as five categories and each category is coded in order. Count means the number of observed accidents get involved in the relevant category and also it showed with corresponded percentages. To represent the degree of injury, ISS scores of incidents were used. If the score is lower than 74, the degree of injury value is assigned as non-fatal (1), if the score is 75, then the value is assigned as fatal (2). Besides, it should be noted that non-fatal injuries are covered serious injuries such as brain trauma or loss of limbs.

Table 1. Data exposition.

Attribute	Categories	Code	Count	Percentages (%)
Degree of Injury (DoI)	Non-fatal	1	538	80.7
	Fatal	2	129	19.3
Unsafe Act (UA)	Inappropriate position for task	1	204	30.6
	Unsafe work practices	2	37	5.5
	No Personal Protective Equipment (PPE) Usage	3	350	52.5
	Unsafe act by a third party	4	41	6.1
	Defective/Inappropriate Equipment In Use	5	35	5.2
Unsafe Condition (UC)	Insufficient/ Lack of Written Work Procedures	1	48	7.2
	Poor Housekeeping	2	186	27.9
	No PPE provided	3	53	7.9
	Faulty tool/equipment/ machinery	4	46	6.9
	No collective protection systems	5	334	50.1
Activity Type (AT)	Formwork	1	160	24.0
	Material handling	2	85	12.7
	Plaster/ Paint	3	130	19.5
	Assembly/ disassembly	4	69	10.3
	Others	5	223	33.4
Construction Trade (CT)	Form worker	1	150	22.5
	Unskilled worker	2	170	25.5
	Plasterer/ Painter	3	115	17.2
	Assembly/ Installation/Maintenance	4	56	8.4
	Ironworker	5	42	6.3
	Others	6	134	20.1

Research Methodology

Weka (Waikato Environment for Knowledge Analysis) is an open-source data mining software involving many classifications, regression, bunching, correlation rules, neural network algorithms, and pre-processing methods. Also, Weka supports all steps of data mining, such as processing raw data, statistical evaluation of learning methods on data, visual monitoring of raw data and the model derived from raw data. It has a wide range of learning algorithms as well as many data pre-processing filters.

J48 algorithm is a modified version of C4.5 and ID3 algorithm which is used to construct the decision trees (Quinlan, 1996). J48 (C4.5) classifies a new instance by creating a decision tree from the attribute values of the given data set. When the algorithm meets the training set, it recognizes the attribute that is responsible for categorizing the various instances most accurately. The possible feature values with no ambiguity are assigned to the concerned branch by terminating it (Panigrahi & Borah, 2018). The decision tree uses a tree-like graph and acts as a decision support system. In decision tree, the internal node states test on attribute, branch signify outcome of test, and leaf node states class label (computational analysis of all attributes). The path from the roof to leaf is called classification rules. The tree consists of decision nodes and chance nodes which are denoted by squares and circles (Yadav & Chandel, 2015). Also, if data has missing attribute values then it will end up with fractional instances at the leaves. When splitting on an attribute where some of the training instances have missing values, J48 will divide a training instance with a missing value for the split attribute up into fractional parts proportional to the frequencies of the observed non-missing values (Witten et al., 2011).

The prediction criteria are used to identify input attributes and are based on entropy and information gain (Sugumaran et al., 2007). First, the highest amount of information on the data is selected as root and then separation is going on through to leaves. The information rate (entropy) and information gain formulas are described by Equation (1), Equation (2) and Equation (3).

$$Info(M) = -\sum_{i=1}^{k} \left(\frac{frequency(S_i, M)}{|M|} \times \log_2 \frac{frequency(S_i, M)}{|M|} \right) \tag{1}$$

For any samples is denoted by M, frequencies are counted according to the values in that class is denoted by S and also |M| indicates the number of samples.

$$Info_x(P) = \sum_{i=1}^{n} \left(\left(\frac{|P_i|}{|P|} \right) \times Info(P_i) \right) \tag{2}$$

The information is split and the partition which denotes by P is calculated. For each *i* value, information rate is determined.

$$InformationGain(AttributeX) = Info(P) - Info_x(P) \tag{3}$$

For any X attribute, the information gain is equal to the difference of the whole sample to which that attribute is related and the part that concerns only that attribute.

In this research, the target attribute is determined as the degree of injury. The output of the attribute is fall accidents end with non-fatal injuries or fatality. 66% of the data using in training process to test remaining. Also, the pruning mechanism was applied during the classification process that is provided not only simpler results but also avoiding potential overfitting.

Results and Discussion

The rule set of the tree with the corresponding percentages is shown in Table 2. Associations between the attributes can be determined from rules. The truncated decision tree is shown in Fig. 2. Abbreviations used in Fig. 2 is the same as in Table 1.

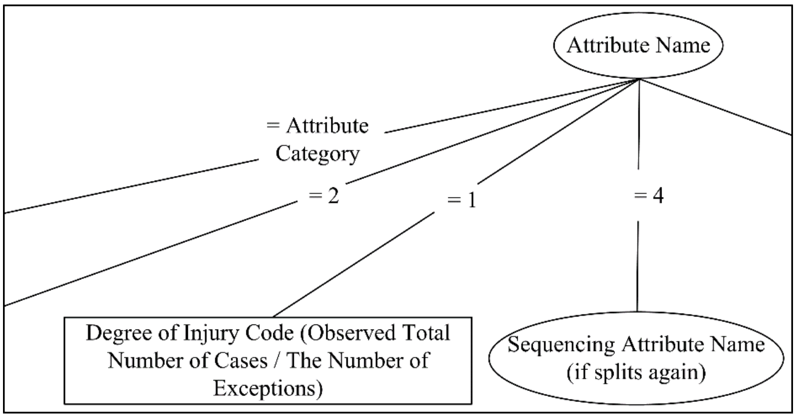

Figure 1: Explanation of the tree.

As an explanation for the tree, the number on the left is the number of observations that conform the classification (Fig. 1). On the right, the number of exceptions that are misclassified is pointed out. In other words, if there are no observations, the rule is extracted from the Table 2 but yet can be seen from the Fig. 2 as zero such as sequenced activities for UA=3& CT=4& AT=3.

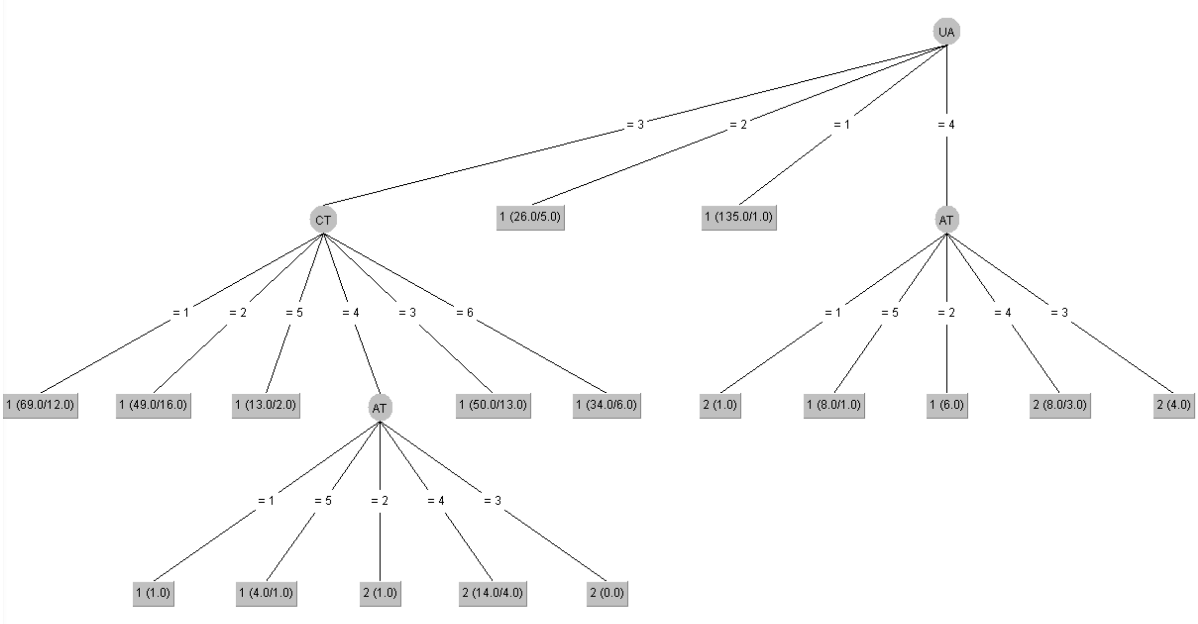

Figure 2: Truncated decision tree- Weka J48 classifier.

Table 2. Rules for degree of injury.

Rule Number	Rules	Degree of Injury (%)		Number of Cases
		Non-fatal (1)	Fatal (2)	
I	UA=1	99.26	0.74	135
II	UA=2	80.77	19.23	26
III	UA=3& CT=1	82.61	17.39	69
IV	UA=3& CT=2	67.34	32.66	49
V	UA=3& CT=5	81.62	15.38	13
VI	UA=3& CT=4& AT=1	100	0	1
VII	UA=3& CT=4& AT=5	75	25	4
VIII	UA=3& CT=4& AT=2	0	100	2
IX	UA=3& CT=4& AT=4	28.57	71.43	14
X	UA=3& CT=3	74	26	50
XI	UA=3& CT=6	82.35	17.65	34
XII	UA=4& AT=1	0	100	1
XIII	UA=4& AT=5	87.5	12.5	8
XIV	UA=4& AT=2	100	0	6
XV	UA=4& AT=3	0	100	4
XVI	UA=4& AT=4	37.5	62.5	8
XVII	UA=5& CT=1	100	0	6
XVIII	UA=5& CT=2	0	100	5
XIX	UA=5& CT=5	75	25	4
XX	UA=5& CT=4	0	100	1
XXI	UA=5& CT=3	80	20	5
XXII	UA=5& CT=6	100	0	1

The following results were observed and obtained from the analysis of fall accidents:

- Rule I reveal that inappropriate positioning on tasks cause almost no fatalities in fall accidents. This category can be completely eliminated by the contribution of ergonomics training and right posturing. Because there is no specific equipment for training.
- From rule number II, it can be seen that fall injuries due to unsafe work practices resulted in fatal injuries with about 20% ratio.
- About 33% of the unskilled workers who fell from height and were not using Personal Protective Equipment (PPE) lost their lives after the fall. (Rule number IV)
- Rule Number IX shows that among assembly, installation and maintenance workers whose assigned assembly& disassembly activities, 71% of fall cases resulted with fatality in workers who did not use PPE. A similar result was obtained if there is an unsafe act by a third party (62.5% of fatality, Rule number: XVI).
- Among plasterer& painters, due to no PPE usage, 26% of fall cases ends with fatality (Rule number X).
- It can be seen in rule number XXI, 20% of plasterer and painters suffered fatal injuries due to using defective/ inappropriate equipment.

In the determined classification model, the accuracy rate is calculated as 83.7%. In similar studies related to construction and occupational accidents, Mistikoglu et al. (2015) used C5.0 and CHAID algorithms and the model's accuracy rate is determined as 67.9 and 66.8% respectively. Altunkaynak (2018) used J48 classification and it reached 71% accuracy rate. Mutlu and Altuntas (2019) are employed the J48 and Random Forest (RF) algorithms and it resulted in high confidence and support values which means strong accuracy. Sarkar et al. (2019) preferred optimization-based decision tree models and used Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) as optimization methods and classification and regression tree (CART), C5.0 and Random Forest (RF) as decision tree algorithms. Results show that all combinations of proposed model's (GA-CART, GA-C5.0, GA-RF, PSO-CART, PSO-C5.0 and PSO-RF) accuracy rate are determined between 77-78%. It refers that the model is successfully validated. Also, the predictor importance of the attributes can be understood from the root and leaves of the tree. For instance, unsafe acting is more important attribute than activity type and construction trade of worker in fall accidents. Besides, the unsafe condition parameter (attribute) has no considerable impact on the model.

It should be also noted that fall height is definitely the most important factor in the outcome of the fall accident. However, reported cases that the database derived from did not include that information. Therefore this study intended to find out the effects of other factors without the influence of fall height.

Summary and Conclusions

Fall from height is one of the most important incidents in construction. Root causes of past accidents should be investigated, and solutions should be proposed to prevent them. The purpose of the study is to determine the factors related to fall accidents in constructions by using data acquired from the SSI of Turkey. In total, 667 incidents were statistically analyzed and results were evaluated. Associated factors were gathered and linked to fall accidents with classification. As a common data mining approach, decision tree analysis was used, and Weka Software was utilized. The J48 (C4.5) algorithm was successively applied and results showed that the data was effectively classified. The factors that influenced most and related parameters were determined in fall accidents. It was found that "unsafe act" is the most significant factor that influences the degree of injury. Also, the results of the analysis showed that workers who are engaged in Assembly/ Installation/Maintenance activities tend to suffer the most from fall accidents. Similarly, the same result is observed for plasterers& painters.

OHS professionals can use these results to minimize risk and increase safety levels. Results of the study i.e. root causes of the accidents should be considered as a cause-effect relationship to decrease injury and death rates.

Limitations of this study include the occurrence of SSI accident reports, unavailability of wide range data, unfilled information categories, and inadequacy of employment data solely for fall accidents. For future research, other decision tree algorithms or classification techniques can be implemented to determine other attributes that may be regarded as important. Also, various optimization methods can enhance the accuracy rate of the model depends on the datatype and categorization of the data.

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In Return For Condo Unit Construction Contract and a Contract Proposal

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Abstract

This study prepared a related sample contract proposal that wide application area for type construction contracts in return for the Condo Unit in Turkey. This type of contract is a form of partnership where the land is covered by the landowner and the financial budget by the contractor. This sample contract proposal has been prepared on behalf of the landowner. The purpose of this article is: to prevent the landowner from being victimized in construction work in return for the Condo Unit. Is an atypical contract, is considered within the scope of the Turkish law of obligation. Also, a literature review of this type of contract flat received for landownership has been examined as both legally and technically. Countries to which it is applied to this contract are Malaysia, the Philippines, and India. It is named as "Joint Development Agreement" in Malaysia, names as "Joint Venture / Development Agreement" in the Philippines, name as "Joint Development Agreement" in India. These related contract type problems were detected with a comprehensive literature review together with Surveys conducted in Turkey. Especially these problems are amended contracts, termination of a contract, force majeure, election, title transfer, work schedule, technical specification, consultancy services, etc. The housing project, in which the landowner, which finds the application area of these problems in Istanbul, is a foreign company and the developer is a Turkish company, has been selected as a case study. The problems experienced in this case analysis and the problems determined as a result of the questionnaire were examined and a solution proposal was tried to be created. Thus, a sample contract proposal was created in which the owner of the land, who does not have sufficient technical and legal knowledge, will not be victimized.

Keywords: *collaboration, construction contract, joint development agreement, in return for flat, in return for the condo unit.*

Introduction

After the 1960s, with the start of industrial development, started migration from village to city in Turkey, rapid population growth in metropolitan cities has been experienced due to migration. These population increases also caused housing needs. To solve this housing demand, construction contracts have been started to be applied in return for the condo unit. At this point, a collaboration arises between the developer and the person or institutions that have land but do not have financing to build. This cooperation created obligations by creating a debtor-creditor relationship with the parties. The landowner will transfer the title deed due to the project progress at the rate of sharing to the developer, and the developer will complete the construction within the contract period by adhering to the contract and its annexes. Since there is no specific legislation for the construction contract in return for the condo unit in Turkey, contracts is been regulated under the laws of obligation, creating a debtor-creditor relationship between the parties. These obligations as a basic principle under the contract; Depending on the progression of the landowner according to the share of the developer, the title deed is transferred according to the progress of the project, while the developer must complete the construction by adhering to the contract period. There is no special law for the meeting construction contract in return for the condo unit. Since such contracts create a debtor-creditor relationship, they are covered by the law of obligations. Construction contract in return for the condo unit was targeted to acquire housing in the past for the landowner, but in recent years, this type of works has been seen as an investment goal for the landowner. Like Istanbul Metropolitan Municipality Kiptaş etc. like institutions were been signed contracts with developers in return for the condo unit, and the lands purchased by these institutions are considered as an investment instrument. Depending on the supply-demand balance in the housing sector, and to meet this housing requirement, the construction contract in return for the condo unit method is applied in the construction sector. Construction works in return for the condo unit are generally referred to as build-sell. However, it is generally practiced as a sell-build. If we explain this statement, the developer cooperating with the landowner is starting to work either by financing with less capital or without putting any capital. Thus, the progress of the work continues depending on the income from the residence and commercial units sold. However, with the influence of fluctuation in the global economy, to the deterioration of the economy in the country, this leads to conflicts between the landowner and the developer. Economic fluctuations lead to a partial or complete cessation of house sales that's why that the financing of the work cannot be met. Lack of financing of the work either lowers the quality of the construction that the landowner has in common or causes the work to stop completely.

According to the news published on the internet on 24.06.2019, "Hundreds of construction companies, which have not been able to fulfill their recent commitments on the decreases in demand for housing, increases in foreign currency, and consequently the serious increases in construction costs, have been pending rearranging the share rates made with landowners. It is preparing to file an adaptation case and construction companies are waiting for regulation and support from the state.'' (Özer, 2019).

As can be seen in Fig. 1, the number of housing productions increased until 2017. There has been a decrease in housing production with the economic fluctuation in Istanbul since 2018. It was observed that after 2018, in with a decrease in production, more sales were made than the production, and stock of residence production has finished. The housing production number has decreased with the global economy and currency fluctuations experienced since 2018 in Turkey. As the main reason for the decrease in production in this housing sector, it is shown that the developer cannot where complete their projects together with the economic crisis. In this article; although the third parties who buy apartments from the housing project are victims, to protect the interests of the landowner has been aimed to create a proposal construction contract in return for the condo unit.

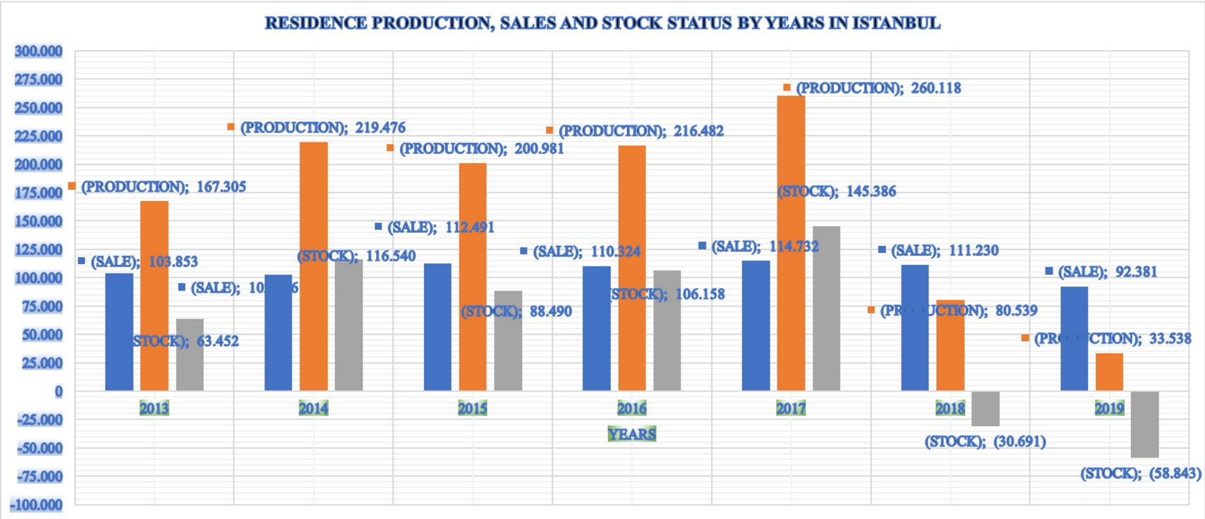

Figure 1: Residence production, sales and stock status by years in Istanbul (Tuik, 2019).

This article related to the scope of construction works in return for the condo unit were carried out comprehensive literature research in Turkey and worldwide. Construction contracts in return for the condo unit will be examined as legal, technical under two titles.

Research Infrastructure

Legal Review of Construction Contracts in Return for Condo Unit

Construction contracts in return for the condo unit area kind of construction contract composed of the debtor-creditor relationships. The developer undertakes to complete the construction against the land provided by the landowner. The landowner will perform the title deed transfer debt. In contract, the developer undertakes to complete construction.

In Construction contracts in return for the condo unit, sharing should be done between the landowner and the developer through the agency of independent evaluation offices. This sharing should be by least two independent evaluation offices and these values of units of evaluating companies should be averaged. In this context, the developer will continue to construct with the income of its units sold to third parties. The real estate sales will have to be done between the developer and third parties. Consequently, the construction contract in return for the condo unit is mixed-type contracts and since it constitutes the borrowing between the parties, it is within the scope of the law of obligations. Construction contract in return for condo unit; It is a contract that the landowner transfers to the developer in return for his commitment to deliver the ownerships of the building on which the part of his land will be built on the developer (Erman, 2010).

The condition of validity of the contract between the parties; According to Turkish law of obligation (T.B.K. 29 and 237) and Turkish civil law (T.M.K. 706) is necessary for the arrangement of the contract as an official deed. What is meant by the official deed here is the official arrangement in the notary. Here, the contract is to be made mutually in the presence of a notary public. At this point, the contract is to be made mutually in the presence of a notary public. Except that, the documents that are notarized by determining conditions between the parties are not valid. Legal nature; Anonymous (Atypical) contract, It is the contract that burden debt on both sides, mutual consent is a must, subject to official form, it is a contract with a lump sum, a mixed type is a contract.

Related Laws: Turkish law of obligation No. 6098, Turkish Civil Law No. 4721, Turkish Construction Law No. 3194, and Turkish Building Supervision Law No. 4708.

Amendment of Construction contracts in return for the condo unit must be made official from the notary, like the main contract. It should be noted here that the amended items are the main element of the contract. However, the amendment does not need to be made from the written and notary public for the secondary elements of the contract *"*Except for the essential elements of the contract, additional contractual amendments that complement the contract, which secondary important degree elements, do not have to be made officially or even in writing." (Kostakoglu, 2017).

One of the most important points to be considered when signing construction contracts in return for condo units is the transfer of title deed. Although this transfer of title deed is not real sales, it may cause conflicts in the future. Transfer of shares to the contractor and assent to the sale of independent units that will her own in sharing is considered as an advance to finance the contractor of the work before the completion of the construction (Court of Appeals 15th. H.D., 2005). In the contract, how much title deed will be transferred at which stage of the construction according to the share rates and should not be ambiguous. At this point, a table of percentage distribution of producing should be added to the contract with calculated approximate construction cost for title deed transfer stages. In this way, the problems that may occur in the future will be prevented for the landowner.

Technical Review of Construction Contracts in Return for Condo Unit

Construction contracts are the constitution of work and it will be a problem to prepare the construction contract under legal conditions without technical examination. At this point, the preparation of all contract documents becomes important. A clear listing of contract documents is useful for minimizing possible disputes (Sözen, 2015). Contract documents are mentioned in AIA A201-2007, 1.1.1.

Construction contracts should be prepared in an open language, without ambiguous. According to T.B.K. 23, "If a provision in general transaction conditions is not clear and understandable or if it means more than one, it is interpreted against the organizer and in favor of the counterpart."

Contract documents should have a priority order. In this regard, the priority order in the Construction Contract is as follows; (1-General specifications of construction works, 2- Administrative specifications, 3- Contract draft, 4- Application project, 5- Site list, 6- Special technical specifications, 7- General technical specifications, 8- Explanations (if any), 9- Other Appendix). Contract documents can be determined in this way and can be changed with special conditions.

The application of force majeure to be specified in the contract differs from country to country. The economic crisis in our country is not implemented as a force majeure if it has not been announced by the state. The Supreme Court did not find the 1994 and 2001 crises occurring in our country as "unpredictable" (Arat, 2006).

Applications in the world of Contracts in Return for Condo Unit

In Malaysia, the name of the contract is referred to as a "joint development agreement" for construction works in return for condo units. In Malaysia, the contract made in return for giving the landowner an independent section is called Joint Development Agreement (Sütcü, 2017). In India, there is a contract with the same name. (Joint Development Agreement) (Rou, 2013). In the Philippines, the equivalent of the construction contract in return for the condo unit is called the Joint Venture / Development Agreement. In a dispute in China, the landowner agreed on the sharing of benefits to be obtained from the independent departments to be made with the real estate company (developer), and then a construction contract was signed between the real estate company and the construction company. In the lawsuit filed by the construction company to the landowner after the real estate company did not pay the production price, the joint responsibility of the financier was accepted even for the landlord. Mallesons (2017) criticized the Supreme Court of China in the Civil Judgment (2007) based on the decision of the landowner, which does not have a contractual relationship, that the construction price cannot be claimed (Sütcü, 2017).

Purpose and Scope of the Research

The purpose of the study, of Construction contracts in return for the condo units is the investigation of impacts for the landowner, necessary precautions are taken and adequate preparation of contracts between the landowner and the developer in Turkey.

The Contracts concluded between the landowner and the developer has not been developed and not based on a certain format unfortunately in Turkey. Construction contracts in return for the condo units shouldn't be against contradiction with the Law, statutes, regulations, the code of ethics, and the principle of equality of the constitution. Also, it should be noted that ambiguous statements should not be included in the contract and that the results of ambiguous statements will be against the landowner who regulates the contract. The results of ambiguous statements will be must be remembered that it will damage the landowner who regulates the contract. In this article, a contract proposal is been aimed to solve the problem of Construction contract in return for the condo units which defend the rights of the landowner.

Material and Method

Material

In the sample case analysis specified within the scope of this article, a construction contract in return for condo unit has signed on land purchased for investment purposes by a foreign firm for 3 blocks and revenue sharing agreement has signed within 1 block between landowners with the Turkish company (the developer) Turkey in 2016. The construction of the concept project started according to the agreement reached between the parties in April 2016. The construction is started by a contractor firm on behalf of the developer. The project includes residential and commercial units. In the Construction contract in return of the condo unit; it consists of 3 blocks (C-D-E blocks). The sharing of residence and commercial units are determined in the rate of 52.5% to landowners and 47.5% to developers. E block is designed as a residence by the developer during the initial phase of the construction. E block is revised as a hotel by the developer with the change of environmental planning in the progress of construction. In contract sharing revenue; it consists of a single block, an F block. Sharing rates for both residential and commercial units; it has been determined as 55% landowner and 45% developer.

The construction has been slowed down by the developer due to the economic crisis in the summer of 2018 and the project could not be completed within 3 years, which is the contract period. The developer has decided to change the contract informally, predicting that the work will not be completed in 2018, and the contract deadline has been set between the parties as of December 2019. The landowner stopped the title deed transfers as a result of the developer not speeding up the project, following the unofficial amendment of the contract. As of May 2020, the title deeds of more units were transferred, which is more than they deserve from the developer, the land registry office with the approval of the relevant ministry and municipality, based on the opinion of the building audit, inappropriately. Finally, the work has stopped as of July of 2019. As of June 2020, Landowner has rescinded the contract by stating that the work has not been completed in due time. The developer claimed that the landowner has not made the title deeds that he had to do as per the contract. The contract was terminated by the landowner in June 2020 and the subject was moved to the court.

The table, which uses to determine the progress payment level of the building audit, never shows the construction progress rate. The landowner has taken an injunction decision from the court for these extra title deed transfers.

The contract contains the table showing the title deed transfer stages according to the producing progress.

Method

Within the scope of this research, a semi-structured survey was organized and the problems were investigated in terms of landowners in a construction contract in return for the condo unit. In this survey, the participants were asked questions 4 demographic and 23 multiple-choice questions to determine in which area the problems are concentrated. 32 participants were answered to the questions directed to 53 participants. The participant's experiences were also taken into account when analyzing the questions answered by the 26 civil engineers and 6 architects. It is observed that the participants are concentrated in middle and senior managers. That the majority of the participants were determined to have over 15 years of experience. Also, the majority of the participants work in the private sector. The questions directed to the participants are the main topics; Deed transfer, Technical specification, and methodology, supervision of the work to be done by the landowner, contract form, amendment of the contract, force majeure, sharing of independent sections(units that can be shared), submission of material selection to the landowner's approval, penalties and collateral in the contract, work schedule, evaluation of construction contracts in return for the condo unit under the law of obligation.

Analysis and Findings

The survey method was used as a data collection tool in the study. The survey is one of the tools used to standardize observations. The survey can be defined as a systematic data collection technique by asking questions to resource people who form a universe or sample depending on the hypotheses or questions determined on a particular subject (Balcı, 2015). The survey requires resource persons to be literate. Therefore, the survey can also be defined as a written data collection tool. In this study, 53 civil engineers and architects participant was applied to a survey consisting of 27 questions in the construction industry. In this context, the first four questions are demographic and the remaining 23 questions are multiple-choice. Likert scale for problems that may arise in terms of landowners. (1 = strongly disagree, 5 = strongly agree). Details are given in Table 1.

Table 1. Scale and limit range (Memnum et al., 2012).

Scale	**1**	**2**	**3**	**4**	**5**
Limit Range	1,00-1,80	1,81-2,60	2,61-3,40	3,41-4,20	4,21-5,00
Result	Strongly Disagree	Disagree	No Idea	Agree	Strongly Agree

26 of the participants are civil engineers (81.25%) and 6 of them are architects (18.75%), and the profile of the participants consisted mainly of private-sector employees (81.25%). Besides, 28.13% of the participants are mid-level managers and 31.25% are senior managers. It is seen that the participants are predominantly 16 years or more experience. (68.76%). The professional experiences of the participants are presented in Fig. 2.

The reliability of the scale was evaluated for 23 questions defined on the five-point Likert scale. In this context, the Cronbach Alpha coefficient (α), was calculated which is a frequently used measurement for internal consistency. (α) It is used to explain or question the homogeneous structure of the items in the scale. The reliability of the scale was evaluated for 23 questions defined in the five-point Likert scale. In this context, the Cronbach Alpha coefficient (α), was calculated which is a frequently used measurement for internal consistency. (α) It is used to explain or question the homogeneous structure of the items in the scale. The scale with (α) high value is interpreted as consistent with each other. (Yıldız & Uzunsakal, 2018). (α) Value is calculated with the following formula (Alpar, 2013).

In this context; K: number of items (number of questions prepared with the Likert scale), σyi: (i) variance of the item in the total sample, σx: Variance of total test score. Within the scope of this study, it was calculated as $\alpha = 0.964$ for a total of 23 questions presented on a 5-point Likert scale. In the literature, measurements with an α value of 0.70 and above are considered reliable (Bernardi, 1994). Taking the value of 0.70 can be said that the scale is reliable as the limit value. The average and standard deviation values are shown obtained from the questions asked to the participants in Table 2.

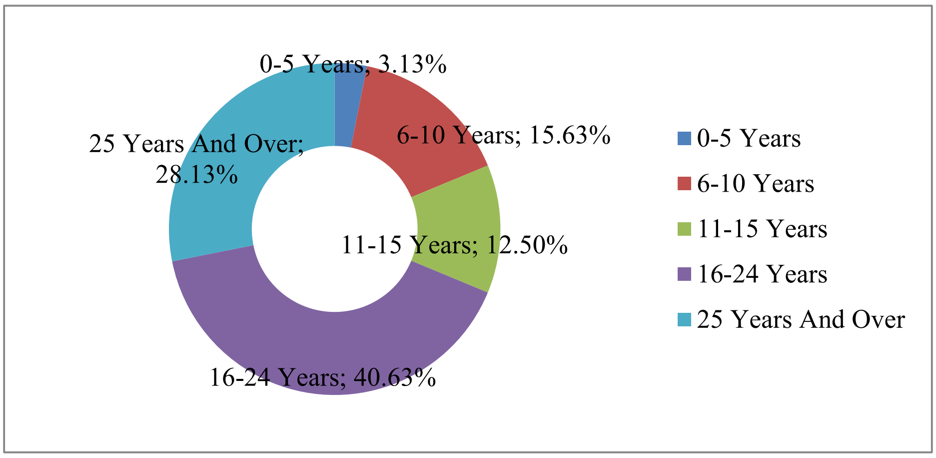

Figure 2: Professional experience.

Table 2. Survey results.

No	Survey Question	($\bar{x}$)	(σ)
1	The start-end date and duration of the work must be indicated in the contract with an exact expression without an open comment.	4,69	0,46
2	The landowner should be indicated package work schedule in the contract which may follow the work-progress rate and the delay days.	4,44	0,70
3	The landowner should agree with the consulting firm to specify in the contract and should have been supervising the construction works by the construction and consulting firm. (Control of project suitability on-site-quality and safety)	4,28	0,76
4	Quality control books, technical specifications, and the methodology should be specified in the contract.	4,53	0,79
5	The law of obligations is enough to evaluate construction contracts in Return for Condo Unit.	2,97	0,92
6	The application ranking of documents should be indicated in the contract if there is a mismatch between the project, the technical specification, and the contract.	4,31	0,77
7	If the contract is an amendment from without editing from a notary public, it may cause problems for the landowner.	3,72	1,04
8	In the contract, it is sufficient to specify the minimum technical specification and site list.	2,47	1,17
9	To the developer, it is not right to slow down or stop the work due to the delays in the title deed.	2,63	0,99
10	The state should be accepted as a force majeure in the economic crisis or the exchange rate fluctuation.	3,19	1,38
11	The developer should be production critical direction in the work schedule so that he can request an additional production time due to extraordinary weather conditions.	3,88	0,99
13	Independent evaluation institutions are needed to ensure fair sharing.	3,47	1,32

14	I find it right that the landowner uses its right of election (rescission of a contract, completion works, and damages for delay in performance, fee reduction from the developer) under the law of obligations if the	4,16	0,75
15	Material approval must be submitted to the landowner's approval	3,47	1,27
16	"The title deed transferred to the developer should be canceled in the works that don't reach 90 % level as per the supreme court decision." I find the appeal court decision correct.	3,19	1,10
17	Landowners can a right to rescission a contract if the delay of the progress in the work schedule of the developer is more than 20% in the monthly period or if the delay of the duration of the work is more than one-fifth from the total duration.	3,31	1,16
18	It is not sufficient under the Obligations Law that the developer is responsible for 5 years for open defects and 20 years for hidden defects.	2,25	1,00
19	The landowner should be indicated in the contract the penalty clause against the developer if there will be a delay in the work schedule by the developer.	4,50	0,66
20	The landowner must have a guarantee in the contract if the developer cannot complete its work.	4,25	0,90
21	The contract should be a table that indicates the stage of transfer of the title deed.	4,50	0,71
22	The approval of the landowner should be obtained in case of a project change by the developer during the progress of the work.	4,50	0,50
23	The landowner should benefit from this increase if there is an increase in the area of salable units with project revision during the work progress stage.	4,59	0,49

When the survey is analyzed, survey questions that are of high importance (1,2,3,4,6,14,19,20,21,22,23) are determined in Table 3.

Table 3. Relative importance index (RII).

No	$\bar{x}$	σ	σ^2_x	σ^2_y	Scale/Number of Question					R.I.I.	Level
					1	2	3	4	5		
1	4,69	0,46		1,08	0	0	0	10	22	0,94	**H**
2	4,44	0,70		0,96	0	1	1	13	17	0,89	**H**
3	4,28	0,76		0,86	0	2	0	17	13	0,86	**H**
4	4,53	0,79		1,23	0	2	0	9	21	0,91	**H**
5	2,97	0,92		1,55	2	8	11	11	0	0,59	**L**
6	4,31	0,77		0,90	0	2	0	16	14	0,86	**H**
7	3,72	1,04		1,12	0	7	2	16	7	0,74	**M**
8	2,47	1,17		3,19	6	16	0	9	1	0,49	**L**
9	2,63	0,99		2,39	2	18	2	10	0	0,53	**L**
10	3,19	1,38		2,32	3	12	0	10	7	0,64	**M**
11	3,88	0,99		1,03	1	4	0	20	7	0,78	**M**
12	3,59	0,93		0,93	0	7	2	20	3	0,72	**M**
13	3,47	1,32		1,90	2	9	2	10	9	0,69	**M**
14	4,16	0,75		0,74	0	2	1	19	10	0,83	**H**

15	3,47	1,27		1,78	1	11	0	12	8	0,69	**M**
16	3,19	1,10		1,61	2	9	4	15	2	0,64	**M**
17	3,31	1,16		1,61	1	11	1	15	4	0,66	**M**
18	2,25	1,00		3,44	5	21	0	5	1	0,45	**L**
19	4,50	0,66		0,99	0	1	0	13	18	0,90	**H**
20	4,25	0,90		1,07	0	3	1	13	15	0,85	**H**
21	4,50	0,71		1,05	0	1	1	11	19	0,90	**H**
22	4,50	0,50		0,80	0	0	0	16	16	0,90	**H**
23	4,59	0,49		0,94	0	0	0	13	19	0,92	**H**
TOTAL	**3,778**	**20,760**	**430,98**	**33,47**	**25**	**147**	**28**	**303**	**233**		

$$\alpha = \frac{K}{K-1} \times \left(1 - \frac{\sigma_y^2}{\sigma_x^2}\right) \quad (1)$$

$$\alpha = 0{,}964$$

Conclusion and Discussion

The problems between the landowner and the developer pose a risk to the construction's quality safety. Although the security of the building is not affected due to the developer's the anxiety of sale of units concern from time to time, it causes the use of other materials used in the structure in the low segment and the reduction of life the structure.

At this point, the landowner can secure himself with a comprehensive technical specification as an attachment to the contract or the landowner must put a minimum technical specification in the contract attachment, depending on the contractor's sales policy. These risks also continue as a result of the sale of independent parts of the landowner, which fall to their shares, to third parties. The materials used in the structure in the low segment cause the life of the structure to decrease.

The points to be specified within the scope of Construction Contracts in return for condo unit; Table showing the scope of the work, the parties and contact addresses, the sharing rates, the start date of the work, the completion time of the work, the extension of the work, the technical specification and site list of the work, which package work program to use, force majeure, delay penalty, guarantee, title deed transfer stages, It is the authorization of the consultancy firms to make an audit on behalf of the owner of the land.

At this point, The landowner should add a decision to the contract to prevent the problems in the construction works in return for the condo unit. This decision is A certain percentage of the cost of the work to be done by the developer should be kept as collateral during the working period.

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Using the Earned Value Analysis in the Monitoring of Construction Projects

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Abstract

The construction sector has a critical importance for developing countries in terms of contribution to economic development. There is serious competition in the sector arising from this situation. As a result of this competition, companies aim to create products with the desired quality standard, in the specified time and at the lowest cost. This is only possible with the adaptation of technology, that is, modern techniques to the industry. Earned value analysis is one of the modern techniques mentioned. Earned value analysis in project management; It is an important analysis method in terms of cost, time, project performance, progress measurement and control. It includes information about the progress of the project as well as the planned and spent costs. Within the scope of this study, deviations in the planned values of the basic work items of a superstructure project were determined. The traceability and follow-up of the project have been ensured with the information obtained through the earned value analysis, and the deviations that will occur in the basic targets could be predicted at the beginning.

Keywords: *construction sector, cost tracking, earned value analysis.*

Introduction

Construction planning is a fundamental and challenging activity in the management and, execution of construction projects. It involves the choice of technology, the definition of work tasks, the estimation of the required resources and durations for individual tasks, and the identification of any interactions among the different work tasks. A good construction plan is the basis for developing the budget and the work schedule. Developing the construction plan is a critical task in the management of construction. In addition to these technical aspects of construction planning, it may also be necessary to make organizational decisions about the relationships between project participants and even which organizations to include in a project (Baracco & Miller, 1987).

The performance of the projects should be measured in line with the specific goals and objectives of the projects. For this reason, it is necessary to measure the performance of projects involving the activities of reaching a specific goal within a predetermined time, budget, and quality constraint by considering the extent to which these constraints are used effectively (Duran, 2016).

In construction projects, planning is important in the execution and monitoring processes as well as in the initial phase of the project. In order for the projects to be successfully completed, the possibilities of achieving the targets must be constantly evaluated during the project's execution. Project progress needs to be analyzed at certain times to keep the project budget and duration under control.

In the successful completion of construction projects, the monitoring and control of the projects are very important. However, it is quite difficult to reach definitive results with the data obtained as a result of the project's monitoring. Duration, cost, and quality are three components that play a major role in the successful completion of projects. In project management, managing these components integrated is the best solution. However, in case a decision is made for one of these components; due to stakeholder needs, and decisions taken at the beginning of the project; other components are shaped around it.

The earned value analysis technique is one of the ideal methods that can be used to monitor the progress of the projects and to determine the schedule and cost performance of the projects. In the light of the results obtained with earned value analysis; possible delays and cost exceeding for the project are determined in advance and project stakeholders are ensured to take proactive measures for these cost and time overruns.

With this study, it was aimed to determine the duration and cost performance indicators of a construction project and the progress towards the project targets. For this purpose, a superstructure project was modeled, and the acquired value analysis was applied on the model. In light of the data obtained as a result of the analysis, the deviations in the main objectives of the project, and the factors that may cause these deviations were examined.

Monitoring Performance of Construction Projects

Performance is a concept that has gained value either quantitatively or qualitatively as a result of planned activities for a specific purpose (Eraslan & Algün, 2005). Performance measurement in projects reveals how successful the project is in line with its targets. In terms of traditional project management, success is achieved when project performance indicators are realized at the optimal value in the execution of a project. In this context, in order for the projects to be successful, the project must be completed in the desired quality, at the lowest possible cost, and as soon as possible. Therefore, the first condition for a project to be successful is that the management plans the project in line with realistic goals (Navon & Sacks, 2007).

In the project performance measurement, the real success of the project cannot be determined accurately. However, it is possible to obtain the most realistic results with good measurements. Also, it is foreseen that the performance measurements to be carried out in the projects may increase the performance of these projects (Kerzner, 2013).

The technique called Earned Value Analysis (EVA) facilitates the answers to these questions. The validity of each monitoring system depends on accurate and reliable data. The usefulness of this analysis depends on the data in the work breakdown structure (resources, time and cost estimates, a time-based budget for each activity) and realistic estimates for percent completion (Bahar, 2008).

Earned Value Analysis basically provides a photo of the data of any date of the project and provides an estimation of how the future of the project will be shaped through these data. However, this method does not take into account the project risks that may be encountered in the future. Earned value analysis estimates are obtained using standard formulations without being affected by project risks and uncertainties. In order to measure the key aspects of the project and take the right actions in the future, the performance indicators obtained from the analysis will provide the project stakeholders with better monitoring and decision-making opportunity (Babar, 2016).

To better understand the Earned Value Analysis technique, Earned Value Analysis parameters and related equations are described in detail below:

- ***Earned value (EV):*** The "earned value", also expressed as "budgeted cost of the work done", shows the total value of all the works completed in the project in any given period. These total values are measured in terms of planned value.

- ***Planned value (PV):*** It refers to the total budget of all planned works until any date in the project calendar. Planned value is also known as the "Budgeted Cost of Planned Work". PV is usually shown with an S-shaped curve diagram showing the budget versus time, and the performance of the project is evaluated according to this diagram.

- ***Actual cost (AC):*** The "actual cost", which is also expressed as the "real cost of the work done", shows the sum of the resources spent on all works completed in the project in any period.

- ***Estimate to Complete (ETC):*** The expected extra cost necessary to finish the project.

- ***Estimate at Completion (EAC):*** It is the total cost at which the project will be completed, which is calculated assuming that the project productivity will remain the same at any moment of the project.

- ***Budget at Completion (BAC):*** The total approved budget when the scope of the project is completed (including any project contingencies).

To analyze the present status of a project and estimate its future probability, the following data points can be utilized. Earned Value Management (EVM) analysis has two parts: cost analysis and schedule analysis. In schedule analysis, EVM uses both schedule variance (SV) and schedule performance index (SPI). Also, the cost variance (CV) and cost performance index (CPI) are used in the cost analysis of the EVM.

$$SV = EV - PV \qquad CV = AC - PV$$

$$SPI = EV/PV \qquad CPI = AC/PV$$

When CV= 0 (CPI= 1) and/or SV= 0 (SPI= 1) the project is respectively on cost and /or timely. If CV<0 and CPI<1, it shows the project is over budgeted, and if SV<0 and SPI<1, it means the project is delayed. The graph is shown in Fig. 1 is a useful tool for the project manager to check project efficiency based on CPI and SPI data depending on the progress reports.

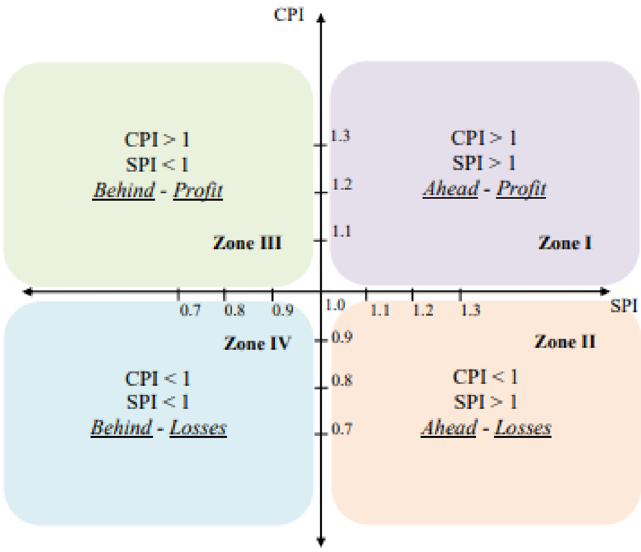

Figure 1: SPI and CPI analysis matrix of a project.

By following the developments related to these indices in the project's existence cycle, managers can determine deviations from the arrangements through which they can perform initial restorative actions along these lines. An example of an ideal format to outline level reporting to management is demonstrated in Fig. 2 (Eirgash et al., 2017).

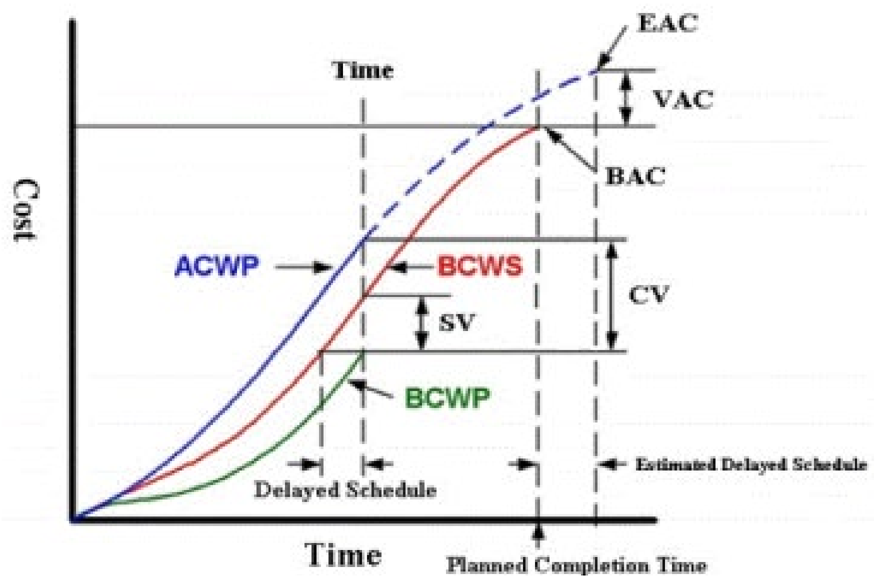

Figure 2: EVM chart (Source: Chou, 2003).

Methodology

With this study, it was aimed to evaluate the duration and cost performance of a sample superstructure construction project by using the earned value analysis technique, which is one of the methods that can be used in the performance monitoring of construction projects.

In this study, the rough construction of a single block (A block) of a 4-block residential project with a total area of 85000 square meters was investigated as a case study. The block taken as a case study; has 17940 square meter construction area and reinforced concrete structural system and consists of 3 basement floors, 1 ground floor, 10 normal floors, and 1 roof floor. The typical floor plan of the project is shown in Figure 3.

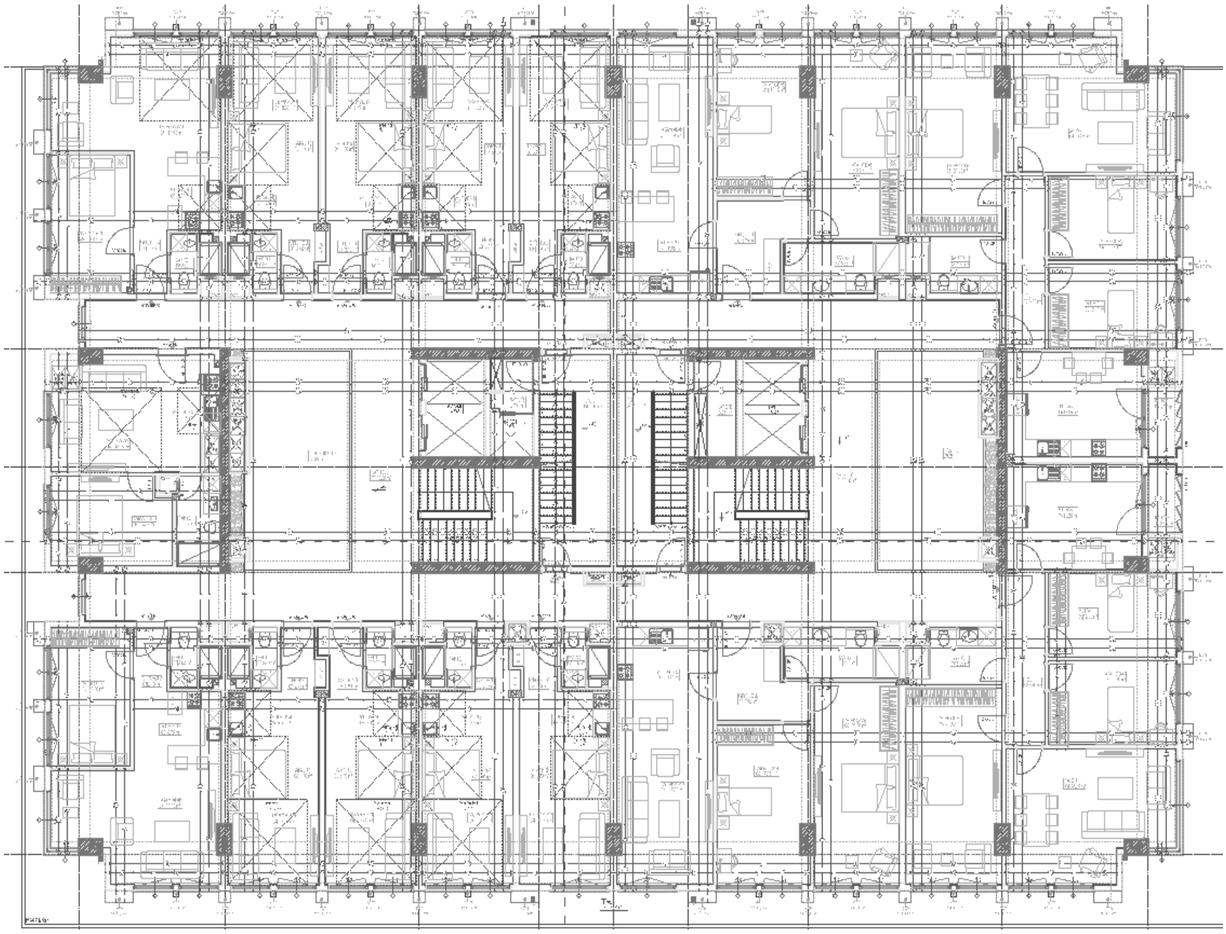

Figure 3: Typical floor plan.

Within the scope of the study, the rough construction work process of the project was planned through Primavera P6 software. Then, in accordance with the progress information received from the field, the actual (spent) time and cost values of the project were determined. Later on, in the light of the data obtained from the field and calculated in line with the planning, the earned value analysis was carried out. Finally, in the light of the results obtained from the analysis, the duration and cost deviations of the project were determined, and the factors that may cause these deviations are examined.

Findings and Discussion

Within the scope of the study, the rough construction process of a superstructure project is planned, and the results obtained by applying the earned value analysis over these planning are examined. In line with this purpose, the rough construction work process of the project was planned, and the estimated project duration and cost were determined. Then, it was checked whether the project was progressing according to the plan determined by EVM analysis.

As a result of the planning, the planned finish date of the rough work process of the project, which is planned to start on 01.05.2018, has been determined as 12.12.2018. The project is expected to be completed in a total of 226 days with a cost of 5.547.751,00 TL. The activity duration and costs of some of the project activities are shown in Table 1.

Table 1. Duration and cost values of activities.

Activity ID	Activity Name	Duration	Budgeted Cost
1	Excavations	30	167.877 TL
2	Waterproofing + Lean concrete	7	91.284 TL
3	Foundation formwork	2	49.475 TL
4	Rebar placement for mat foundation	10	639.880 TL
5	Pouring concrete for mat foundation	1	451.947 TL
6	Drainage	2	7.524 TL
7	Basement formwork	8	113.225 TL
8	Basement rebar placement	4	581.538
9	Placement of electrical pipes	1	2.000 TL
10	Pouring of basement concrete	1	278.664 TL
11	Concrete setting and remove formwork	14	
12	Building wall	10	41.311 TL
13	Waterproofing of basement shear walls	4	30.702 TL
14	Floor formwork	8	50.575 TL
15	Floor rebar placement	4	159.120 TL
16	Placement of electrical pipes	1	2.000 TL
17	Pouring of floor concrete	1	70.458 TL
18	Concrete setting and remove formwork	14	
19	Building wall	10	20.574 TL
20	1st floor formwork	8	30.600 TL
21	1st floor rebar placement	4	121.885 TL
22	Placement of electrical pipes	1	2.000 TL
23	Pouring of 1st-floor concrete	1	49.194 TL
24	Concrete setting and remove formwork	14	
25	Building wall	10	35.153 TL
80	Building gable and chimney walls	7	17.713 TL
81	Plastering	7	9.425 TL

82	Finishing roof frame	15	42.359 TL
83	Finishing rain gutters	3	2.600 TL
84	Finishing roofing	10	314.110 TL

EVM analysis was made according to the date of 02.10.2018, which corresponds to the 155th day of the project. The Gantt chart and resource usage, where the works up to this date can be seen, are shown in Figure 4.

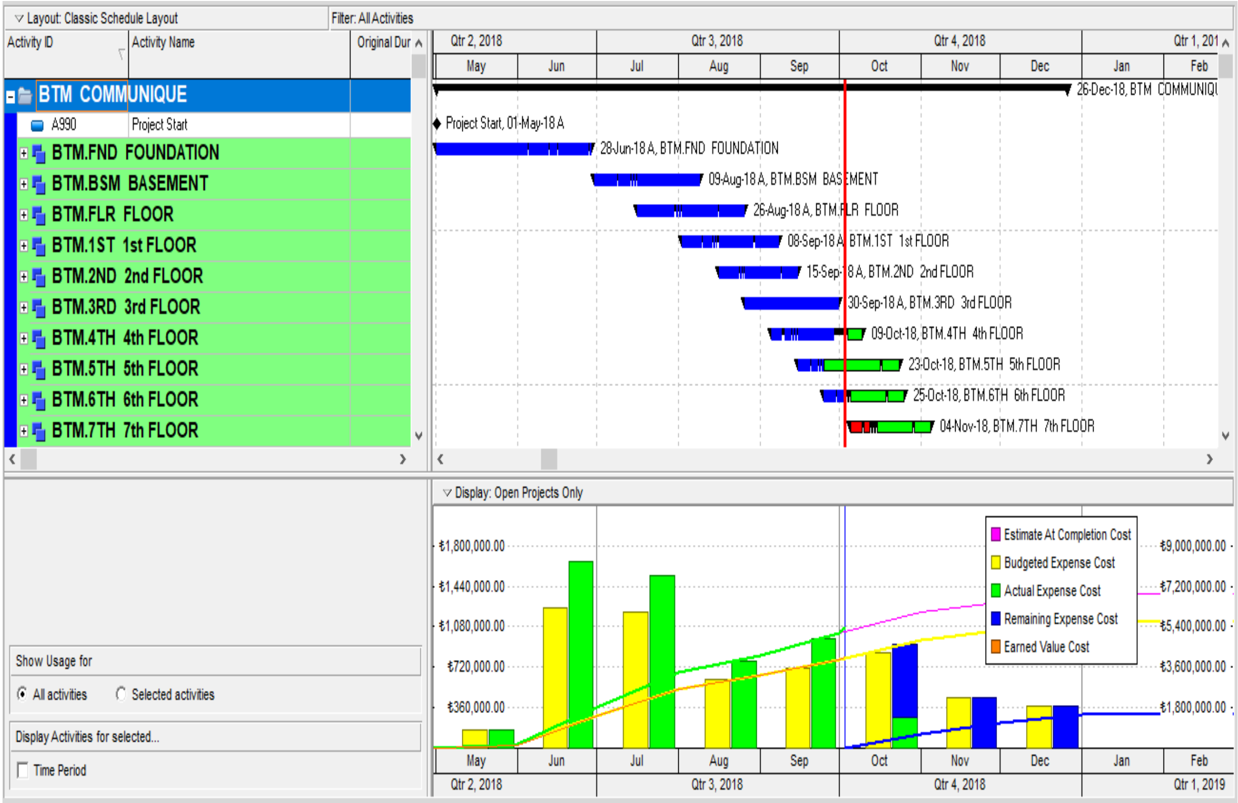

Figure 4: Gantt chart and resource usage.

According to the results, the Program Performance Index (SPI) value was determined as "1" and it was seen that the project continues according to the determined time. In the EVM analysis made for the 155th day, the EV value was designed as 4,033,683 TL, and the PV value as 4,033,683 TL. According to these values, the SPI value for this analysis is calculated as follows:

$$SPI = \text{Earned Value} / \text{Planned Value} = 4{,}033{,}683 / 4{,}033{,}683 = 1$$

According to the planned cost, while 4,033,683.00 TL should be spent at the end of the 155th day, 5,616,557.00 TL was spent. 155. At the end of the day, the earned value of the project was calculated as 4,033,683.00 TL. In case the project is completed with this trend, it can be said that the project, which has a total budget of 5,547,751.00 TL, will go beyond the budget limits and end the project to 6,849,749.00 TL. In other words, a total deviation of 1,301,998.00 TL is expected. A comparison of earned value and planned value is shown in Fig. 5. And the planned, actual, and earned values of the project are shown in Fig. 6.

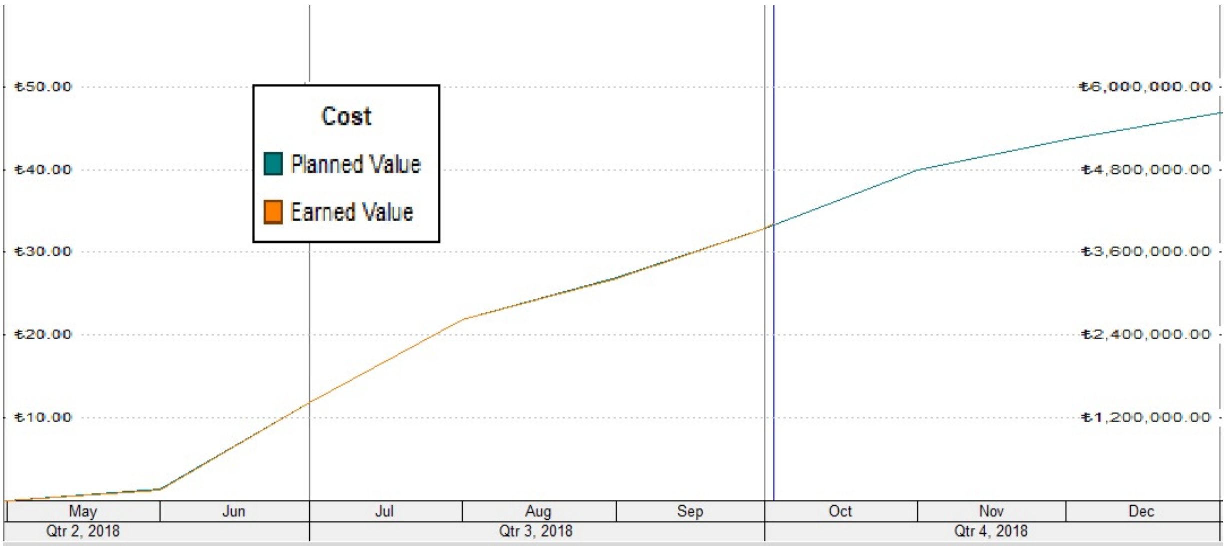

Figure 5: Comparison of EV and PV.

According to EVM analysis for the 155th day, the AC value was calculated as 5,388,105 TL. According to this value, the CPI value for this analysis is calculated as follows:

$$CPI = \text{Earned Value} / \text{Actual Cost} = 4,033,683 / 5,388,105 = 0.75$$

Activity ID	Activity Name	Original Duration	Start	Finish	Estimate At Completion Cost	Budgeted Total Cost	Estimate To Complete	Planned Value Cost	Earned Value Cost	Actual Total Cost	Schedule Performance Index	Cost Performance Index
BTM	COMMUNIQUE	240	01-May-18 A	26-Dec-18	₺6,849,749.00	₺5,616,557.00	₺1,461,644.00	₺4,033,683.00	₺4,033,683.00	₺5,388,105.00	1.00	0.75
A990	Project Start	0	01-May-18 A		₺0.00	₺0.00	₺0.00	₺0.00	₺0.00	₺0.00	0.00	0.00
BTM.FND	FOUNDATION	59	01-May-18 A	28-Jun-18 A	₺1,806,756.00	₺1,407,987.00	₺0.00	₺1,407,987.00	₺1,407,987.00	₺1,806,756.00	1.00	0.78
BTM.BSM	BASEMENT	40	30-Jun-18 A	09-Aug-18 A	₺1,328,320.00	₺1,047,440.00	₺0.00	₺1,047,440.00	₺1,047,440.00	₺1,328,320.00	1.00	0.79
BTM.FLR	FLOOR	41	16-Jul-18 A	26-Aug-18 A	₺388,673.00	₺302,727.00	₺0.00	₺302,727.00	₺302,727.00	₺388,673.00	1.00	0.78
BTM.1ST	1st FLOOR	38	02-Aug-18 A	08-Sep-18 A	₺318,466.00	₺238,832.00	₺0.00	₺238,832.00	₺238,832.00	₺318,466.00	1.00	0.75
BTM.2ND	2nd FLOOR	31	16-Aug-18 A	15-Sep-18 A	₺318,466.00	₺238,832.00	₺0.00	₺238,832.00	₺238,832.00	₺318,466.00	1.00	0.75
BTM.3RD	3rd FLOOR	31	26-Aug-18 A	30-Sep-18 A	₺318,466.00	₺238,562.00	₺0.00	₺238,562.00	₺238,562.00	₺318,466.00	1.00	0.75
BTM.4TH	4th FLOOR	36	05-Sep-18 A	09-Oct-18	₺318,466.00	₺238,562.00	₺0.00	₺203,409.00	₺203,409.00	₺318,466.00	1.00	0.64
BTM.5TH	5th FLOOR	39	15-Sep-18 A	23-Oct-18	₺318,466.00	₺238,562.00	₺0.00	₺203,409.00	₺203,409.00	₺318,466.00	1.00	0.64
BTM.6TH	6th FLOOR	31	25-Sep-18 A	25-Oct-18	₺289,297.00	₺238,562.00	₺86,077.00	₺152,485.00	₺152,485.00	₺203,220.00	1.00	0.75
BTM.7TH	7th FLOOR	31	05-Oct-18	04-Nov-18	₺325,250.00	₺307,368.00	₺256,444.00	₺0.00	₺0.00	₺68,806.00	0.00	0.00
BTM.8TH	8th FLOOR	31	15-Oct-18	14-Nov-18	₺240,917.00	₺240,917.00	₺240,917.00	₺0.00	₺0.00	₺0.00	0.00	0.00
BTM.9TH	9th FLOOR	31	25-Oct-18	24-Nov-18	₺240,917.00	₺240,917.00	₺240,917.00	₺0.00	₺0.00	₺0.00	0.00	0.00
BTM.10TH	10th FLOOR	31	04-Nov-18	04-Dec-18	₺251,082.00	₺251,082.00	₺251,082.00	₺0.00	₺0.00	₺0.00	0.00	0.00
BTM.ROOF	ROOFTOP	42	15-Nov-18	26-Dec-18	₺386,207.00	₺386,207.00	₺386,207.00	₺0.00	₺0.00	₺0.00	0.00	0.00

Figure 6: Planned, spent and earned value costs of the project.

According to the SPI value obtained as a result of this study, it is understood that there is no time overrun in the project. As can be understood from the value of CPI = 0.75, it is seen that much more money was spent on the 155th day of the project than the planned cost. This situation is thought to be caused by the sudden increase in material prices due to the increase in the exchange rate, and the raising in the amount of work due to the changes made during construction. Also, it is thought that the extra labor costs incurred due to the increasing amount of work contribute to the total cost exceeding for the project to be completed in the planned time.

In line with these data, measures should be taken for the expected cost overrun for the advanced stages of the project. Proactive measures must be taken by the project team, especially for ongoing activities that have the greatest impact on the total cost of the project.

Results

In this study, it is aimed to analyze the time and cost performance of construction projects and to reveal the factors affecting these performance values. For this purpose, the rough construction phase of a residential construction was taken as an example and the time and cost performances of the project were examined using the earned value analysis technique. The data obtained as a result of this study; shows that performance monitoring in construction projects is critical in achieving the time and cost targets planned in the project. In light of the data obtained; it is also seen that project performance monitoring helps to balance project constraints throughout the project life.

The project's time and cost estimates made during the execution of the project are very important in terms of the orientation of the project over time. As in the project chosen as an example for this study, if the project delay is not tolerable according to the decisions taken, the cost can exceed the optimum level in order to maintain the quality. Since the projects are unique in the construction industry, each project can have different risks. When the risky situation occurs, it is necessary to shape the others in this framework, whichever is desired to be protected from these components.

As in similar studies on this subject, this study aimed to help measure and increase project performance. Solid steps can be taken for the future of the project, as long as there is a tight follow-up between construction work at the site and baseline plan at the beginning. It is considered that monitoring project performance will enable a proactive management transition and this proactive approach will be a positive effect on project success.

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A Risk-Based Approach to Prevent Unbalanced Bids

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Abstract

An unbalanced bid is a bid that contains manipulated unit bid prices that do not reflect the reasonable unit bid prices. Owners should be able to stop an unbalanced bid because it may increase the cost of construction. Therefore, the majority of the current literature on unbalanced bidding focused on how to detect unbalanced bids in order to reject them. However, encouraging owners to reach a compromise between what they want and what bidders want can provide mutual benefits. Therefore, this study proposes an approach that prevents unbalanced bids instead of rejecting them. It adjusts the submitted bids by using a parameter called counterbalance ratio. It is calculated by dividing the bid price of the bidder by the adjusted bid price determined by Monte Carlo Simulation. The use of counterbalance ratio helps to counteract the impact of unacceptable unbalanced bids. The proposed approach is illustrated on an example from the literature to demonstrate the effectiveness of the proposed approach. The findings reveal that it can be used to prevent unbalanced bids. It is also anticipated that, the proposed approach will deter bidders from unbalancing their bids.

Keywords: *Monte Carlo simulation, prevention, unbalanced bidding.*

Introduction

Unbalanced bidding has always been a serious problem for owners. It is a bidding strategy that involves manipulating the unit prices of bid items to make more profit (Manzo, 1997; Su and Lucko, 2015; Hoogenboom et al., 2006; Hyari, 2016). There are two main categories of unbalanced bids: (1) mathematically unbalanced bids and (2) materially unbalanced bids. According to the Federal Highway Administration (FHWA) guidelines reported by Heinz (page A-113, 1998), a mathematically unbalanced bid has been defined as “A mathematically unbalanced bid is one containing lump sum or unit bid items which do not reflect reasonable actual costs plus a reasonable proportionate share of the bidder’s anticipated profit, overhead costs, and other indirect costs, which he/she anticipates for the performance of the items in question.”. In other words, a bid is considered mathematically unbalanced if the prices of bid items are significantly overstated or understated when compared to the owner’s estimate or other bidders’ prices.

Having a mathematically unbalanced bid does not mean that it is unbalanced in a way that can increase the cost to the owner. At this point, the second type of unbalanced bid becomes the main topic of the conversation, namely, materially unbalanced bid. Therefore, if an owner doubts that a bid is mathematically unbalanced, the bid has to be examined in detail in order to determine whether it is also materially unbalanced. According to the FHWA guidelines (page A-113, 1998), "A bid is materially unbalanced if there is a reasonable doubt that award to the bidder submitting the mathematically unbalanced bid will result in the lowest ultimate cost to the government.". If the analysis of the mathematically unbalanced bid reveals that it may cost more money to the owner, then it is a materially unbalanced bid. It should also be noted that a bid can be mathematically unbalanced, but not materially unbalanced (Arditi and Chotibhongs, 2009). Bids can be unbalanced via three methods, namely, front-end loading, back-end loading, and quantity error exploitation (Cattell et al., 2007; Cattel et al., 2008).

The majority of the current literature on unbalanced bidding in construction focuses on how to unbalance a bid (e.g., Yizhe and Youjie, 1992; Afshar and Amiri, 2010; Cattell et al., 2011) while only a few studies have investigated the ways of detecting and preventing unbalanced bids (e.g., Arditi and Chotibhongs, 2009; Polat et al., 2020; Su et al., 2020). It is important to detect and prevent an unbalanced bid to eliminate its negative effects. Most of the studies focused on how to detect unbalanced bids intended to reject them. However, encouraging owners to reach a compromise between what they want and what bidders want can provide mutual benefits. Therefore, this study proposes an approach that prevents unbalanced bids instead of rejecting them. It adjusts the submitted bids by using a parameter called counterbalance ratio. It is calculated by dividing the bid price of the bidder by the adjusted bid price determined by Monte Carlo Simulation. The use of counterbalance ratio helps to counteract the impact of unacceptable unbalanced bids. The proposed approach is illustrated on an example from the literature to demonstrate the effectiveness of the proposed approach.

Literature Review

The main objective of this literature review is to summarize the studies focused on approaches that attempt to detect and prevent unbalanced bids. Wang (2004) proposed a bidder-based quantitative approach to prevent unbalanced bids. This approach mainly concentrates on reviewing and adjusting unit prices offered by the bidders. Wang (2004) also stated that the procedure had been successfully utilized in the detection of unbalanced bids in Taiwan. Arditi and Chotibhongs (2009) presented two different models to detect bids unbalanced by front-end loading and quantity error exploitation. The main idea behind these models is based on comparing unit prices of each bid item with the owner's estimates and the average prices offered by all bidders. Hyari et al. (2016) developed a model that considers the factor of uncertainty in estimated quantities of bid items to detect unbalanced bids. The proposed model uses Monte Carlo simulation to measure the risk impacts of differences between actual and estimated quantities of bid items. Hyari (2016) suggests preventing unbalanced bids instead of rejecting them. The proposed model provides a systematic procedure to neutralize the negative effects of unbalancing. It uses the average unit price of all bidders to adjust the unit price of every bid item submitted by each bidder. This procedure does not change the total bid amount of bidders. Nikpour et al. (2017) proposed an unbalanced bid detection tool, which is based on Bid Markup Distribution Index (BMDI) graph. The developed tool also uses Monte Carlo simulation to consider the impacts of cost uncertainties and risks. An et al. (2018) developed a model that is based on the owner's estimated price as an evaluation criterion. Polat et al. (2020) propose an approach which contains eight grading systems. In this approach, the final score of each bidder is calculated assigning weights to each grading system according to the project characteristics. Su et al. (2020) developed a multi-criteria decision making model to detect unbalanced bids. The proposed model uses VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) method. In order to detect unbalanced bids, it considers the bid items and bidders as criteria and alternatives, respectively.

Even though researchers have attempted to solve the detection of unbalanced bids problem by offering different approaches, most of these attempts have ignored the notion that reaching a compromise between what owners want and what bidders want can provide mutual benefits. In other words, the review of the current literature on unbalanced bidding reveals that researchers ignore the fact that mutual benefits can be reaped by owners and contractors while solving the unbalanced bidding problem. Therefore, the main objective of this study is to develop an unbalanced bidding detection model in which owners can reach a compromise between what they want and what bidders want.

Model Development

The presented model is designed to prevent unbalanced bids instead of rejecting them. The development steps of the model are described below. The first step of the model is the utilization of Monte Carlo simulation to calculate the average unit price of bid items. The average unit price is used to adjust the unit price of every bid item submitted by each bidder. Previous models (e.g., Hyari, 2016) used arithmetic mean for this purpose. There is a reason for using Monte Carlo simulation instead of the arithmetic mean to calculate the average unit price of bid items. Arditi and Chotibhongs (2009) state that the bid item prices may be skewed by several bidders. Therefore, using the arithmetic mean to calculate the average unit price of bid items may not neutralize the negative effects of unbalanced bids. In addition, the bid item prices offered by different bidders are also estimates that increases the uncertainty inherent in the process. In order to utilize Monte Carlo simulation, the model first determines the minimum, most likely, and maximum values for each bid item to define a triangular distribution. The minimum and maximum unit prices offered by the bidders represent the minimum and maximum values for the triangular distribution, respectively (Eqs. 1 and 2). The average unit price of all bidders for each bid item is defined as the most likely estimate (Eq. 3).

$$UP_{min_n} = min_{m=1}^{M} \left\{ UP_n^m \right\} \tag{1}$$

$$UP_{max_n} = max_{m=1}^{M} \left\{ UP_n^m \right\} \tag{2}$$

$$UP_{ave_n} = \frac{\sum_{m=1}^{M} UP_n^m}{M} \tag{3}$$

where UP_n^m = unit price of the bid item *n (n= 1 to N)* submitted by the bidder *m (m= 1 to M)*; UP_{min_n} = minimum unit price for the bid item *n* submitted by all the bidders; UP_{max_n} = maximum unit price for the bid item *n* submitted by all the bidders; UP_{ave_n} = the average of unit prices submitted by all the bidders for each bid item; N = the number of bid items, and M = the total number of the bidders who submit a bid into the project.

In the second step, the Monte Carlo simulation generates random bid item prices based on the designated range of values, and triangular distribution. This process is repeated for the number of iterations determined by the user. Thereafter, the Monte Carlo simulation provides a distribution of the bid item prices. The arithmetic mean of the values of bid item prices in this distribution is calculated in order to be used in the computation of the counterbalance ratio (Eq. 4).

$$UP_{MCS_n} = \frac{\sum_{t=1}^{T} MCS_t \left\{ UP_{\min_n}; UP_{ave_n}; UP_{\max_n} \right\}}{T} \tag{4}$$

where UP_{MCS_t} = unit price for the bid item n generated in each iteration t *(t= 1 to T)*, T = the total number of iterations determined by the user, and UP_{MCS_n} = the average unit price for the bid item n derived by Monte Carlo simulation.

The proposed model intends to stop excessive unbalancing by keeping it within reasonable limits. Therefore, it uses a counterbalance ratio to adjust the bid item prices submitted by each bidder. In the third step, in order to compute the counterbalance ratio, the total bid price of a bidder (BP_m) is divided by the adjusted bid price (BP_{MCS}) calculated using the average unit prices of each bid item obtained as a result of Monte Carlo simulation (Eqs. 5-7).

$$BP_m = \sum_{n=1}^{N} \left(UP_n^m \times q_n \right) \tag{5}$$

$$BP_{MCS} = \sum_{n=1}^{N} \left(UP_{MCS_n} \times q_n \right) \tag{6}$$

$$C_{countb}^m = \frac{BP_m}{BP_{MCS}} \tag{7}$$

where C_{countb}^m = counterbalance ratio for the bidder m, and q_n = quantity of the bid item n estimated by the owner.

In the fourth step, the bid item prices submitted by the bidders are multiplied by the counterbalance ratio to compute the adjusted bid item prices (Eq. 8). Thus, the proposed model neutralizes the negative impacts of manipulated bid item prices. In other words, the proposed model rebalances all the bids submitted by the bidders.

$$UP_n^{m(adj)} = UP_n^m \times C_{countb}^m \tag{8}$$

where $UP_n^{m(adj)}$ = adjusted unit price for the bid item n submitted by the bidder m.

In the last step, the total bid price submitted by a bidder is recalculated by using the adjusted bid item prices (Eq. 9). The proposed model ensures that the total bid price of a bidder remains unchanged after adjusting the bid item prices. Thus, the nature of competitive bidding is preserved.

$$BP_m^{(adj)} = BP_m = \sum_{n=1}^{N} (UP_n^{m(adj)} x q_n) \tag{9}$$

where $BP_m^{(adj)}$ = the adjusted bid price submitted by the bidder *m*.

Most of the previous unbalanced bid detection models reject unbalanced bids without considering the adjustment of bid item prices. The proposed model in this study adjusts the bid item prices instead of rejecting unbalanced bids. Thus, it protects the interest of the owner. In addition, the proposed model preserves the total bid price offered by a bidder to provide a fair competition environment.

Case Study

The illustration of the proposed model can be best demonstrated by an example. An example project from the literature is used for this purpose (Arditi and Chotibhongs, 2009). The example project consists of 17 bid items. Five bidders submitted bid offers for the project. The information on the estimated quantity and unit prices offered by the bidders for each bid item is presented in Table 1.

Table 1. Bid results of five bidders on the example project.

Bid Item	Estimated Quantity	Unit Price ($)				
		Bidder 1	Bidder 2	Bidder 3	Bidder 4	Bidder 5
1	29	5.000	16.394	17.589	16.554	16.217
2	14	34.538	5.000	33.431	34.240	32.326
3	12	18.552	18.704	19.486	20.335	19.609
4	30	90.000	69.923	69.380	72.040	67.827
5	6	600.000	450.000	300.000	306.527	324.964
6	12	1.132	1.059	1.006	946	1.006
7	30	40.000	50.000	88.806	87.769	96.949
8	14	4.760	4.515	4.501	4.533	4.313
9	25	61.587	67.031	73.251	70.689	71.043
10	25	98.816	140.000	109.241	110.383	113.937
11	7	4.957	4.894	4.350	4.433	4.487
12	30	3.674	3.759	3.313	3.505	3.501
13	2	20.000	172.000	165.000	170.000	165.000
14	16	2.979	3.114	2.751	3.005	3.212
15	18	7.851	8.510	8.078	8.178	8.780
16	5	3.485	3.278	3.134	3.005	3.153
17	32	9.131	9.573	11.064	11.170	10.217
Total ($)		13.124.973	13.336.015	13.413.891	13.482.422	13.766.763

Bidder 1 submitted the lowest (i.e., $13.124.973) total bid price. If one reviews the unit prices presented in Table 1, one will see that Bidder 1 submitted extremely low unit prices for bid items 1, 7, and 13, when compared to unit prices of other bidders. On the other hand, Bidder 1 submitted extremely high unit prices for bid item 4 and 5, when compared to unit prices of other bidders. This discrepancy generates a reasonable doubt that award to the Bidder 1 will result in the lowest ultimate cost to the owner. In order to investigate this further, the steps explained in the previous section are followed to run Monte Carlo simulation for 5000 iterations. In order to calculate the average price of the bid items, random bid item prices were generated at each iteration using minimum, most likely and maximum values. The adjusted bid price is calculated using the average price of the bid items obtained from the Monte Carlo simulation and the quantities estimated by the owner for the bid items. After calculating the adjusted bid price, it is divided by the bid price of each bidder to compute the counterbalance ratio for each bidder. The counterbalance ratios and adjusted bid item prices of each bidder are presented in Table 2. The total bid price of each bidder is preserved unchanged even if the bid item prices are adjusted by counterbalance ratio (Table 2).

Table 2. Adjusted unit prices based on the rebalancing model.

Bid Item	Average Unit Price ($)	Bid Item Price ($)	Adjusted Unit Price ($)				
			Bidder 1	Bidder 2	Bidder 3	Bidder 4	Bidder 5
1	12.368	358.658	11.996	12.189	12.260	12.323	12.583
2	22.358	313.018	21.685	22.034	22.163	22.276	22.746
3	19.406	232.871	18.822	19.125	19.237	19.335	19.743
4	77.205	2.316.138	74.883	76.087	76.531	76.922	78.544
5	432.430	2.594.579	419.422	426.166	428.655	430.845	439.931
6	1.035	12.421	1.004	1.020	1.026	1.031	1.053
7	69.870	2.096.109	67.768	68.858	69.260	69.614	71.082
8	4.531	63.431	4.395	4.465	4.491	4.514	4.610
9	67.904	1.697.604	65.861	66.920	67.311	67.655	69.082
10	117.882	2.947.039	114.336	116.174	116.853	117.450	119.927
11	4.641	32.487	4.501	4.574	4.600	4.624	4.722
12	3.540	106.205	3.434	3.489	3.509	3.527	3.601
13	110.998	221.996	107.659	109.390	110.029	110.591	112.923
14	2.990	47.833	2.900	2.947	2.964	2.979	3.042
15	8.302	149.444	8.052	8.182	8.230	8.272	8.446
16	3.234	16.169	3.137	3.187	3.206	3.222	3.290
17	10.188	326.008	9.882	10.040	10.099	10.151	10.365
Bid Price ($)		13.532.010	13.124.97	13.336.01	13.413.89	13.482.42	13.766.76
Counterbalance Ratio			0,969919	0,985514	0,991269	0,996334	1,017346
Rebalanced Bid Amount ($)			13.124.97	13.336.01	13.413.89	13.482.42	13.766.76

The total bid prices are based on the estimated quantities, however, the actual quantities rarely match them. Therefore, the cost of the example project is also determined by multiplying the submitted bid item prices with the actual quantities identified during the construction (Table 3). Assuming that the lowest bidder (i.e., Bidder 1) is awarded, the findings reveal that the owner ends up paying $708.179 more than the submitted bid. It should also be noted that the lowest bidder becomes the second lowest bid when the actual quantities are considered.

Table 3. Cost of the project based on actual quantities.

Bid Item	Actual Quantity	Unit Price ($)				
		Bidder 1	Bidder 2	Bidder 3	Bidder 4	Bidder 5
1	32	5.000	16.394	17.589	16.554	16.217
2	16	34.538	5.000	33.431	34.240	32.326
3	14	18.552	18.704	19.486	20.335	19.609
4	30	90.000	69.923	69.380	72.040	67.827
5	7	600.000	450.000	300.000	306.527	324.964
6	12	1.132	1.059	1.006	946	1.006
7	35	40.000	50.000	88.806	87.769	96.949
8	14	4.760	4.515	4.501	4.533	4.313
9	28	61.587	67.031	73.251	70.689	71.043
10	22	98.816	140.000	109.241	110.383	113.937
11	7	4.957	4.894	4.350	4.433	4.487
12	33	3.674	3.759	3.313	3.505	3.501
13	2	20.000	172.000	165.000	170.000	165.000
14	16	2.979	3.114	2.751	3.005	3.212
15	18	7.851	8.510	8.078	8.178	8.780
16	5	3.485	3.278	3.134	3.005	3.153
17	35	9.131	9.573	11.064	11.170	10.217
Total ($)		13.972.881	13.953.694	14.251.683	14.311.549	14.641.465

Table 4. Cost of the project based on actual quantities after adjusting unit prices.

Bid Item	Actual Quantity	Adjusted Unit Price ($)				
		Bidder 1	Bidder 2	Bidder 3	Bidder 4	Bidder 5
1	32	11.996	12.189	12.260	12.323	12.583
2	16	21.685	22.034	22.163	22.276	22.746
3	14	18.822	19.125	19.237	19.335	19.743
4	30	74.883	76.087	76.531	76.922	78.544
5	7	419.422	426.166	428.655	430.845	439.931
6	12	1.004	1.020	1.026	1.031	1.053
7	35	67.768	68.858	69.260	69.614	71.082
8	14	4.395	4.465	4.491	4.514	4.610
9	28	65.861	66.920	67.311	67.655	69.082
10	22	114.336	116.174	116.853	117.450	119.927
11	7	4.501	4.574	4.600	4.624	4.722
12	33	3.434	3.489	3.509	3.527	3.601
13	2	107.659	109.390	110.029	110.591	112.923
14	16	2.900	2.947	2.964	2.979	3.042
15	18	8.052	8.182	8.230	8.272	8.446
16	5	3.137	3.187	3.206	3.222	3.290
17	35	9.882	10.040	10.099	10.151	10.365
Total ($)		13.894.761	14.118.180	14.200.624	14.273.174	14.574.192

After adjusting the unit prices by using the counterbalance ratio, the owner saves $13.754 when compared to the amount found by multiplying actual quantities with the unadjusted bid item prices (Table 4). It should also be noted that after recalculating the bids using the actual quantities but the adjusted unit prices proposed by the bidders, the original lowest bidder remains the lowest bidder.

Conclusion

Detection and prevention of unbalanced bids is crucial for both owners and contractors to maintain a fair competitive environment. Even though owners tend to reject unbalanced bids, reaching a compromise between what owners want and what bidders want can provide mutual benefits. For this purpose, an unbalanced bidding prevention model is presented in this study. The proposed model provides a procedure to prevent unbalanced bidding by rebalancing the bids rather than rejecting them. A parameter called counterbalance ratio is used to adjust the submitted bids. The counterbalance ratio is computed by dividing the submitted bid price by the adjusted bid price determined by Monte Carlo Simulation. The use of counterbalance ratio does not change the total bid price submitted by the bidders, but it alters the bid item prices. An example project from the literature is used to demonstrate the application of the proposed model. Indeed, the findings reveal that the model prevents unbalanced bids while keeping the original lowest bidder as the lowest bidder. It is also anticipated that, the proposed approach will deter bidders from unbalancing their bids. However, the proposed model has a limitation, as it does not consider the time value of the money. In addition, comparing the developed unbalanced bidding prevention model with alternative models can be explored in future research.

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Life-cycle Cost Analysis of the Radiant Heating & Cooling System Integrated with Air Source Heat Pump

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Abstract

In this paper, a new sustainable design of hybrid radiant heating and cooling system shall be discussed within the framework of Life Cycle Cost (LCC) and Life Cycle Assessment (LCA). The literature shall be reviewed regarding the system components advantages such as significant efficiency and human comfort and health. In today's world, efficient use of energy resources have become more crucial than ever. Many types of resources have been used to meet the additional burden of the growing population throughout the history. Their limitations lead to develop synergic combination of diverse resources in the face of this ever-increasing demand. A hybrid hydronic radiant system was aimed to be designed so that it could be used in all residence and office structures, and the aim of the design is to achieve a very substantial energy efficiency through synergy. This system contains two elements in particular; one is the radiant (hybrid) wall system and the other is the heat pump. The hybrid system shall be eventually implemented to an office building to create harmony and synergy together. Despite of the initial cost, they provide far greater thermal comfort and overall economic efficiency in the long term in comparison with conventional HVAC systems.

Keywords: *energy efficiency, heat pump, life-cycle cost analysis, radiant system.*

Introduction

Radiant heating method heats the surfaces of floors and walls in a room. These surfaces then slowly radiate most of the heat through radiation. Thus, people and other living creatures in the area benefit from this heat as much as they need. The best example of life that can be given to the thermal comforts given by heating with radiation is the following: Given that there is no breeze, a person feels comfortably warmed when he steps on earth that has been warmed through solar rays with no footwear, in spite of the low weather temperature. In a radiant heating system, initially the floor surface heats up, and the heat rises upward by radiation. In this case, there is no need for air current and no mass of hot air accumulating at the roof level occurs. It feels cooler at the head level and warmer at the foot level in radiant heating systems, which are the most suitable methods for human comfort.

Radiant heating cooling systems, which have been out of use for several centuries, were used by the Romans 2000 years ago and have become widespread in Europe in the last 50 years in modern form, these systems are the ideal way to heat the human body in homes and commercial buildings (US5292065, 1996). Radiant underfloor heating systems were used thousands of years ago according to the history of radiant heating cooling systems written by ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) members (Bean et al., 2010a). As stated in this historical record and as archaeological studies reveal, these systems were started to be used in ancient Asian countries such as China and Hun Empires, and later on they were used in the form of ground channels carved by Greeks and Romans were used. Similar systems were also used in the Middle East. Heating systems made of stone or kiln clay soil material consisting of a series of chambers called Hypocaustum and laid under the floor were used to heat all the rooms.

Figure 1: Remains of Hypocaust channels in Roman baths (Bean et al., 2010b).

First radiant cooling system, in which chilled water was used, has been observed in the early 8th century in the territory of Turkey (in Iraq). Much later, in the 20th century, the system, which was established by laying copper pipes on a concrete floor of a bank building in England, was used for both heating and cooling. Before the World War II, a radiant cooling system was installed to the German Parliament building. The system design included central heating, humidifier, and cooling. Radiant systems, which provide a great advantage compared to other heating and cooling systems in terms of energy and comfort, are becoming widespread today due to the ease of installation, dismantling and transportation brought by the developing technology. It is especially preferred in modern commercial and government buildings, as well as in individual private house buildings. For example, in 1933, after the accidental discovery of the polyethylene material in the ICI laboratory in the UK, this discovery led to the development of PEX pipes which became the solution to many of the previous piping challenges (Bean et al., 2010b).

Despite its many disadvantages, radiator systems, which use hot water convection heating, are used for heating and as for cooling; forced convection of cold air is used in air conditioning system, which cools the environment heterogeneously. Although the total installation and usage costs of these two methods are quite high, they also create an unbalanced temperature distribution within the space in terms of comfort. In these classical air-conditioning methods, heating is performed above the human comfort temperature for heating and cooling below the human comfort temperature for cooling. These have negative effects both in terms of cost and health. In addition, the air movement that the air conditioner generates in the space while working also adversely affects human comfort and health (Koca, 2011).

There are around 20,000 sensors that detect heat in the human body, 45% of them detect warmth and 55% of them detect cold and transmit the sensation to our brain. Our body constantly changes the blood flow rate to achieve thermal comfort. While this movement is constantly tiring our bodies, it creates both discomfort and fatigue and causes stress. As a result of the researches about the thermal comfort of humans (Bedir, 2012; Fabrizio et al., 2012; Koca et al., 2014; Tye-Gingras & Gosselin, 2012), a completely different system was developed to provide comfort to the people living in buildings, instead of the principle of heating and cooling buildings themselves like classical systems. This high level of comfort may be the case when the following conditions are met; the heat distribution in the living area is homogeneous, emitting very high radiation as the air temperature and the room temperatures are close to each other, the air is neither dry nor humid and the air movements are not disturbing (Markov, 2003).

As an ideal illumination is not possible with a single lamp in a room, it is not possible to provide high thermal comfort with a single classical heating unit. A more homogeneous ambient temperature can be provided with fan cooling systems, but in this case the sound and air movement level does not provide comfort as it reaches uncomfortable dimensions. It is necessary to optimize many variables together for human comfort. A high-comfort and hygienic system has been developed, which offers both high comfort and energy efficiency of around 60% and does not cause any discomfort or disease due to high-flow blowing such as air conditioning. This system is called radiant panel air conditioning system. Radiant panel air conditioning system can be offered as the most suitable solution for villas, hospitals, offices, shopping mall projects, educational and cultural facilities that will add value and design in terms of architecture and mechanics (mirhybridwall.com).

Unlike air conditioning systems, radiant panel air-conditioning systems do not have high air movement and they also do not have high energy expenditure for cooling, and convectional transmission that disrupts comfort as in hybrid radiant systems. Instead, there is radiation, which is the most suitable method for human comfort, with ceiling and wall temperature close to the ambient temperature with minimum air movement. Classical systems provide an air movement where humans can only receive maximum 30% heat. However, humans receive heat with 50% radiation. Therefore, classical systems do not contribute significantly to thermal comforts with very low radiation rate. However, hybrid radiant panel heating and cooling systems with integrated heat pump source offer the most ideal comfort conditions for people with around 70% radiation and around 30% air movement (Zhao et al., 2016).

Hybrid radiant wall panel systems are a lightweight composite structure consisting of a glass fiber reinforced outer shell (GRC, precast concrete) for surface heating and cooling, filled with a low density, thick foam concrete and PEX pipes with 10mm diameter oxygen barrier embedded in the foam. It is designed as a facade cladding system. Hybrid wall systems also contribute to heat and sound insulation. In addition to being light, flexible, and low cost, it also contributes to building resistance against earthquake by increasing its strength with glass fiber reinforcement. Glass fiber reinforcement increases the breaking and bending resistance of the hybrid wall. It prevents or reduces cracks caused by thermal stress on the panel due to external temperature differences. The fire resistance of the system also increases with its melting point at 170ºC, as it creates steam at high temperatures and this steam also creates ducts reducing the risk of fire. Thanks to the insulation layer inside the developed panel, heat losses that may occur behind the panel are prevented (Erikci Çelik et al., 2016; Koca, 2018; Koca & Cetin, 2017; Koca et al., 2014).

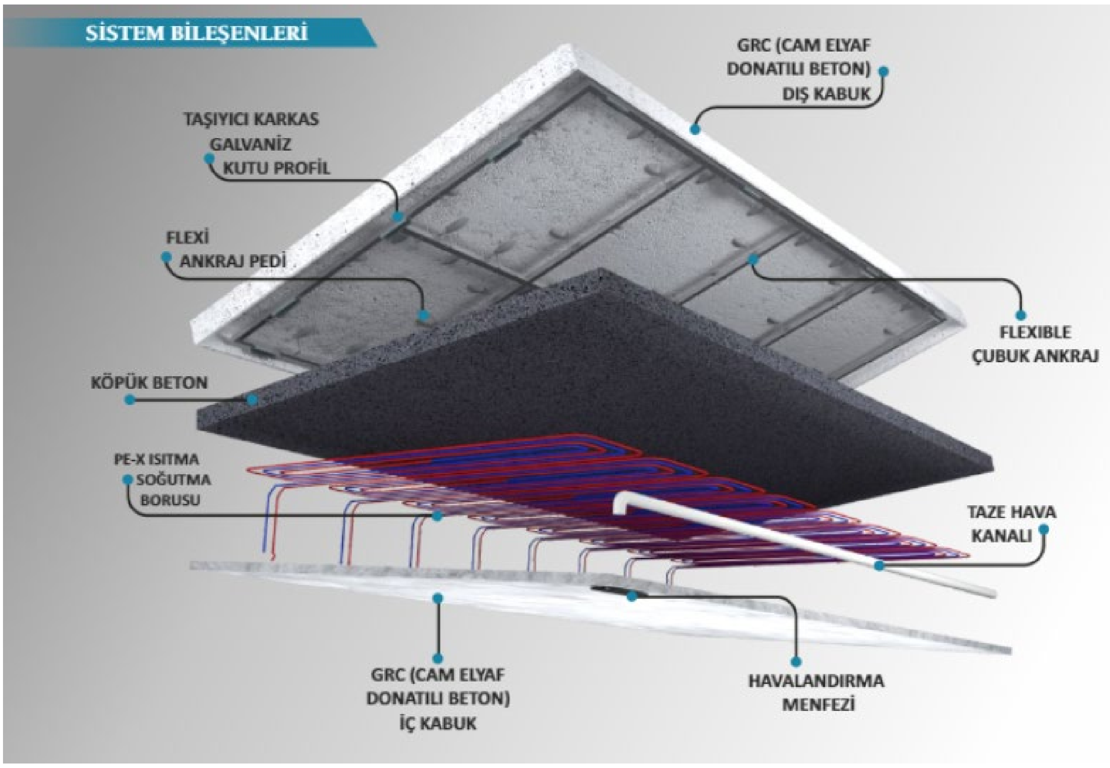

Figure 1: Precast hybrid radiant heating cooling system (mirhybridwall.com).

When a radiant panel is used to heat an environment, heat energy is transferred directly to the objects in the environment along with the radiation emitted from the panel, and the radiant temperature rises due to the high panel surface temperature. Thus, heating with radiant panels can be made at lower air temperatures than heating systems and the same comfort conditions can be provided (Bedir, 2012; Koca et al., 2014).

Radiant Panel Air-Conditioning System Advantages and Disadvantages

The main advantages of the radiant panel air conditioning system compared to conventional systems can be listed as follows:

- Depending on the application, there is a decrease in heat loss between 20-50%,
- It is a suitable system for all types of water heaters, from high temperature producing boilers to low temperature source heat pumps and solar panels,
- Ideal for high, large interior spaces and glassy spaces that are difficult to heat,
- Since it does not cause air movement inside the building, it does not cause dust and dirt accumulation and air contamination, thus eliminating allergic problems,

- Since the radiant system is not visible, it does not narrow down the heated space and does not prevent mobility in the area. There is no such thing as working around heating equipment.
- It is the air conditioning system where thermal comfort is provided at the best level and provides the most suitable environment for human physiology. It is the most suitable system for human physiology. In principle, instead of air-conditioning, comfort is achieved by direct heating and cooling of people with high radiation through convection.
- Equal thermal comfort and homogeneous temperature distribution is provided at every point of the site.
- No extreme cold or extreme hot surface is formed, system temperature changes between 16-35 ^{o}C throughout the year.
- It does not dry the air.
- There is no annoying high-speed air flow in the area.
- Since both heating and cooling can be done, the same system can be used all year round by changing the fluid temperature without the need to install heating and cooling systems separately.
- Compared to conventional systems, a more aesthetic appearance is obtained as well as more living space is provided within the space.
- It saves up to 60% energy in the case of heating and cooling as the peak load is reduced compared to conventional systems.
- With the fluid temperature requirement closest to room temperature, the efficiency of the heater or cooler heat generators used in these systems increases significantly, as energy consumption and operating costs decrease. It also maximizes the performance of heat pump devices, as it concerns our subject closely.
- In cooling, the efficiency of the chiller and heat pump devices increases as the return water temperature difference is low.
- The thermal loss / gain of the building is reduced by up to 15% since thermal comfort is provided at 2-3 degrees lower / higher temperatures due to the radiative temperature effect in winter and summer.
- Since it can be heated with 30 degrees of fluid and cooled with 20 degrees of fluid, it is the ideal system for the use of low energy sources called low quality energy and the use of renewable energy sources. In this way, it is perhaps the most important air conditioning system that will reduce our country's dependence on foreign energy.
- It contributes to the sustainability of the natural environment. It is also possible to insulate the building from the inside with the insulation it contains.
- It does not create any sound, noise, as it passively air conditions the place.
- It makes it easier to obtain certificates such as LEED and Breeam.
- It is compatible with all conventional or renewable energy generators.

The condensation problem of hydronic (hot water circulating) radiant systems creates maintenance and equipment costs in the long term. Significant developments will be reviewed in the literature review to minimize these costs. For example, the use of PEX, very strong flexible material polyethylene pipes, in hot water circulation eliminated many problems and contributed significantly to the ease of installation and maintenance. PEX plastic pipes must be produced with oxygen barriers. Oxygen diffusion of the system should not be allowed. This is with regards to the tests conducted by the German standard institute (DIN), where the presence of 5mg (mg / lt / day) oxygen in 1 liter of water per day in the closed hot water cycle of oxygen eliminates the phenomenon of dead water (oxygen-free water) and creates a serious corrosion problem as if there is fresh water in the system. The safe oxygen diffusion limit set by DIN to prevent corrosion in heating system equipment has been determined as 0.1mg / lt / day at 40 °C water in PEX plastic pipe system.

Keeping the water temperature fed by the hydronic heating cycle low may seem more suitable for the long life of the pipes but setting the boiler to low temperature results in the condensation of fossil fuel. The condensation temperature of the fossil fuel can rise up to 60 °C. To avoid this condensation, it is undesirable to go below this threshold temperature. In radiant wall heating systems that generally supply hot water to the system by burning fossil fuels, it should be above 60 ° C and generally around 90 ° C. To extend the life of the pipes, the hot water coming out of the boiler can be lowered before it is dispersed into the system. Before using the hydronic heating cycle in 1990, closed-loop control system was used, it provided feedback with thermostat for water temperature control (US00519988A, 1992).

Life Cycle Cost and Life Cycle Assessment

In this study, it is desired to make the necessary design improvements that are required by the radiant panel heating and cooling system in order for it to be an economical system with low life cycle cost, optimum installation, operation and energy costs. Scrap cost (Glick et al., 2010), fossil fuel use and harmful emission values are also (Kilkis, 2006) included in this life cycle cost. 'The LCC is the total cost of owning, operating, maintaining, and (eventually) disposing of the building system(s) over a given study period (usually related to the life of the project), with all costs adjusted (discounted) to reflect the time value of money" (Glick et al., 2010). The authors also considered to include the salvage value in calculation of LCC.

The cost of obtaining a product is 30% of the total cost of ownership. Seventy percent is the operating, maintenance, spare parts and financial costs. The conclusion we need to draw from here is that when buying a product or a system, the issue we need to focus on during installation is the costs that will arise during the life cycle after installation rather than the initial installation cost and the fact that they are predictable. The competition and superiority of product developers against each other help minimizing lifetime costs. At this point, the life cycle cost (LCC) concept comes to the fore in controlling a product's lifelong maintenance and operating costs. The concept of winning while buying a product should not be considered as the most inexpensive, instead as the most economical by taking into account the total cost of ownership. With the amendment made in the Turkish Public Procurement Law in August 2013, in determining the most economically viable proposal; it is allowed to determine the most economically advantageous bid by including the factors not only the price but also the operation and maintenance cost, effectiveness, efficiency, quality and technical value. Therefore; considering the total possession cost in construction and supply, tenders will provide a significant gain to the administrations in determining the most suitable bid and will allow avoiding or at least reducing the resource waste which has not been considered much at this point so far in the long term. In this study, the radiant panel system developed by MİR Holding Heat Systems will be transformed into a hybrid radiant panel air conditioning system with integrated heat pump. Necessary design models and numerical analysis will be carried out for this. In addition, a life cycle cost analysis will be carried out not only in terms of purchase and installation costs, but also with long-term experimental measurements made during the hottest and coldest periods of the thermal and economic parameters during operation.

There are many valuable researches in recent years regarding thermal comfort and energy efficiency of radiant air conditioning systems (Koca & Cetin, 2017; Zhao et al., 2016). Many design optimizations are possible to improve these two parameters. It has been developed since the first years with its modern structure with the advancement of technology over the (US005579996A, 1996; US5292065, 1996; US005931381A, 1999) years. Many patents have been obtained regarding the developed radiant heating and cooling systems. Many numerical and experimental analyses have been made on this subject and this subject has been the focus of many articles and papers in theses and international journals and conferences. In recent years, patent and publication studies on radiant systems have made significant progress in our country. However, there are still aspects of the system that need to be developed in design to increase thermal comfort and energy efficiency. In addition, the economic parameters of the system should be analysed comprehensively in terms of life cycle costs.

Even though heat pumps or geothermal energy is not covered with regards to the cost effectiveness, Leckner and Zmeureanu, (2011) mentions that using these energy sources are likely more efficient due to their coefficient of performance (COP) values. Similar to the LCC analysis, they monitor cumulative cash flow (CCF) over life cycle of a HVAC product used in a certain house to figure out the financial payback and eventually they conclude that the system is expensive so that it never financially pays back due to the high cost of the solar technologies and low electricity costs in the location (Montreal, Quebec, Canada) where they conducted the measurements, which would not be assumed to be the case in Turkey. However interestingly another study including LCA found different payback results for solar heating system in the U.S: Hang et al. (2012) assessed life-cycle inventory of solar hot water system using commercially available LCA database softwares SimaPro and EcoInvent. They included manufacturing, use, disposal as well as transportation among these stages. As a benchmark, they provided the result with respect to comparison of solar heating system with electrical water heating system: The energetic and environmental payback periods for solar water heating systems are less than half of a year, and the life cycle cost payback for solar water heating systems vary from 4 to 13 years for different cities and different configurations when using the conventional electrical water heating system.

Even more interestingly, another study presented by Cheng Hin & Zmeureanu (2014) in Montreal (Quebec), Canada conducted combination of three analyses: life cycle energy (LCE), and life cycle exergy (LCX) and, LCC for optimization of a solar combi-system and found these results: four different optimal configurations depending on the objective function used. The optimizations were able to reduce, compared with the base case combi-system, the life cycle cost of the combi-system by 19%, the life cycle energy use by 34%, the life cycle exergy destroyed by 33% and 24% using the technical boundary and physical boundary, respectively. Due to the high cost of the solar collector technologies and the low price of electricity in Quebec, none of the optimal configurations have acceptable financial payback. Lifespan was taken as 40 years in the calculation. LCC is calculated using Eq. by taking present worth (PW) into account as well as financial parameters such as the inflation rate, discount rate, price of electricity (average price of electricity for customers using an average of 1000 kW h per month), increase rate of electricity price (Average rate of increase in electricity prices in Quebec between 2006 and 2010).

$$LCC = \text{Initial Cost} + \text{PW}_{\text{repl.cost}} + \text{PW}_{\text{Energy-cost}} \quad (1)$$

In order to maintain the combi-system at comfortable temperatures in the house, a new metric, hours under the heating set point (HUSP) was also taken into account. For this, the operative air temperature is monitored in each area the number of hours in each room HUSP temperature is counted over the heating season and while set-back temperatures are not in effect. The HUSP is the sum of the total number of hours that each zone spends under the heating set point throughout the year. Due to the sudden change in set point temperatures immediately after the set-back temperature is no longer in effect, a certain amount of HUSP is inherent depending on the heater capacity. The HUSP takes into account, along with other factors, how quickly the system is capable of raising temperatures to comfortable levels when the house occupants wake up. For the purpose of the optimization, the acceptable number of HUSP is increased to 550. This value is used as a baseline for adequate thermal comfort performance of the combi-system. In order to modify the objective function such that any design that allows more than 550 HUSP is omitted, a penalty function is added to the objective function, which adds an arbitrarily large amount to the objective function value such that the underperforming configuration can never be selected as optimal. The LCC objective function (Eq.(1)) is modified as follows:

$$LCC = \text{Total Initial Cost} + \text{PW}_{\text{repl.cost}} + \text{PW}_{\text{Energy-cost}} + \text{lt}\left(550, HUSP\right) \cdot 200.000 \qquad (2)$$

where the function lt(550, HUSP) returns 1 if 550 is less than HUSP and 0 otherwise.

“Life cycle assessment (LCA) is to date the most widely used tool for generating the environmental profile (including energy consumption and greenhouse gas emissions) of a product or process” (Hang et al., 2012). The researchers commonly combine LCA and LCC analyses for different lifespan (10-25 years) of HVAC systems.

Glick et al. (2010) compared life-cycle environment effects in terms of Life Cycle Assessment (LCA) and LCC of a residential gas forced air and solar hydronic radiant heat system in Colorado, US. LCA is composed of five phases: material extraction, conversion, manufacturing, maintenance/use, and disposal/reuse. In LCA, the environmental impacts including energy consumptions, emissions, and carbon footprints need to be determined from raw material phase – i.e. even before a product or process has complemented – to it is salvaged or recycled after it is scrapped according to the authors. Glick et al. (2010) implemented combination of traditional process based LCA and an alternative LCA methodology using the strength of each LCA and eliminating their weaknesses. the Economic Input / Output LCA (EIO-LCA) expanding the case study boundary to include upstream supply chain impacts and reduces the impacts of time, cost, and proprietary issues that affect traditional process-based LCA.

Conclusion

In this study, we will conduct experiment in collaboration with Mir Holding and take measurements in the summer and winter of 2021 using an experimental setup in the Mir Holding’s office where 80 people currently work. The acquired data shall be examined in two different ways:

LCC (Life Cycle Cost),

Cumulative cash flow analysis shall be conducted by examining the invoices with regards to energy consumption of the office building. The effects of the heat pump and radiant heating and cooling system on the energy consumption and therefore the material expenses will be financially observed. The data comparison of conventional systems with combi-radiators and air-conditioning systems will be performed. Significant difference is expected to be obtained herein due to the synergy generated by the hybrid system that is novel example in Turkey. The system is expected to shed light on all residential and business buildings.

LCA (Life Cycle Assessment),

Under this title, we the issues such as the sustainability of the system, its impact on the environment, and carbon emissions shall be generally examined. Since the novel hybrid HVAC system from which thermal measurements are to be acquired, operates at low temperature, which increases environmental efficiency in this regard. Under the LCA title, through the use of a company called *Metsims'* database included in LCA software called *SimaPro* (Hang et al., 2012)*,* all components will be handled one by one and a detailed comparison will be made.

Through this work, we aim at minimizing the inefficient use causing a vicious cycle and raising the awareness for the radiant wall systems especially in Turkey. Instead of providing efficiency with a single device, obtaining synergy by applying multiple equipment as hybrid heating and cooling system to a structure shall fill a deficit in the HVAC sector that is rigid and lacking in innovation. The works carried out will form a base for the future works and they may also be enhanced with the addition of some sustainable system. For example, photovoltaic panels can be used in electricity generation and can feed the heat pump.

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Feasibility Study of Using BIM in Design-Bid-Build Contracts of Iranian Public Projects

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Abstract

Implementing Building Information Modeling (BIM) is a managerial decision that requires fundamental changes in organizations and inter-organziational relationships. Considering significant increasing in BIM application in project design and construction, it is necessary to identify the critical success factors in BIM implementation and identify the challenges of its implementation in the Iranian construction industry. Effective adoption building information modeling (BIM) by the project parties requires an appropriate contract to assign responsibilities that will encourage various companies to issue standards related to BIM protocols and recommendations for contract adjustments. In this research, the legal aspects of BIM have been discussed using data of a construction project in Iran. The results provide insights for organizations to make informed decisions on adding contract clauses to reduce the complexity of BIM approval. The results help employers, consultants, and contractors use BIM to be more competitive in a changing construction market.

Keywords: *Building Information Modeling (BIM), legal aspects, contract provisions, implementation*

Introduction

BIM Background

Building Information Modeling was founded in 1975 by Professor Chuck Eastman of Georgia Tech University. Up to now, BIM technology has experienced a budding phase, a production phase and a development phase. The American National BIM standard defines it as: " BIM is a digital representation of the physical and functional characteristics of the facility and a source of shared knowledge and a process for sharing information about this facility, and providing a reliable basis of all decisions in the whole life cycle of the facility from concept to dismantling.

At different stages of the project, diverse stakeholders can support and reflect the collaborative work of their respective functions by inserting, extracting, updating and modifying information in BIM ". BIM is compared with typical computer aided design (CAD) technology. It can retrieve the geometric and rich semantic information of the building model and the relationship between them, so as to support the sharing of life cycle data. (Chen and Ni, 2019;, Ghaffarianhoseini et al., 2017)

Building Information Modeling helps as an innovation in the digitalization of construction. (Zimmerman, 2013) BIM affects various stakeholders in complex environments, such as government structures, companies, and industrial groups. It notably changes the performance of construction companies and by constantly sharing information between the lower layers of the supply chain, it leads to cooperation in all categories. BIM is a set of information technology systems that work together to generate, control and manage building information. (Papadonikolaki, 2017; Sebastian, 2010) Implementing Building Information Modeling is increasingly known as the best procedure in the construction industry, because it provides a new set of processes and technologies to improve productivity in construction projects. (Zimmerman, 2013) BIM provides digital simulation of a project from the initial stages of design to the stages of utilization of facilities by integrating the information required for design, construction and management. BIM implementation requires the creation of a new platform of technological and organizational processes that create special legal and contractual requirements. (Abdirad, 2015; Huntsinger et al., 2013)

BIM implementation often begins with a bottom-up implementation in a company, as a result of a person seeking personal interest or advantage, and only then is this limited introduction approved by the company. The dissemination of BIM innovation is undoubtedly at a macro level, whereas its adoption is at the micro level. Entities adopt innovations micro-scale innovations, e.g. firms, and ultimately innovation diffuses at a macro-level. (Papadonikolaki, 2017) Companies that have followed a bottom-up path tend to operate in less collaborative environments; Hence, the top-down structural approach used by most BIM guides and standards seems appropriate to achieve this aim. (Davies, 2017) The best way to adopt technology is when the employer imposes it in the contract, because it is not negotiable. (Porwal and Hewage, 2013)

The use of BIM during the project process can be used in two ways (1- at the individual level, 2- at the organization and project level). As the level of BIM acceptance in the organization increases, the level of communication and coordination increases, and the risks created between individuals are distributed, and this risk is assigned to that person according to the responsibility that each person has. Although BIM can be used under any type of contract delivery method, it is arguable that current market projects that are done with BIM at the organizational level are more coordinated than other projects (BIM at the individual level). (Kuiper and Holzer, 2013; Fountain and Langar, 2018; Lindblad and Vass 2015)

Information Gap

The BIM institute in Canada suggested that one way to facilitate BIM acceptence may be a mandatory requirement for public projects. In addition, it was recommended to develop clauses in the contract and prepared documents. The public sector is more focused on administrative decision-making, where the use of BIM is not their first priority, but only one of their responsibilities. BIM approval in public construction projects requires a change in existing work practices to achieve better results with higher quality buildings that costs less. Also, the level of integration of team members in the early stages of design is high, and the opportunitiy to get the maximum benefit from BIM is greater. (Porwal and Hewage, 2013) According to research conducted in Iran, the most barriers to BIM acceptance are entirely related to the structure of the Iranian market, the nature of the construction industry and the business environment in the country and the lack of attention of policymakers and the government. Lack of knowledge about the BIM acceptance process, lack of access to a proper infrastructure, lack of support from managers to accept the change of current methods and lack of standards and practical instructions in the country are also known as barriers to BIM acceptance in Iran. (Kiani et al., 2015; Hosseini et al., 2016)

One of the most important factors influencing the adoption of BIM in public sector organizations is that these organizations are reluctant, or even unable to apply BIM use based on specific software or standards. To preserve information open and non-proprietary, there is a need for standards and protocols with a common language, through which the software packages are able to communicate with each other. There are various protocols for resolving interoperability issues. The IFC protocol and the Standard for the Exchange of Product model data (STEP-ISO) are currently supported among major BIM software vendors. (Porwal and Hewage, 2013)

Similarly, BIM is a new method in the Iranian construction industry, but many efforts have been made to upgrade BIM in Iran. These include the establishment of the BIM Council in Iran (www.iranbimcouncil.com/) and the Iran BIM Association (http://www.ibima.ir/en/) with the aim of disseminating BIM knowledge among project people and accelerating the process of BIM absorption in the project. However, there are very few studies on BIM in Iran. (Hosseini et al., 2016Therefore, the purpose of this article is to assess the feasibility of implementing BIM in government projects and to review the feedback of contractors participating in government tenders that contribute to the existing literature.

The following points have been specifically discussed in this article: 1- Collecting and comparing the effective factors in BIM dissemination and the factors of BIM non-approval in other countries and in Iran, 2- Introducing the clauses and the proposed contractual structure according to previous studies, 3- Introducing a case study done in Iran, 4- Analyzing the contractors' opinions regarding the addition of contract clauses in the tender process.

Research Methodology

To accomplish the above, this article begins with the following: In the next section, we review the relevant literature on technology acceptance and BIM implementation studies. This study addresses several factors influencing decision making regarding BIM approval and non-approval. In the third part, by examining the literature of the text, the legal and contractual risks of BIM are examined and the required clauses are categorized, and this section ends with the introduction of DBB method in Iran. In the fourth section, we examine the case study done in Iran and the hierarchy of work done in the tender process. To validate this issue, by designing a questionnaire, the familiarity of the contractors participating in the tender and their willingness to implement BIM in the relevant organization will be analyzed and by conducting face-to-face interviews, their views on adding BIM-related clauses to private terms are examined. Finally, we will conclude by introducing the process of doing work for future research and limitations.

Text Literature Review

BIM Implementation

BIM implementation refers to a set of activities performed by an organizational unit to prepare, deploy or improve BIM products and related workflows (processes), which are divided into 3 categories: organizational readiness, ability to apply, and finally the maturity of the BIM. (Succar and Kassem, 2016) Building information modeling works much differently than AutoCAD. BIM is a tool for integrating information and communication technology and aspects of calloboration. Its essence lies in cooperation and communication between the stakeholders. The higher the level of our needs and wants from BIM, the greater the level of cooperation and communication between project stakeholders and the need for processes and strategies tailored to the same company. As the level of cooperation and work experience of employees increases, we will see an increase in the maturity of BIM in the organization. (Sebastian, 2010)

Reasons for Not Approving and Accepting Building Information Modeling

The construction industry is moving towards BIM adoption and knows many of its benefits, such as better modeling and design features, increased 3D rendering, and facilitated team collaboration through a common model. Slow approval to date has led researchers around the world to investigate existing barriers. These barriers include: technical problems (compatibility and reliability), project team disintegration, resistance to change, lack of training and business process issues, non-technical barriers to people, culture, legal, contractual and the organizational concepts of BIM can also be considered as a problem. (Ghaffarianhoseini et al., 2017; Fountain and Langar, 2018; Alreshidi et al., 2017; Jin et al., 2017, Hatmoko et al., 2019; Ahmad et al., 2019; Barlish and Sullivan, 2012; Chien et al., 2014; Lu et al., 2018; Rokooei, 2015) According to research, these obstacles are also the same for Iran; (Kiani et al., 2015) And the most important obstacle for the implementating BIM in Iranian construction include legal and contractual obstacles and the lack of support from the government. (Hosseini et al., 2016)

Legal Conditions

Legal issues related to BIM have been ferequently identified as one of the challenges in overcoming this issue, including the need to develop contractual arrangements that complement the goals and results of BIM. Understanding how to use BIM in a project provides the foundation for creating a potential contractual platform. As a result, as with any project risk, it may be managed administratively or contractually be inserting specific rules and requirements. (Kuiper and Holzer, 2013, ; Fountain and Langar, 2018; Hosseini et al., 2016; Smith, 2014)

BIM as a tool and process is able to test, convert and potentially change the approach of the construction industryto the methods required in contract delivery. Meanwhile, some contract methods are more capatible with BIM and other forms of contract delivery may need to be reviewed in various cases. (Kuiper and Holzer, 2013; Habibi, 2017) The use of BIM in a project, with issues related to project responsibilities and risks, contractual rewards, copyright and use of documents not mentioned in standard industrial contract forms. These are potentially major concerns about the rapid acceptance of BIM. (Porwal and Hewage, 2013; Fountain and Langar, 2018)

BIM is an emerging technology in the construction sector. However, management in the BIM operation phase is quite challenging and unstructured, which causesmany legal issues throughout the project life cycle. (Linderoth, 2010) Even if the employer does not understand the benefits of BIM, the existence of specific contracts facilitates its use and ease of acceptence. BIM coordination in a project requires the tools and knowledge needed to implement and set specific contracts. Without these elements, each party to the project pursues its own individual processes with little motivation for a single approach. (Davies, 2017) An effective contract administration is one of the keys to regulating insurance through the provisions of a written contract. The terms of contract are effectively used to regulate legal issues and implement the necessary steps in projects with BIM. Therefore, it should identify and clarify the important legal aspects of BIM practices. In general, the relevant legal aspects can be divided into three main categories, namely: 1) contract structure and policy, 2) contractual relations and obligations, and 3) BIM pattern and security. (Fan et al., 2019)

Contract Structure and Policy

To enable the implementation of BIM in a favorable environment, it is necessary to make some changes in the terms of the contract that focus on the type of contractual relationship, how the model is delivered during the project, cooperation in the electronic environment and appropriate punitive measures for lack of focus function. In a participatory environment, the most beneficial contractual relationships are considered for the implementation of BIM, in which stakeholders can enter information in a situation where no one objects to them. The contract should clearly state the deliverables of the model, such as the employer's wishes and the information available for review. (Manderson et al., 2015)

The existing BIM contract protocols are mainly used as backup documents and as add-ons to the original contract. There is currently a lack of transparency and insufficiency of information regarding the changing legal roles and responsibilities required for BIM project requirements. This creates the need for an alternative contracting structure to finance construction, contracting methods including progress payments and project financing options. (Alreshidi et al., 2017; Fan et al., 2019; Chong et al., 2017; Antwi-Afari et al., 2018)

Contractual Relations and Obligations

All project stakeholders work together in BIM-equipped projects. BIM implementation plan will be developed to prepare a checklist and as a guide for the successful implementation of BIM. Although this document is generally not part of the contract, the role of the stakeholders and the scope of the project should be well defined and managed. In the absence of a specific contractual relationship, the legal responsibilities arising from these partnerships may be removed and no one may take responsibility. Clear contractual relationships with the key stakeholders (including the BIM manager) will help set up the required responsibilities or functions in the BIM implementation plan (Alreshidi et al., 2017; Fan et al., 2019; Chong et al., 2017; Antwi-Afari et al., 2018).

BIM Pattern and Security

Security and privacy issues are likely to prevent BIM from being widely accepted. BIM information has been digitized and parameterized so that the information can be easily and completely extracted and reused. Therefore, it raises a new issue of how to protect business knowledge. A Quick Response Code (QR Code) has been successfully integrated into BIM to optimize the information flow of the BIM model. It can be done to prevent any infringement or copyrights issues on maps and documents in BIM projects. A data management policy is needed to prevent the exchange of unnecessary and incorrect information in BIM-enabled projects. The data management policy should also address common issues of interoperability through various software. Apart from that, the development of BIM model can be considered as a joint effort of different parties. There is a possibility of a third party claiming infringement. So intellectual property rights should be defined in the early stages of project development. All digital data must be well maintained and controlled. Compensation may be considered in the BIM model to protect the interests of the customer. (Alreshidi et al., 2017; Manderson et al., 2015;Fan et al., 2019; Chong et al., 2017; Antwi-Afari et al., 2018)

DBB Method

Design-bid-build (DBB) is a procurement method in which the design is completed before construction begins. This provides an opportunity to receive competitive bids, which is why it separates design from construction and communication between teams. According to studies, the framework of BIM-based design collaboration includes five stages of management. This phase starts with a planning phase, in which a feasibility study is prepared to validate the jobs in question, followed by a modeling phase, in which a participatory contract is executed for to prepare the tender. After preparing and selling the tender documents, invitations will be sent to the contractors within a specified period of time and bids will be received. After opening the proposals, the relevant contractor will be selected. The BIM collaboration phase is the final phase in which a complete design is prepared. Accordingly, all parties cooperate within a pre-arranged framework. Involving BIM's participation approach in DBB obliges the contractor to commit to the design model (Alwash et al., 2017).

The design-bid-build (DBB) method has become the industry standard for project delivery and it is known as the most widely used project delivery method. However, BIM’s benefits have not been fully realized in the context of the DBB delivery method. (35) The most common method of project delivery in the Iranian construction industry is DBB. The most important factor in choosing the DBB method in Iran is due to its long history, sufficient information and extensive experience in this field. The most widely used software in construction is Auto CAD. Extensive use of Auto CAD prevents the emergence of new technologies such as BIM. Encouraging experts to use advanced technologies such as BIM removes potential barriers to use BIM. (Bahmeni, 2017)

Case Study

Due to the restrictions on BIM admission barriers in Iran, we have selected a project to meet these restrictions. In order to do this, we selected the dormitory project for this research, which is a DBB delivery method, and in addition to being a government project, it is required to hold a tender to start the work. As the literature showed, the shortage of skilled labor is one of the obstacles to the use of BIM in Iran. To solve this problem and further integrate, I did the modeling research myself.

Project Overview

Due to the need for dormitories to provide more services to university students, a new project was started in the form of 4 blocks of 2500 square meters (a total of 10,000 square meters) on 3 floors. Due to the existence of older dormitories on the university site and observing the principle of coordination between old and new buildings, the new project plan is the same as the older plans. This project is designed in 3 floors with a height of 16 meters with a concrete structure. This project includes bedrooms for 4 and 6 people, bathroom, kitchen, library, laundry room, etc

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BIM Service Content

Due to the age of the plans, we started by modeling the architectural, structural and installation parts of the project (Figure 1). And by eliminating the executive interactions between water and sewage piping with the main beam, observing the appropriate slope for the installation pipes, eliminating the interference between the air duct and the false ceiling, etc., We optimized the plans and referred them to the consultant to correct the defects. In the next step, we estimated the cost of the project by surveying and estimating with the consulting team, and finally, after approving and completing the work plan, it was sent to the employer to hold a tender.

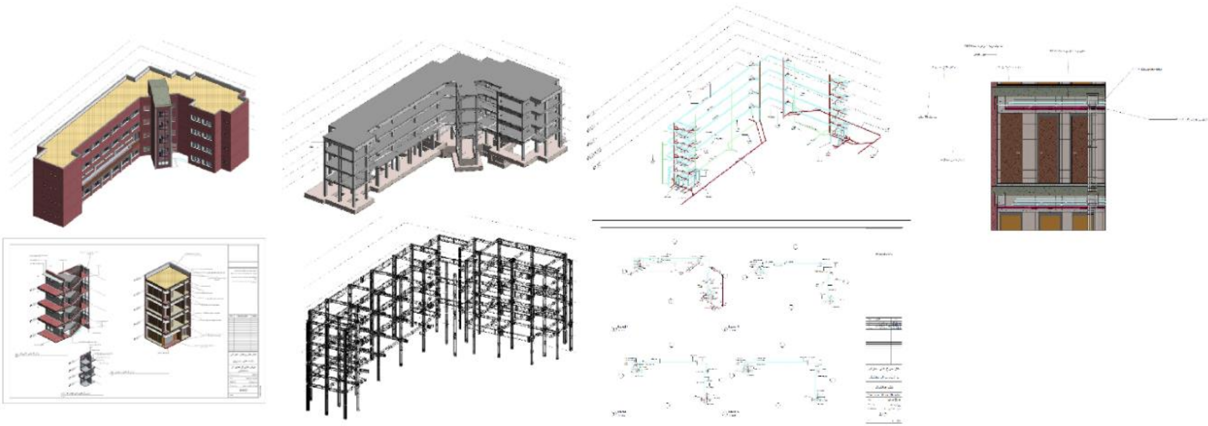

Figure 1. Modeling process in the project.

Questionnaire

In order to obtain the quantitative and qualitative data needed to gain a better understanding of the BIM acceptance process and to analyze the contractors' views on the feasibility of using contract clauses in the bidding process, a questionnaire was prepared that consists of two parts. The first part is related to personal questions, the amount of work experience, number of staff, level of familiarity with BIM and the amount of services provided to the employer, and the second part was related to questions about the intention to accept and implement BIM in their organization. The questionnaire is based on the Likert seven-point ranking scale, ranging from 1=strongly disagree to 7=strongly agree with a neutral expression in the middle. In addition to the questionnaire, by conducting face-to-face interviews and giving brief explanations to those who did not have sufficient information about BIM, the contractors' opinions on whether or not to add proposed contract clauses were examined.

The target population of this research includes experienced contractors who have participated in the tender for this project in Tehran. According to the official classification of contractors currently in Iran, construction companies active in government projects are classified into 5 groups. Class 1 people have the largest size and are allowed to carry out projects with the highest value (Qudusi and Hosseini, 2012), while Class 5 companies are usually start-ups that do small projects. Apart from these 5 categories, some companies are active in housing developments in the private sector.

General Information of the Audience

After the tender was sold by the employer, 30-40 contractor companies bought the documents and only 16 companies were approved by the university and then submitted their documents, but only 12 companies showed up on the day of the tender. The characteristics of the respondents, as shown in Table 1, indicate the diversity of respondents in terms of the nature of their activities and their role in the construction industry.

Table 1: Demographic information on respondents.

Number of companies	12
Company history 10 to 19 years 20 to 29 years 30 to 39 years	 2 5 5
Number of Employees 199-20 499-200	 9 3
The rate of use of BIM Not used professionally Less than 6 months 6-12 months 12-24 months	 10 1 - 1
BIM capability 3D modeling Analysis of environmental conditions Quality Control Optimization of materials used Cost estimation Project Management Find design errors None	 4 1 2 2 3 3 2 6
BIM tools Revit Architecture Revit Structure Revit MEP Naviswork sketchup Archicad	 4 6 4 4 1 1

The date of establishment of the newest company is 2004 in and with more than 15 years of experience in the Iranian construction industry and the date of establishment of the oldest bidder is in 1981 and with more than 35 years of experience in the Iranian construction industry.

Interview results

In order to reduce errors related to the questionnaire questions and to complete the information, I attended this meeting and spoke with the contractors' representatives during the tender. Representatives have different positions, including project manager, office manager, etc. In general, the technical office was more familiar with building information modeling than the other representatives, so I started the interview with an initial explanation of this science for other representatives who have poor or incomplete information.

Most of the delegates, after hearing the initial explanations and fulfilling more commitments in the project, did not see any problem in implementing and bringing contract clauses in private, provided that it is really efficient and effective and not just a formality. The people of technical offices, due to their initial acquaintance with Revit, whether in the field of architecture, structures or facilities, the benefits of this science were clear to them and can be seen in the answers to their questionnaires. These people used Revit more in the field of architecture and due to the lack of skilled technicians, they used less of Revit in the field of structures and facilities. Some companies attributed the lack of implementation to the lack of skilled technicians and heavy operating system and announced that they have done projects in the field of architecture and achieved good results, and if the employer requests, the necessary responsibilities can be assigned to contractors and consultants and add clauses in this regard to the terms of the contract. According to these companies, one of the main problems of this company is the optimal modeling in the facilities sector, which did not use Revit in this area due to the lack of proper technicians, while they want to implement BIM in the project.

According to most contractors' representatives, if the employer wants, they are willing to provide more services to better implement the plan in the project. One of the project managers who had experience working with BIM stated that according to the main task of the project manager is analyzing output data taken from management software and then transmitting this analysis in a simpler language to the executive department, if Revit has capabilities in the project management department and its use helps to improve the quality of execution, he is willing to implement building information modeling in the project.

Conclusion

This study was the first study of its kind with the aim of feasibility study of BIM implementation in DBB projects in Iran. According to the surveys, the familiarity of contracting companies about BIM has increased compared to previous years and brings a positive point for the implementation of BIM in companies and projects. Analyzing the contractors' response to the implementation of BIM in the company, we achieved good results and shows the enthusiasm of the contractors in accepting this technology. Through interviews with contractors, it was determined that it is possible to add contract clauses to private conditions if the employer wishes. Among the restrictions of this research, we can mention the lack of up-to-date barriers to BIM acceptance in Iran, and limited factors have been investigated. Another limitation is the small number of bidders, which can be achieved by doing more case studies.

For future research, it is suggested that according to the classification of barriers to non-acceptance of BIM in the text literature in Iran, it should be collected and analyzed again and the most important barriers should be identified and categorized so that more up-to-date research is available for future studies. By adding legal clauses to the bidding documents, another research can be done following the completion of this article and the contractors' feedback can be analyzed.

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The Energy Efficiency Challenge for Turkish Historical Buildings

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Abstract

Today, the energy efficiency is one of the common targets to improve energy performance of buildings. Thus, the application of retrofitting measures to existing buildings can reduce the energy consumption in the building sector because of their high rate in building stock. In this context, special attention should be given to historical buildings, which represent a significant part of the Turkish building stock. This paper presents a preliminary energy retrofitting of the historical building of the Ahmet Aga Mansion located in hot-humid climate zone in Izmir (Turkey). It was built in the first half of the 19th century, is one of several public buildings of historical and architectural interest for the city of Izmir and it is constrained architecturally. Special attention has been focused on the energy consumption for heating during the winter season. The energy performance of selected historical building was simulated by using national building energy performance calculation software of Turkey (BEP-TR) and a dynamic simulation software called DesignBuilder which is based on EnergyPlus simulation engine. The results of the energy analysis showed that an important energy saving is possible with improvements.

Keywords: *energy performance, historical building, building energy simulation.*

Introduction

People spend most of their time in buildings which have a share of 40% in total energy consumption. These amounts of consumption cause an important problem associated with energy efficiency in buildings include building construction, operation, and maintenance processes (Daniels & Hammann, 2009; Ganic, 2012). It is possible to significantly reduce the amount of consumption by providing energy efficiency in buildings. Artificial heating, cooling, ventilation and lighting needs in buildings cover between 40% -70% of the total building energy consumption and with energy-efficient measures energy savings could be achieved approximately 60% in heating and cooling energy and 50% in lighting energy (Harputlugil et al., 2009).

Energy efficiency in buildings could be achieved by reducing losses, energy consumption and energy related costs without sacrificing occupant thermal comfort. Systems such as heating, cooling, hot water, ventilation, and lighting consume significant amounts of energy for providing favorable thermal comfort conditions. As a result of energy efficiency in existing buildings, approximately 35-40% reduction in the amount of energy used by the construction sector and 45% reduction in CO_2 emissions could be result in environmentally sensitive structures against climate change (Tıkır, 2009).

European Union (EU) has been set a goal whereby CO_2 emissions are to be decreased by 40% by 2030 compared to 1990 and energy efficiency of a minimum of 27% is to be achieved (EC, 2014). The sector with the greatest energy savings potential is the existing building stock within historical buildings where more than 40% was constructed before 1960 and 90% before 1990 (Artola et al., 2016). The existing building stock is a key element in the process of achieving this aim of 80–95% reduction in greenhouse gas emissions in the EU by 2050 compared to 1990 (EC, 2012).

Historical buildings are a part of existing building stock of the countries. In Europe statistics reveal that 14% of building-stock dates before 1919, other 12% between 1919 and 1945 (Troi, 2011; Ascione et al., 2017). In 2018, there are 108,813 cultural assets in Turkey which registered by the Turkish Ministry of Culture and Tourism (TMCT, 2019). Historical buildings are considered as immovable cultural and natural assets that should be protected in terms of their architectural, historical, aesthetic, archaeological and other features. Historical buildings are the documents that provide information about the past periods and traditional construction methods. They are the structures that protect and raise the social, cultural, and commercial value of the regions where they are located. In addition to the necessity of preservation in terms of the cultural values it carries, it is inevitable that historic buildings, which have a significant share in the building stock, should be handled within the scope of energy efficient improvement.

Historical buildings are often low-performance constructions due to the fact that they are equipped with ineffective and high-emissions heating, ventilation, and air conditioning systems. However, it is more difficult to apply an adequate refurbishment action on old buildings than existing buildings (Galatioto et al., 2017). It is known that historical buildings present many artistic and architectural constraints and that make the energy efficient improvement process more difficult, especially in the application of envelope refurbishment measures (Pacchiega & Fausti, 2017) The energy, structural and architectural retrofit of this building stock is often very challenging due to the constraints of the existing regulations for the preservation of their historic value (Ubertini et al., 2017). Therefore, it is very difficult to implement comprehensive passive and active strategies for the energy efficiency and environmental sustainability, since the architectural appearance of such buildings usually could not be modified (Castaldo, 2017). Therefore, even more than in modern buildings, it is necessary to focus efforts on exploitation of renewable sources. Currently the application of alternative energy supply systems in common retrofit has not generally been fully explored, in particular for historical buildings (Pacchiega & Fausti, 2017)

In this study, the energy performance of a historical building which located in the historical center of Izmir, Turkey was performed by using national building energy performance calculation software of Turkey (BEP-TR) and a dynamic simulation software called

DesignBuilder. By applying energy simulation, it is possible to assess the real effects produced from different energy efficiency interventions.

Methodology

Within the scope of the work, the methodology was applied consists of these main steps; (1) energy performance was simulated by national building energy performance calculation software of Turkey (BEP-TR), (2) creating dynamic energy simulation model of the building (DesignBuilder), (3) applying energy-efficient improvement scenarios.

The selected historical building was modeled by using BEP-TR and DesignBuilder energy simulation program. The BEP program could assess the building to include heating, sanitary hot water, cooling, ventilation, lighting, cogeneration, and photovoltaic systems. The BEP-TR-2 program classifies building energy performances into energy performance classes such as A, B, C, D, E, F, G. It is classified as Class A which is the highest energy performance and Class G is the lowest (Bilen et al., 2020). DesignBuilder is a software to uses the Energy-Plus code to analyze the buildings and their thermal systems in dynamic regime. To simulate the energy performance of a building necessary information are reference building geometry, climatic conditions, description of the structural elements and the thermo-physical properties (thermal transmittance, solar factor, airtightness, etc.), characterization of the technical systems and their components and building user profiles. DesignBuilder simulation tool calculates the annual energy consumption of the building and CO_2 emissions by using these properties.

A plethora of improvement scenarios proposed by DesignBuilder energy simulation program were modeled and the results of all recommendations were compared in terms of energy efficiency. First, the energy efficient improvements on building envelope were executed and the need of the active energy systems of the building was reduced. The most efficient improvements on building envelope were received for assessment and combined with the improvements on energy systems to reduce the energy consumption.

Case Study

The case study is a historical building, named Ahmet Aga Mansion dated on the first half of the 19th century and was restored in 2013 by İzmir Metropolitan Municipality in accordance with its new function as a public building. For its historically and artistically important features in the province of Izmir, the building is subject to monumental restrictions and located in old city center. The building with its new function as a public building was allocated to the use of the Izmir Metropolitan Municipality, Directorate of Historical Environment and Cultural Heritage (Figure 1).

The case study consists of a two-storey building of about 365 m2 and a mezzanine floor. The plan has a rectangular shape, the height of the building is 10.85 m and there are adjacent buildings on the north and west facades of the building. The historical building has a masonry structure with a wooden frame. Although the inner and outer wall thicknesses of the building differ, they consist of the same layers. While the outer wall thicknesses vary between 40 cm and 75 cm to the project plan views, the inner wall thicknesses start with 20 cm and go up to 70 cm (Table 1). The existing roof of the building is in the form of a hipped roof and 5 cm thick rockwool insulation was used in the attic flooring. The window sizes of the building vary which all consist of a single-glazed wooden joinery (Table 2).

Figure 1: Architectural drawings of the building façade – Eastern and West front.

Table 1. Characteristics of the building envelope components.

Envelope Components	Layers	Thickness (m)	λ (W/mK)	U (W/m²K)
External Walls	Plaster	0,02	0,72	1,467-0,898
	Hard stone	0,36-0,71	0,81	
	Internal plaster	0,02	0,51	
Interior Walls	Internal plaster	0,02	0,51	1,866-0,867
	Hard stone	0,16-0,66	0,81	
	Internal plaster	0,02	0,51	
Basement Walls	Hard stone	0,68	0,81	0,964
	Internal plaster	0,02	0,72	
Floor (ceramic)	Reinforced concrete	0,25-0,35	2,3	2,781-2,481
	Screed concrete	0,05	1,5	
	Ceramic tiles	0,006	0,8	
Floor (marble)	Reinforced concrete	0,25	2,4	2,773
	Screed concrete	0,05	1,5	
	Marble tiles	0,03	3,5	
Mezzanine	Wood covering	0,02	0,14	1,397
	Air void	0,15	R = 0,22	
	Wood covering	0,02	0,14	
Roof	Shingle	0,025	1	2,163
	Air void	0,24	R = 0,22	
	Felt	0,005	0,19	
	Wood roofing (OSB)	0,013	0,105	
Attic	Air void	0,24	R = 0,22	0,531
	Rockwool	0,05	0,04	
	Wood covering	0,02	0,14	

Table 2. Characteristics of the windows.

Windows	Thickness (m)	U (W/m^{2}K)	Solar factor	Luminous Transmittance
Single-glazed wooden joinery	0,03	5,894	0,861	0,898

Results

According to BEP-TR calculation, the annual total energy consumption for the building was found as 46.068,96 kWh, with 20.165,92 kWh for heating, 10.296,05 kWh for hot water, 9.574,72 kWh for cooling, 2.286,57 for ventilation, and 3.745,70 kWh for lighting. The energy class of the historical building is C according to the Turkish energy identity certificate. The CO_2 emission is 20,29 equivalent kg for CO_2/m^2.year. As a result of DesignBuilder energy simulation, the primary annual energy consumption rate is 54.951,39 kWh with 33.531,69 kWh for equipment, 5.249,39 for heating, 11.451,36 for cooling and 4.718,96 for lighting purposes (Figure 2).

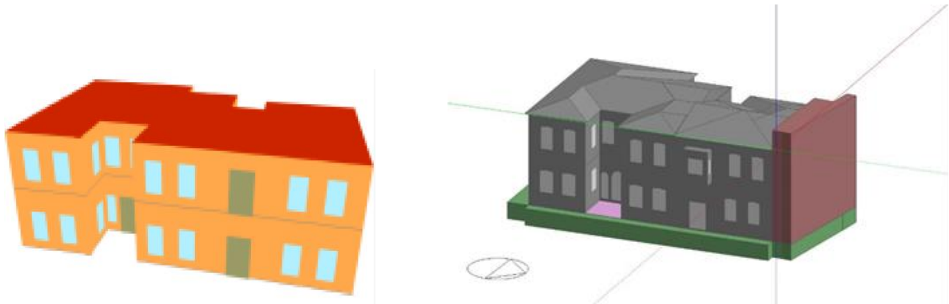

Figure 2: Simulation models of the historical building – BEP-TR (on the left), DesignBuilder (on the right).

In regard of a historical building, the architectural appearance did not modify during the energy-efficient retrofit scenarios. The main retrofit interventions applied consists of (i) building façade, (ii) the installation of a PV panels, (iii) the application of LED lighting system and (iv) mechanical improvements. The list of the energy improvement scenarios was presented in the Table 3. Total number of constituted scenarios was 135 by the combination of the energy efficient measures (Table 4).

The contribution of the measures on windows to the improvement of the energy consumption varied according to the thickness of the wall insulation. The use of low heat gain glasses (P1) provided 3.231% increase in heating load, 6.106% decrease in cooling load and 0.964% decrease in total energy consumption when there was no wall insulation. When the outer wall insulation was increased to 6 cm, heating load decreased to 2.791%. The decrease in cooling load rose to 7.001% and the decrease in total energy consumption rose to 1.192%. It was observed that the increase in outer wall insulation thickness contributed to the improvement of energy consumption of low heat gain glasses (P1). In the secondary window application (P2), the contribution to improvement of energy consumption up to 4 cm insulation thickness (D2) increased and decreased at higher thicknesses.

It had been observed that roof insulation variations did not provide a significant contribution to the heating and cooling loads. Application of additional 8 cm thick roof insulation mattress

(C1) increased the heating load by 0.004%, the cooling load by 0.013% and the total energy consumption by 0.003%. Application of additional 10 cm thick roof insulation mattress (C2) increased the heating load by 0.005%, cooling load by 0.015% and total energy consumption by 0.004%. It was determined that the 5 cm thick roof insulation mattress in the attic flooring is sufficient in terms of heating and cooling loads. In the case of using a 5 cm thick glass wool mattress (B1) on the basement ceiling decreased 0.1148% in heating load, 0.017% in cooling load and 0.018% in total energy consumption. In case of using 8 cm thick glass wool mattress (B2), the heating load decreased by 0.237%, cooling load by 0.030% and total energy consumption by 0.029%.

Table 3. List of energy efficient measures.

No	Energy Efficient Measures
D1	Internal insulation on outer wall (3 cm Rockwool)
D2	Internal insulation on outer wall (4 cm Rockwool)
D3	Internal insulation on outer wall (5 cm Rockwool)
D4	Internal insulation on outer wall (6 cm Rockwool)
C1	Insulation of the roof floor with 8 cm thick roof mattress (addition to the existing insulation)
C2	Insulation of the roof floor with 10 cm thick roof mattress (addition to the existing insulation)
B1	Insulation of 5 cm thick glasswool mattress on basement ceilings
B2	Insulation of 8 cm thick glasswool mattress on basement ceilings
P1	Usage of glasses with lower solar heat gain (SGHC:0,716)
P2	Internal second joinery (6mm + 6mm thickness, 9mm spacer lath, first glass with heat control coating)
A	LED lighting system (15 W/1200-7 W/630 lumen)
M1	3-pipe VRV system (COP: 4.3; EER: 6.2)
M2	Air-source heat pumps (COP: 3,8/EER:4,0)
PV	PV panel system (5.0 kW power and 16.77% efficient module, battery powered system)

Table 4. Effects of energy efficient measures.

Energy-efficient Measures	Effect of the Measures (%)		
	Heating Load	*Cooling Load*	*Total Energy Consumption*
D1	-23.95	-1.68	-2.65
D1 + P1	-24.28	-2.32	-2.82
D1 + P2	-27.85	-3.37	-3.38
P1	3.23	-6.11	-0.96
P1 + D4	-2.79	-7.00	-1.19
C1	0.00	0.01	0.00
C2	0.01	0.02	0.00
B1	-0.11	-0.02	-0.02
B2	-0.24	-0.03	-0.03
D4 + B2	-57.82	-14.45	-8.53
M1	-16.24	-47.70	-11.49
M2	-5.25	-19.72	-4.61
PV	0.13	-0.07	14.45
D4 + B2 + P2 + A + M1 + PV	**-63.73**	**-56.65**	**-21.24**

The most energy efficient scenario among the all façade related scenarios, was the combination of 6 cm thick wall insulation (D4), 8 cm thick basement ceiling insulation (B2) and secondary window application (P2) which decreased the heating load by 57.82%, the cooling load by 14.45% and the total energy consumption by 8.53%. The implementation of LED lighting system (A) increased the heating load by 0.952%, decreased the cooling load by 1.076%, lighting load by 21.267% and total energy consumption by 1.960%. The 3-pipe VRV system (M1) provided an average decline of 7.787% in heating load, 41.226% in cooling load and 9.335% in total energy consumption on 84 scenarios. In the scenarios which were the 3-pipe VRV system was applied to the current situation with no measures applied on building façade, the contribution to the improvement of energy consumption was higher (decline in heating by 16.240%, in cooling by 47.701% and in total energy consumption by 11.492%). In all scenarios evaluated for air-source heat pumps (M2), it was achieved an extra reduction of 2.525% in heating load, 17.034% in cooling load and 3.791% in total energy consumption. In the absence of measures taken in the building envelope, the contribution to energy consumption is determined as 5.250% decrease in heating load, 19.716% in cooling load and 4.610% in total energy consumption.

The PV panel application (PV) designated to benefit from renewable energy sources was adapted to the DesignBuilder program in accordance with the technical information provided by the manufacturer (Tommatech, 2019). PV panels placed on the roof of the building affect the heating and cooling load at low rates by reason of shading effect and played an important role in reducing the total energy consumption with an annual energy production of 7.936,44 kWh. The average contribution to the PV panel application was calculated as 0.126% increase in heating load, 0.072% decrease in cooling load and 14.446% decrease in total energy consumption.

The most energy efficient scenario among the all 135 scenarios was the combination of 6 cm thick outer wall insulation (D4), 8 cm thick basement floor insulation (B2), secondary window application (P2), LED lighting system (A), 3-pipe VRV system (M1) and PV panel system (PV). According to the current situation, this scenario achieved 63.73% decrease in heating load, 56.65% decrease in cooling load, 21.24% decrease in lighting load and 34.16% decrease in total energy consumption.

Conclusion

In this study, the energy performance simulations of a public historical building in Izmir, Turkey was carried out by using two different energy simulation tools. In order to improve the energy performance of the building, combination of 135 different energy efficient scenarios were developed and applied on the simulation model on DesignBuilder. The combination of 6 cm thick outer wall insulation, 8 cm thick basement floor insulation, secondary window application, LED lighting system, 3-pipe VRV system and PV panel system was the most energy efficient scenario according to the significant decrease on total energy consumption. It should be noted that the benefits to be obtained from the applied energy efficient improvements may vary depending on the climate and environmental conditions of the building.

Acknowledgment

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Integrated Project Delivery (IPD) and Traditional Procurement Methods in Construction Industry – Toward a Team-Based Approach

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Abstract

The Global Construction industry seems to be stuck in unprofitability when compared with other industries. The industry is suffering from high operational costs, low rates of productivity, construction safety problems, slow pace of digitization and lack of innovation. It is therefore imperative to implement new procurement models which portrays real productivity gains and alternative project delivery methods. Drawing on sector specific documents, as well as other documentary sources, this paper examines the traditional procurement methods, defines Integrated Project Delivery (IPD) method and compares it with other traditional procurement methods. This review indicates that IPD can help construction industry to grow by delivering more profitable projects while maintaining the quality of construction projects' output. In this research, benefits of IPD has been discussed based on a literature review and these sources analyzed by qualitative analyses. Finally, improved process shall be demonstrated by a flowchart of IPD in a sample complex construction project. Additionally, IPD implementation issues such as team building efforts and motivational effects shall be better explained.

Keywords: *integrated project delivery, procurement methods, productivity, team approach.*

Introduction

There are several project delivery methods in construction industry. This research explores the similarities and differences of project delivery methods, explaining the benefits and advantages of the integrated project delivery in the project profitability environment.

First section includes an overview of the construction industry. It examines the industry in terms of supply / demand, profitability, and technology. It concludes that the sector has cost overrun, low efficiency and technology adaptation problems. And a strong construction sector seems to be indispensable for all economies.

Second section gives a brief explanation of project delivery methods, focusing on integrated project delivery method. The main purpose of the integrated project delivery is to optimize the project results while ensuring efficiency at every stage of the construction process. In addition, the team building efforts and the motivational effects are also explained.

The third section reveals the similarities and differences between traditional delivery methods and alternative delivery methods. Based on the research, it reveals the benefits and advantages of integrated project delivery systems. The integrated project delivery processes are shown in a complex construction project on a process flow chart.

In the last section, the results, limitations, and advantages of the research are discussed.

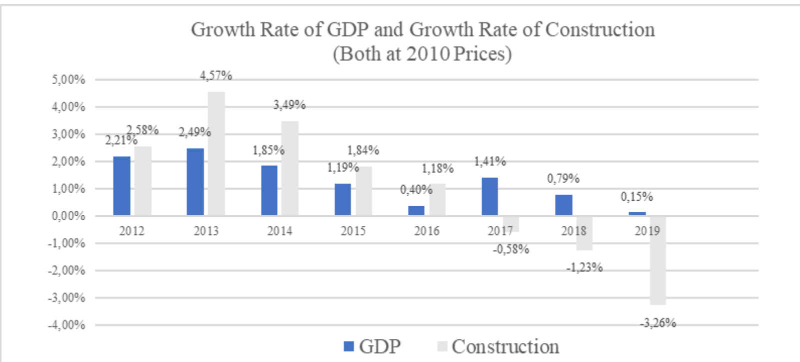
General Evaluation of Construction Industry

Construction Industry contributes to the nation's economy through the achievement of socio-economic development goals such as providing infrastructure, erection of real estate and creating employment. Output in the construction industry does not make certain that the nation's economy shall develop, however presence of transport infrastructure, buildings, hospitals and colleges boost the development of economy and social activities.

And several studies show that construction industry is in a position that creates demand for goods and services produced by its nearly 200 sub-sectors, there are strong linkages between construction and other sectors. The importance of the construction industry also comes from its strong forward and backward linkages with the other sectors of the economy.

Besides, construction industry is a cyclical industry. During periods of accelerated economic growth, construction output grows at a faster rate than the economy, however during periods of stagnation, the construction industry is the first to suffer (Erol, 2015). Additionally, construction GNP increase is more important for the developing countries than for the developed countries, because the contribution of the construction industry to economic growth has a non-linear relationship. Bon (1992) proposes an inverted U-shaped relationship between the share of construction activities and stages of economic development, which is commonly known as the Bon curve. Figure 1 illustrates the growth rate of GDP and the growth rate of Construction Industry.

Figure 1: Growth rate of GDP and growth rate of construction industry (Reportlinker, 2019).



Out of its contribution to the economy, construction industry has another role; it improves the social life, keeps the society connected, constructs the workplaces and provides the services that society needs. A competitive, efficient and digital construction industry is essential for both developed and developing countries.

Managerial Problems of Construction Industry

Today, the problems facing construction industry revolve around profitability problems to development. Despite the size of the industry, profit margins are very low. First among these problems is low productivity. In order to achieve the expected income from the project, resources should be utilized efficiently. Productivity is usually referred to as equation 1.

$$\text{Productivity} = \text{Output} / \text{Resources (Labor + Equipment+Materials)} \quad (1)$$

While poor productivity is one of the major problems in construction industry, the productivity ratio of construction industry is not uniform, heavy construction projects have 20% - 40% percent more productive than smaller construction firms. However, heavy construction firms still have productivity problems which led them to subcontract certain amount of their work to subcontractor firms. (Mckinsey, 2016)

One of the other most significant major problems that construction industry across the globe suffers from is low performance. Most of the projects cannot be delivered on time and within budget. Table 1 indicates the schedule delay performance metrics by regions and Table 2 illustrates the cost overrun by regions.

Table 1. Schedule delay performance metrics by regions (PBRSG, 2016).

Region	% Projects Delayed	% Delay Amount
Africa	75%	53%
N. America	98%	37%
Asia	68%	37%
Europe	53%	55%
Middle East	79%	35%

Table 2. Cost overrun by regions (PBRSG, 2016).

Region	% Projects Delayed	% Delay Amount
Africa	69%	29%
N. America	98%	28%
Asia	59%	16%
Europe	50%	29%
Middle East	65%	15%

Moreover, the integration of technology is the most significant tool to improve processes and to maintain efficiency. However, construction industry has a resistance to technology adoption. Technology implementation costs seems to be an added cost, because of industry’s major problems such as rising costs and low margins. Out of construction industry’s managerial problems, most of the literature indicates that cost of the new systems, capability of learning the IT software by employees, lack of performance analysis are major reasons behind slow pace of technology adoption in construction industry.

And, in the first quarter of 2020, construction industry came under the induced uncertainty of pandemic outbreak.

Project Management and Delivery Methods

Project delivery is a process that is composed of planning, design, and construction activities in order to organize, execute and complete a project. According to Miller et al.,2000, a project delivery method is also defined as a system used for organizing and financing design, construction, operations and maintenance services for a project by entering into legal agreements with one or more parties.

There are several different approaches to manage the delivery process of a project. Some of these approaches are used for many years, and some are very new concepts in the industry.

It is common to distinguish these methods are to classify them as traditional delivery methods and relationship-based delivery methods. Design-Bid-Build, Design-Build, CM at Risk, EPC (Engineer, Procure, Construct), Design CM Contracts, Design Agency CM Contracts and Fast Track Construction are the traditional delivery methods, whereas Partnering and Relational Contracting or Lean Project Delivery is the relationship based delivery method. (Forbes & Ahmed, 2011).

As every project has different characteristics and considerations, the delivery method selected should be aligned with the objectives, schedule, budget, design processes and risk appetite of the project. By choosing the right one for the project, overall risk can be reduced, and budget and schedule objectives can be better met.

Traditional Project Delivery Methods

Construction delivery methods have been used for decades and evolving over time in response to needs and requirements in the construction industry. Starting with Design- Bid-Build delivery method, traditional project delivery methods mostly include; Design-Bid-Build, Design-Build and Construction Management at Risk. All of the project delivery methods have at least three parties; Owner, Designer and Contractor. The following shall be a brief explanation of three of the most common types of traditional project delivery methods.

Design-Bid-Build

Design-Bid-Build also known as Design-Tender is a method in which the owner or agency contracts with separate entities for design and construction of the project.

In this type of procurement method, the design consultant prepares the design and bid documents. The project is awarded to the general contractor with the lowest bid. During the construction stage, general contractor manages the work mainly by sub-contracting the part of the works that require specialization. And, design consultant reviews the progress of the work, issues site instructions, change orders and checks and approves the construction work.

Design-Bid-Build delivery projects are preferred as it maintains reasonable price for the owner and favors competitive bidding. Due to the fact that, the general contractor is brought to the team after design is completed, the contractor does not have chance to collaborate with the designer during the design stages. And, further disputes cannot be solved as the interests of two parties does not match with each other. Moreover, low bids can cause too much change orders which can be costly to solve for inexperience owners. This kind of delivery method is more comfortable for simple and predictable projects, as complex projects can lead to costly change orders under this delivery method.

Design-Build

Design-Build or Design-Builder is a delivery method in which design builder has the overall responsibility of the project with a single contract with the owner. this kind of delivery method is a very common model, however it is not as old as Design-Bid-Build delivery method.

Unlike Design–Bid-Build delivery method, design-builder does not make use of competitive bidding on the basis of completed design documents. Planning and schematic design are carried out by the owner and after the commencement of the contract and the preliminary design is commenced by the design builder. This kind of delivery method is more collaborative in terms of design and construction processes. Depending on it, Design-Build delivery method reduces claims due to design errors.

It is widely preferred by owners who have decreasing funding to closely manage the construction process and who have tendency in more collaborative systems. This delivery is suitable for projects that its scope can be detailed without completed design and when schedule or cost certainty are required. It seems to be an effective system, however it can reduce the quality features of the project in order to protect the profit margin. And, bidding process could be more expensive for design- builders.

Construction Manager at Risk

In this model, the owner establishes two contracts: one with the owner or agency, and one with the designer. This method is selective in choosing the contractor in terms of their previous performance.

Under this delivery method, the Construction Manager becomes a consultant during design delivery stage. It suggests constructability reviews, value engineering suggestions, construction estimates, and other construction-related recommendations. And, before the design completion, Construction Manager negotiates on a guaranteed maximum price. (Molenaar et al., 2014)

Similar to other methods, incomplete design documents shall result in changes in the cost. However, there is no chance to cover the exceeding costs with change orders which will require the construction manager to have a robust cost control mechanism. And, there can be a conflict of interest as the construction manager is also the contractor. Besides, Construction management role of contractor can be an added cost for the owner . (Forbes & Ahmed, 2011).

This kind of delivery method protects the owner’s financial security. And, the selected sub-contractors can be managed more effectively as the construction manager has the overall cost responsibility. It can be best used in more complex projects where it is difficult to previously define the scope of the project.

Alternative Project Delivery Methods

Integrated project delivery and integrated lean project delivery are known as alternative project delivery methods. Both of them use integrated project organizations, multi-party contracting, and integrated processes to deliver project outcomes. The main difference between these delivery methods are their operating systems. Integrated lean project delivery method requires implementation of lean management system and tools, whereas integrated project delivery method does not point out a specific operational management system. (Mesa et al., 2019)

According to most of the literature, this type of delivery method has been developed in order to solve the problems of construction industry such as; low rates of productivity, lack of innovation and frequent disputes. It maximizes performance and motivation by actively controlled processes with its powerful supporting tools and operating and commercial systems. Beyond these, it is based on project performance other than individual performance which also leads to more open and trust-based culture.

However, it has not been yet implemented widely. The characteristics and benefits of the method are not well known by owners. Studies have shown that there are theoretical and case-based researches about benefits of this method. The subject of researches can be summarized as inherent benefits of integrated project delivery, economic, social and political benefits of integrated project delivery and its quantitative benefits.

Integrated / Lean Project Delivery Method

AIA (2010) defines integrated project delivery as "a project delivery method distinguished by a contractual agreement between a minimum of the owner, design professional, and builder where risk and reward are shared and stakeholder success is dependent on project success."

Once a project has been identified as a good candidate for the integrated project delivery method, the owner, designer and general contractor accept to manage design and construction risks as a single team mostly with a multi-party contract. This kind of agreement enables the team to collaborate towards the project performance, not towards the individual performance. It enables shared savings among project stakeholders, positive result in sharing project information, collaboration, and fewer problems. However, if the opportunities for gain and the potential for loss are not equitably distributed, the parties will not be motivated to collaborate.

Under a multi-party contract, decisions are made through consensus by the decision making body and roles are distributed to the person who is best capable of performing. And, Building Information Modelling (BIM) which is the functional requirements of this model supports the delivery model significantly.

In this sense, according to Ashcraft (2010) and Fischer (2017), the multi-party contract has five major structural elements described as; early involvement of key participants, shared risk and reward based on project outcome, joint project control, reduced liability exposure, jointly developed and validated targets.

And, as per AIA (2010), the integrated project delivery model consists of seven steps; Conceptualization, Criteria Design, Detailed Design, Implementation Documents, Agency Review/Buyout, Construction and Close-Out. The integrated delivery project steps should be adjusted to meet the requirements of the project, as each construction project has its own characteristics. In this paper, integrated delivery project steps shall be illustrated by a flowchart.

Although there are several researches which point out that the challenges of integrated project delivery method, it seems to be the better, faster, more efficient production method of the decade. And challenges of implementing integrated delivery method can be summarize as mistrust, lack of communication, and opposition between Engineer and Contractor.

As previously defined, integrated project delivery method is not just a process, it is about integrating people, value-based team success. And it is supported by latest technologies. However, integrated delivery method is better suited for certain types of projects; complex construction projects, where team members have worked together and / or have a desire to work in a collaborative environment.

IPD Team Approach

Organizationally all IPD projects require team working bringing the right people from every discipline; owner, all construction managers, trade contractors and designers together at the early stages of the project. All of the team members have defined roles and responsibilities.

As per, Forbes and Ahmed (2011), the selected team members should be with the necessary knowledge and experience and are open to working together. From another perspective, integrated teams should have the following features. (Howard et al., 2017)

- Everyone is engaged to its work,
- Project activites are planned according to defined stakeholder requirements,
- Decisions are made as if the project is a single vertical organization,
- People decide on how to execute the project on what's best for the project,
- Problems are discovered at early phases of the project,
- New and different ideas and approaches are received,
- Everyone believes their first responsibility is to learn and improve every day,
- Managers and leaders try to be a role- model rather than talk about behaviors.

Moreover, integrated project delivery requires motivated teams. As per Robbins 2011, external motivation such as high wages do not always satisfy the employees, there is strong relationship between how much employees enjoy their work and how they are satisfied. As per Forbes and Ahmed (2011), the employees of an integrated delivery project becomes more satisfied and consequently productive with their jobs, as productivity is highly related with motivation in construction industry. And, according to Ashcraft, 2011, recognition from management also motivates team members. Especially, if it is tied to external motivations, it can lead to constructive competition within the team.

Benefits of Integrated Project Delivery Method

According to Achieving Construction Excellence Report, 2003, it is seen that construction costs can be reduced in about an average of 2-10% for single IPD projects and up to 30% over a sequence of IPD projects. And, time for structural design was reduced from an expected 15 months to 8 months and better design quality can be achieved. Table 3 summarizes four nos' of case studies on the benefits of IPD Projects.

Table 3. Case studies on benefits of IPD projects (AIA, 2010; Forbes & Ahmed, 2011; Fischer et al., 2017; Smith & Anderson, 2020).

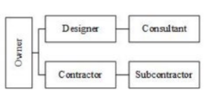
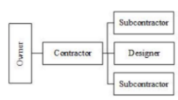
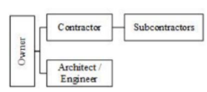
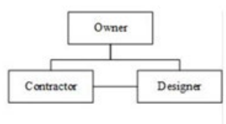
Case Name	Benefits
Encircle Health Ambulatory Care Center Project	• Time and cost objectives are met. • Contract Cost and Final Cost were nearly the same. • Change orders were only owner related.
Maine General Hospital Project	• Schedule is accelerated with 18 months. • LEED certification of the building is developed from Silver to Gold. • Additional profit is gained and shared between team members.
Sakaw Terrace School Project	• Time and cost objectives are achieved. • Issues and clashes are resolved quickly and smoothly. • Operations are improved.
OUC North Plant	• Cooperation is rewarded. • Project transactional costs are reduced . • Disputes were not common either within team and between team and client.

Thus, main benefits of integrated project delivery can be summarized as improvement in productivity, improvement in schedule and cost performance, better design quality, less construction changes and disputes, team motivation and decision-making mechanism.

Comparison of Project Delivery Methods

Most of the literature argues that traditional delivery methods when compared with integrated project delivery methods, result in insufficient details in design documents, waste of materials, low productivity, and lower performance. Table 4. compares Integrated Project Delivery and Traditional Procurement Methods based on literature review and summarized case studies.

Table 4. Comparison of project delivery methods.

Components	**DBB**	**DB**	**CM at Risk**	**IPD**
Business Model				
Major Benefits	Reasonable price for the owner, favors competitive bidding	Collaborative business model, reduction in design claims	Protects the owner's financial security, effective sub-contractor management	Better performance, better design quality, shared savings, collaboration, fewer problems, trust-based culture,

				improved operations and productivity
Challenges	Many change orders, conflict of interest between contractor and designer	Reduces quality features, expensive bidding process for design builders	Exceeding costs, added cost of construction manager role of contractor and conflict of interest	Mistrust, lack of communication, and opposition between Engineer and Contractor
Suitable Projects	Simple and Predictable Projects	Projects where scope can be defined without completed design, projects which require schedule or cost certainty	Complex projects where it is difficult to define the scope of the project	Complex projects where team members have a desire to work in a collaborative environment
Functional Requirements	N/A	CAD (Computer Aided Design Systems)	CAD (Computer Aided Design Systems)	BIM (Building Information Modelling)

Sample Flowchart of the Process

Integrated delivery project activities are planned with a series of workshops. The main purpose of these workshops is to bring all the team members together leading to a more collaborative environment. During these meetings, teams are organized, scheduling methods are considered, BIM plans are prepared, communication plans are formulated. Figure 4. illustrates the sample flowchart of a complex IPD construction project.

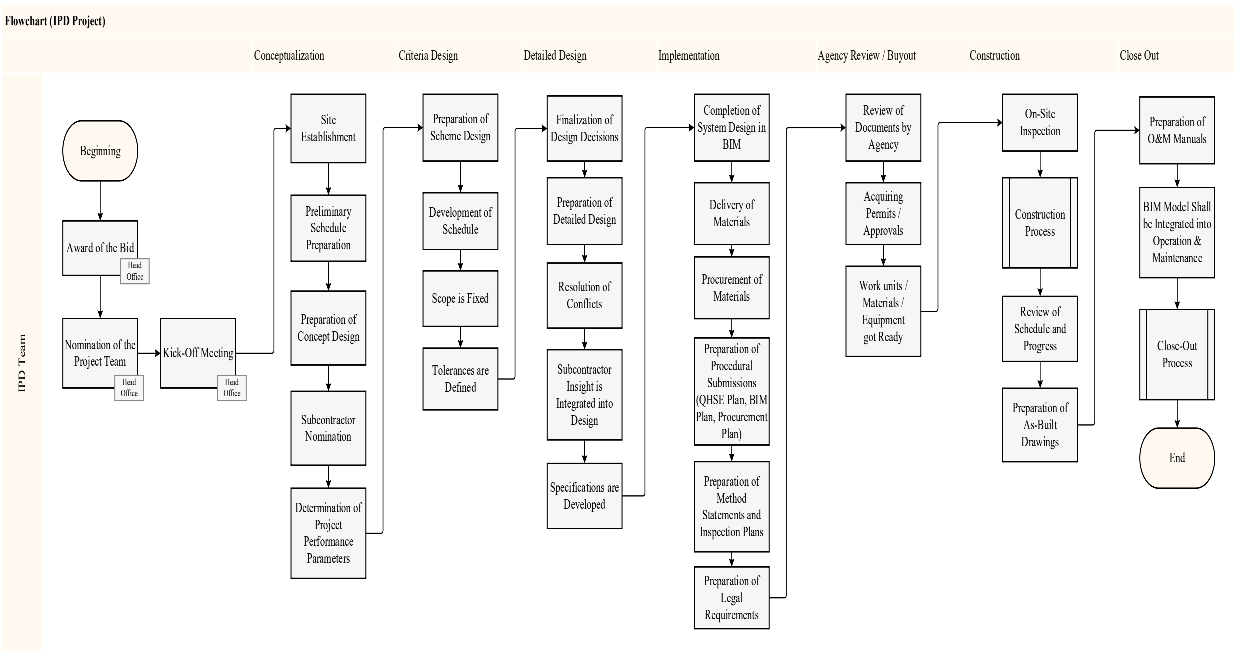


Figure 2: Flowchart of an IPD project.

Results

This paper examined the project delivery methods in terms of their similarities and differences in the framework of construction industry problems. Unlike traditional delivery methods, integrated project delivery method shapes and influences a team approach. The team members cannot be understood apart from each other. Moreover, it is improved in order to be collaborative, efficient and profitable. The integrated project delivery method also tries to motivate the team members and acknowledges that productivity is highly related with motivation.

In this paper, both traditional and alternative project delivery methods are compared in a table based on literature review and analysis of four different case study projects. In addition to this, processes of an integrated delivery project are illustrated by a flowchart under seven steps of integrated project delivery process.

There can be several future researches that can reveal interesting discussions. One can monitor the performance of a construction project when all characteristics of integrated project delivery method is implemented, in comparison with a project in a traditional delivery method. Another interesting discussion can be investigating the role of multi-party agreement, by analyzing the performance of an integrated delivery project in a traditional contract.

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A Case Study of Using Innovation Catcher as an Innovation Performance Assessment Framework for Housing Projects

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Abstract

The crucial role of innovation in improving or even maintaining the strategic position and competitive advantage of construction companies in a highly competitive industry is widely acknowledged. In this sense, construction companies are spending a substantial amount of money and time on innovation activities. However, an in-depth literature review showed that available innovation assessment frameworks are not capable of revealing the outputs of these investments and capturing the actual innovation performance of the companies. In this research, we developed the Innovation Catcher (IC) as an innovation performance assessment (IPA) framework for project-level IPA of the housing projects. Based on the findings from the literature, the dimensions of Innovation Radar that is a previously available model in the literature were modified for housing projects. An application of the IC has been demonstrated by a case study carried out in collaboration with a Turkish contractor. Seven semi-structured interviews were carried out with an expert to collect data. Based on the IC application, it was concluded that IC is capable of reflecting the actual innovation performance of the housing projects and can be used as supportive material in the documentation, and short-term and long-term decision-making processes.

Keywords: *innovation, innovation catcher, innovation in the construction industry, innovation performance assessment, innovation radar.*

Introduction

Innovation as an abstract concept has attracted much attention since its first introduction in the literature as “creative destruction” by Joseph Schumpeter (1947). To conceptualise innovation and make sense of how it occurs in practice, many researchers conducted various studies that resulted in different definitions as well as classifications. Despite the differences in these definitions, most of them are shaped around two ideas; the creation or adoption of a new idea and commercial use of these new ideas. Although there exist comprehensive frameworks explaining innovation, in technology-driven industries, there is a general understanding that innovation is mainly associated with research and development (R&D). Although the outputs of R&D studies constitute an important part of innovative product/services in the technology-driven industries, in traditional industries such as the construction industry, this understanding provides a limited perspective for innovation (Loosemore, 2015).

The construction industry can be classified as a traditional industry where high-tech applications are not intense, and the operations are mostly based on the labour force. It is one of the industries that have a significant effect on the economy and the national development of, especially developing countries. When the effects of the construction industry on nations' economy and development and its unique characteristics are taken into consideration, special attention is required to explore the innovation concept in this industry (Miozzo & Dewick, 2002; Ozorhon & Oral, 2017; Winch, 1998).

Among the sub-sectors of the construction industry, with its direct and indirect effects on the economy and continuous growth, specifically, the housing sector has an important impact on the country as well as the housing sector itself. Also, among other sub-sectors of the construction industry, the housing sector is the closest to the manufacturing industry in terms of the development and sales processes. Like in the manufacturing industry, in the housing sector, the product, in our case, an individual housing unit, is designed, developed and sold to customers. Therefore, innovation development and management practices can be observed relatively clearer in different phases of the housing projects. However, the housing sector differentiates significantly from the manufacturing industry with its specific characteristics which necessitate special consideration.

In this study, we aim to develop an IPA framework for the housing sector that can be practically used to catch innovations considering its multiple dimensions. We took the definition of innovation provided by OECD as the primary reference. In Oslo Manual prepared by OECD, innovation is defined as "the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations" (OECD, 2005). It is hypothesized that companies can use the proposed framework to evaluate innovations in housing projects, monitor innovation performance along multiple dimensions and throughout the years and finally, develop strategies to improve innovation performance.

In the forthcoming parts of the paper, section 2 presents the innovation performance assessment practices and its importance within the literature, followed by the section 3 about research design and methodology. Then, the proposed framework is introduced in section 4. In section 5, the case study on the utilisation of the proposed framework is explained. Section 6 presents the major findings from the case study, discussing the potential benefits and application areas of the proposed framework. Section 7 concludes the paper by presenting the summary and significance of the study as well as the limitations and recommendations for future studies.

Innovation Performance and Its Assessment

Innovation in the construction is a process where new components of construction product form from new ideas that add value to the construction company in terms of the economy, the function of the product or technology (Motawa et al., 1999). Slaughter (1998) defines construction innovation as "actual use of a non-trivial change and improvement in a process, product, or system that is novel to the institution developing the change". Dikmen et al. (2005) provide a more comprehensive perspective for the innovation in construction and consider all significant improvements in company's business that add value to the customer, provide financial benefits to stakeholders and stronger competitive position to the company as innovation. In the literature, whether innovation in the construction industry is rare or not is a controversial issue. Construction companies are usually criticised due to their low innovation performance. The Business Roundtable (as cited in Nam & Tatum, 1997), argued that the absence of a sufficient number of innovative applications in the industry is not due to low innovative capability of construction companies or lack of customer demand, but due to poor coordination of the innovative capability and customer demand. On the other hand, as opposed to this perception, Winch (1998) argues that construction industry persistently creates new ideas, but the reason why it seems there is an insufficient level of innovativeness in the construction industry is the rate of innovation that is relatively lower than most of the other sectors. According to Loosemore (2015), generally, the large-scale innovations rarely exist in the construction industry, but incremental developments frequently occur. Slaughter (1998) supports this idea and discusses that innovations occur continuously in the construction industry and its related markets. When the construction industry is considered as a system with many participants in the project, a change in one component of the system will affect another component or even the whole system (Miozzo & Dewick, 2002). Therefore, by considering a large number of sub-sectors of the construction industry, it would not be wrong to say that innovations have been continuously realised in the construction industry (Porter as cited in Seaden et al., 2003).

Innovation is necessary for companies even to continue their existence in today's highly competitive environment. To enter new markets, to be more active in the existing market, to increase the profitability or to gain competitive advantage, being innovative is vital for companies (Seaden et al., 2003). According to the Australian government, companies will get in return for their innovations in the long-term and their innovative solutions for emerging problems will ensure their competitiveness in the market (Tidd & Bessant, 2009).

However, innovation investments require a considerable amount of money and time, and success cannot be guaranteed. Therefore, there is a need to assess the performance of these innovative efforts so that a company can know where to focus its attention (Gamal et al., 2011). Nevertheless, the innovation process is complex and simplifying this process into measurable elements is not easy (Gamal et al., 2011). Some studies in the literature have used the total number of new products and new properties or functions added to products in the assessment of innovation (Toole as cited in Seaden et al. 2003). However, in most of the cases, even if the production method or the process is new or significantly improved, generally the final product is not different from before. In such situations, traditional innovation indicators may not reflect innovation performance correctly (Seaden et al., 2003). As stated in the Frascati Manual, R&D is only one of the steps in the continuous innovation activities (OECD, 2005). Because, in traditional industries where the technological developments are low, the vast majority of the companies do not invest in the experimental and laboratory-based works (Loosemore, 2015). According to Loosemore (2015), the non-innovative image of the construction industry is resulted from the inappropriate innovation assessment methods. In the construction industry, many innovations are realised by innovation adoption from other companies. Therefore R&D related indicators might not be sufficient to capture these innovations (Ozorhon & Oral, 2017). Also, in Miozzo and Dewick's study (2002), it is stated that R&D funding alone is not a good indicator for IPA since these investments are small amounts when compared to the turnover of the company. In the study of Green and Sergeeva (2018), they present a soft approach and argue that creative projects cannot be evaluated by using quantitative metrics. Therefore, a broader perspective is needed to reflect the actual innovation performance (Winch, 1998).

To sum up, innovation occurrence in the construction industry is not rare but hard to measure and catch. Thus, the research presented in this paper evolved around the idea of "catching" innovations and assessing innovation performance in the construction industry, particularly the housing sector.

Research Design and Methodology

As the first step of this research, a detailed literature review was conducted. Then, the advantages and disadvantages of the available assessment models were evaluated and findings are summarized in Table 1. Innovation Radar (IR) was selected as the base framework to be used in this research considering the criteria depicted in Table 1.

Table 1. Evaluation of innovation assessment frameworks.

	Usability in different types of innovation	Data visualisation	KPIs or assessment metrics availability	Usability in different industries	Practicality for industry use
Innovation Dynamo (OECD/Eurostat, 1997)	-	-	+	-	-
Innovation Radar (Sawhney et al. 2007)	+	+	+	+	+
Innovation Value Chain (Hansen & Birkinshaw, 2007)	+	-	+	+	-
Innovation Funnel (Morris, 2008)	+	-	+	+	-
Innovation Audit (Tidd et al., 2009)	+	+	+	+	-
Model of Ten Types of Innovation (Keeley et al., 2013)	+	+	+	+	+
Model of Dulkeith and Schepurek (Dulkeith & Schepurek, 2013)	+	-	+	+	-
Signposts of Innovation Framework (Hao et al., 2017)	+	-	+	+	-

In the second step, IR was modified to be used particularly in the housing sector, and the "Innovation Catcher" (IC) was developed. Then it was collaborated with a Turkish construction company, specialised in housing to gain insight into the innovation perception and innovation performance assessment practices of the construction companies, second to test how the proposed IPA framework and IC can be implemented in practice. One of the major strengths of case studies over other research methods is the variety of data collection methods that can be used in this method such as archival resources, observations, and interviews (Yin, 2009, p.11). In this research, the case study, including face-to-face interviews and secondary data allowed us to investigate how innovation performance of the construction companies can be assessed at the project level.

We collected data through face-to-face semi-structured interviews and secondary data sources such as project files, archival records, and past newspaper reports. Throughout the research, seven face-to-face interviews were carried out. Each interview lasted about 2.5 hours and was recorded using a voice recorder with the permission of the interviewee. Face-to-face interview and voice recording have ensured the elimination of misunderstandings and missing information. More information about the case study will be depicted in Section 5.

The Proposed Framework: Innovation Catcher

Construction projects are carried out with the cooperation of many parties. Therefore, to reveal the actual innovation performance in the construction industry, the innovation analysis should be done at the project level instead of the firm level (Ozorhon, 2013). Innovation Catcher (IC), which was adapted from Innovation Radar aims to catch the innovations in different parts of a housing project at the project level. Therefore, IC was created considering the possible innovation areas that can be realised in a housing project.

The dimensions of the IC were determined through a detailed literature review. Then, the IC was modified based on the perspective of the partner company and for marketing. The IC (see Figure 1) considers ten dimensions under four main innovation types based on the classification in the Oslo Manual (OECD, 2005).

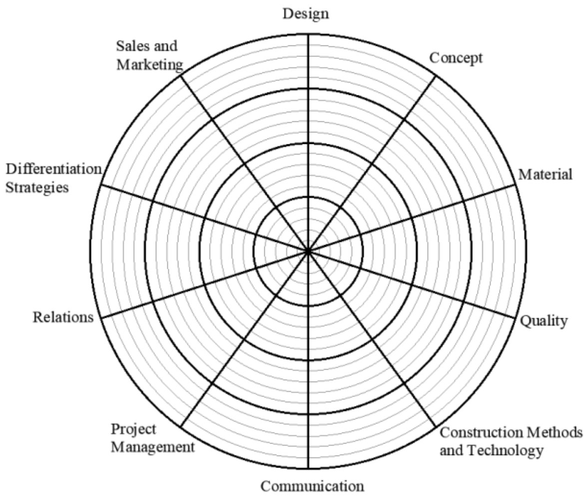

Figure 1: The proposed framework: Innovation Catcher.

Case Study on the Utilisation of Innovation Catcher

The case study was carried out with a 50 years old large size company, which is one of the pioneers in the Turkish housing sector with approximately 100.000 residential units constructed on the total area of 12.000.000 m^2. For the reasons of confidentiality, the company name is withheld and indicated as Company A in this paper. Company A, whose head office is located in Ankara, is one of the largest contractors in Turkey with approximately 4.500 personnel. In addition to the housing sector, Company A has maintained its activities in different industries such as service, manufacturing, tourism, and insurance, both in the national and international markets.

The case study was conducted as a series of face-to-face interviews with staff from Company A. The contact person of Company A was an architect from the marketing department who has been working as the project marketing specialist in the company for three years. As a marketing department employee and an architect, the expert has contributed to the study with her comprehensive knowledge about the projects, in addition to data collected from the archive and organisation of knowledge elicitation sessions with other employees from different departments.

Throughout the research, a pre-interview and six face-to-face semi-structured interviews were carried out. In the pre-interview session, general information about the research and expectations from the company were explained, and the interview process was planned. To provide appropriate time to the expert to collect required information about the projects, the sample projects were selected in this step. Then five interviews were made to collect information about the sample projects. During the interviews, the semi-structured interview form was followed. The first part of the interview form includes general information about the sample projects, which are summarised in Table 2. As can be seen from Table 2, sample projects were selected from different locations in a different context, to understand the capability of IC to reflect the actual innovation performance of the housing projects having different dimensions. In the second part of the interview form, we asked the expert to evaluate the innovation performance of the projects in terms of the degree of novelty of each successful innovation. The evaluation was made based on the following scale; 0 for no innovation, 1 for innovation within the company, 2 for innovation in the region/city, 3 for innovation in the country, 4 for innovation in the world. The last part of the interview form includes opinion questions. In this part, we aimed to understand the company's opinions about the contribution of innovation in gaining competitive advantage and company's stated innovation strategy. In the last interview, the IC profiles of sample projects were evaluated, and the consistency of these profiles with the reality was discussed.

Table 2. General information about the sample projects.

Project ID	Project Year	Project Location	Project Context
1	1985-2004	Ankara	1571 housing units and utilities (school, post office, sports facilities, shopping centre, treatment facility, plant house)
2	1993-1996	Istanbul	253 housing units
3	1994-1997	Mersin	118 housing units, eco-park, boat accommodation and maintenance facilities
4	2011-2015	Istanbul	3600 housing units, a theme park and a business centre
5	2014-2016	Ankara	215 housing units

Discussion of Findings

The findings of the research will be presented in two main parts. In the first part, the major findings from the Innovation Catcher applications to sample projects will be presented and discussed. In the second part, possible utilization areas of IC will be discussed.

Company A has many different "firsts" in its history. It draws attention mostly with their housing projects designed and constructed for different living concepts. These new concepts have inevitably accompanied innovations in different areas. However, in terms of processes and approaches, the expert described Company A as "conventional." For example, as the expert stated, the company has a more traditional attitude towards utilisation of IT. Thus, although the products and services are considered as "innovative", the processes within the company are denoted to be "conventional".

Company A is the pioneer in using and manufacturing tunnel formwork in Turkey, which has led to a significant change in the construction methods within the country. Introduction of tunnel formwork into the Turkish construction industry helped companies to improve the quality and the speed of the construction process. However, in the interview, the expert emphasised the rareness of process innovations and challenges to catch them in the construction industry as follows:

"*Process innovations may not be noticed, even though they are actually realised very frequently on site. Because, most of the time these innovations occur suddenly on-site, and with the thought that they should have already been introduced by other companies before, these innovations are generally overlooked and not identified as innovations"* which is consistent with the findings from the literature.

When the innovation assessment practices of the company were investigated, it was revealed that the company does not use any method or model to assess innovation performance. However, they relate to the success of innovations in the project with the success of sales. Therefore, the expert suggested that they have already a model to assess the sales process, so the success of innovations may be deduced from the success of sales. However, although it may provide insight into the innovation performance very roughly, since the sales may be affected by many factors, it was agreed that to assess the actual performance a separate model is needed.

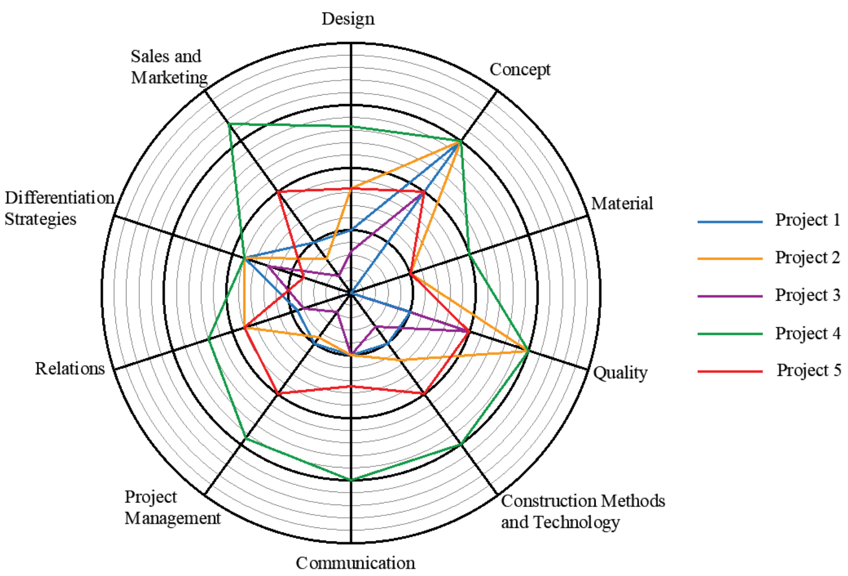

Figure 2: Innovation Catcher profiles of sample projects.

When the overall innovation performance of Company A is evaluated, it is seen that Company A is least innovative in using new materials in their projects. This result is consistent with the stated innovation strategy of the company:

"The materials used in the project are important. However, they have been starting to lose their significance in today's highly competitive environment. By using the available materials, you can still meet the customer needs with a completely new concept and create remarkable living areas. Rather than the material, the quality of workmanship and its usage methods are much more important."

As consistent with the expert's statement, Company A tends to produce housing projects with the new living concepts in differentiated quality. The expert emphasised the importance of the quality of workmanship and product for the company as follows:

"The projects of Company A can be easily distinguished from other projects in Ankara. The quality of production and usage of the material or the production style may be distinctive features of our projects."

Innovations realised in the construction projects may help companies to create a brand image and to increase the attractiveness of their projects. As can be understood from the expert's statement above, Company A has created an image in the housing sector with its distinctive quality of projects and different living concepts it offered by innovating along these dimensions.

The expert discussed the possible utilisation of IC for different purposes which can be grouped under four main categories such as communication, project-based decision-making process, documentation, and long-term company-based strategy formulation. In the construction projects, creating a common language between and within parties is essential both for ensuring effective communication and appropriate project management. It is argued that the visualisation of innovation performance by IC may help construction companies to create a common language. According to the expert, IC profiles may also be used in the documentation process as an effective visualisation tool for summarising the successful innovation activities in the project. Such documents can be used for retrospective researches or in the decision-making process. According to the expert, these documents and researches may help the company to develop more comprehensive and company-based long-term strategies. For example, by considering the overall innovation performance of Company A in a 30 years period (see Figure 2), it can be said that Company A has brought innovative approaches most in quality and concept dimensions to the housing sector. However, whether Company A will continue to focus on these dimensions as it was in the last 30 years or change their innovation focus to other dimensions in the following years is a critical decision that the company should make. The experiences of the construction companies in previous projects affect future decisions and actions. IC profiles reflect the performance of companies in terms of successful innovations, i.e., innovations that are created, implemented and diffused. As the expert stated, the success of innovations in the project can be associated with the success in sales and therefore in the decision-making process of the future projects decision-makers can benefit from the IC profiles of similar projects. In other words, the IC profile of a particular housing project can be used to develop strategies for similar projects in the future.

Conclusions

Construction industry differs from other industries with its characteristics. Therefore, a special interest is required to investigate the innovation concept in the construction industry.

As a result of an in-depth literature review on innovation in the construction industry, the main gaps in the literature are determined as lack of broad view of innovation in the construction industry, lack of IPA framework that can be easily used in practice, and lack of a framework that assesses the innovation performance at the project level.

In this research, in the light of the needs mentioned above, IC was designed for specific usage in the housing sector. While the dimensions of the IC encourage companies to broaden their innovation perspective, being designed for assessing the successful innovations makes IC a practical framework for industry use by removing the necessity of using metrics. Also, the IC enables to visualise the results of IPA which helps companies to store and present the data effectively.

The IC was demonstrated by carrying out a case study with multiple interviews with an expert from the marketing department of one of the largest and most well-known contractors in Turkey. The major findings obtained from the interviews are consistent with the literature review. First of all, the definition of innovation in the construction industry is very narrow. Only the breakthrough innovations are considered as “innovation.” Secondly, IPA is not performed in the construction industry. Lastly, innovations that are realised spontaneously in the construction site are not able to be caught and recognised as innovation when the innovations are investigated at the company or industry level.

IC was applied in five sample projects which are in different size and scopes and from different geographies. The results and possible usage areas of IC were discussed with the expert and First, IC may help companies and project participants to create a common understanding of the innovation concept and its assessment. Secondly, IC profiles may create a strategic basis for similar housing projects. It may be used in project-level decision-making processes and the documentation process as effective visual support or summary. By investigating the IC profiles of multiple projects, the general innovation tendency or strategy of a construction company can be understood, and long-term strategic decisions can be made at the company level. As a result of the investigation of IC profiles, the expert agreed that the results are consistent with the reality and IC profiles are capable of reflecting the real innovation performance of the sample projects to a large extent.

There are some limitations to the study. The major limitation of this study is that in the research, five sample projects of one company were studied. Therefore, the results can not be generalised. In this sense, further studies are required. Secondly, in this research, the data of five different projects in 30 years period was used. Due to the inefficient project information storage methods used in the past, some assumptions were made while answering the questions in the interview form, especially for the earlier projects. Although it did not affect the application of the framework and the research question, it affected the accuracy of IC profiles.

IC can be improved further in the light of the recommendations that the expert made and the results we obtained. First of all, this study was carried out as a case study by working with a company. For testing the application of IC further, more companies should be involved in the study. Secondly, the construction phase of all the sample projects and the sales of three sample projects used in this study were completed. Therefore, the IC profiles of these projects were drawn based on the archival data and some assumptions. However, IC should be applied in on-going projects as well. Thirdly, technological developments and dominant concepts can affect and change the shape of the IC profile of a project. In this study, the interview form was prepared based on today’s technology and concepts which negatively affected the IPA of earlier projects. To reflect the innovation performance of projects from different times accurately, the interview form should be changed or updated. Lastly, in this research, the IC was used to assess the innovation performance of the housing projects. Similar studies can be done for different types of projects by making necessary modifications to the dimensions of the IC. Also, the evaluation can be based on opinions of multiple experts utilizing various perspectives.

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Line of Balance (LoB) Scheduling versus Takt Time Planning (TTP): A Comparison of Two Methods

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Abstract

Lean practices are heavily adopted in the construction industry to increase productivity and eliminate waste. There are several Lean tools and techniques practices for construction projects but planning tools are of utmost importance in terms of creating realistic schedules. Among those, Takt Time Planning (TTP) is an effective means of planning and its use in Lean construction projects is widespread. Among other effective tools for scheduling, Line of Balance (LoB) scheduling offers a management control process for presenting time related facts. When evaluating these scheduling tools, it is clear that there is a strong association in terms of optimizing the schedules and production rates in repetitive works. Hence, this study assesses TTP and LOB scheduling tools and discusess the similarities and differences from a historical perspective and the reasons behind the distinctions are traced accordingly. To better represent how these tools are interrelated or diverging, comparisons are provided through an elaborative literature review. The findings of the study indicated that there are application-related differences exist between the two methods. This study aims to guide researchers, decision-makers, and project managers to deeply understand these concepts and benefit from them accordingly in their projects.

Keywords: *lean construction, scheduling methods, repetitive works.*

Introduction

The competitive nature of the construction industry induces firms to be more dynamic and open to change, leading the industry to embrace new concepts. Although there are regional variations at the statistical data, before Covid-19 pandemic, the construction industry was expected to contribute to about 15 percent of the global Gross Domestic Product (GDP) by

2020 and continue its growth with a rate of 4% annually indicating that it is among the the fastest growing industries (Francis & Thomas, 2019). However, the industry has not still yet shown its potential in contributing to GDP due to inefficient processes in planning and execution of construction projects. To increase efficiency in processes and foster innovation towards achieving excellence, the industry is still seeking for innovative tools, techniques, and methods. Among those, Lean is introduced to the construction industry in 1990s by Glenn Ballard and Gregory Howell after they observed several inefficiencies in construction processes. Then, Lauri Koskela-a Lean pioneer- translated Lean production philosophy from manufacturing industry to construction industry (Koskela, 1992). Lean has recently been adopted by the industry practitioners to eliminate waste and improve productivity. Toyota defines waste as "Anything different from the minimum quantity of equipment, material, parts and labor time that is essential for production" (Alarcon, 1997) or it might be simply defined as undesirable activities that do not add value. Defining and categorizing waste is critical for the Lean studies. Therefore, a major portion of the studies in Lean either focused on waste identification or categorization. In this context, Garas et al. (2001) categorized waste in two components for the construction industry as; time (waiting periods, stoppages, clarifications, variation in information, rework, ineffective work, delays in activities, and inappropriate use of equipment and material) and material (excess ordering, overproduction, wrong handling, wrong storage, manufacturing defects, and theft or vandalism). It is apparent that time management and problems related to material might be handled better with a sound planning. Hence, it is important to benefit from Lean tools and techniques specific to scheduling or other effective scheduling methods for eliminating time and material related concerns. Being one this techniques, Takt Time planning (TTP) is an effective means of managing customer demand and supply chain at the pace the work requires. TTP helps deliver the product or service at the rhythm that the customer desires.

Moreover, Line-of-Balance (LoB) is another effective method to optimize recurring works and manage time. The highest productivity in activities are ensured by the principles of natural rhythm and optimum crew size (Damci et al., 2016). It is closely related to TTP in terms of both adopting the single rate production. Hence, this study scrutinizes both methods and compares them in terms of pros and cons. The study aims to reveal the common functions of both methods so that construction practitioners might benefit and guide planners about managing the projects with zero waste. In this context, the study first presents the historical background of both methods. Then, it provides a comparative analysis to highlight the advantages and drawbacks of the methods.

Literature Review

Line of Balance Scheduling (LoB)

The construction industry is still seeking for better planning and execution practices to suit the characteristics of repetitive works. Structures like highways, high rise buildings, pipelines, or tunnels are examples of repetitive works, where the same basic unit is constructed repeatedly. The repetitive level of work is based on the similarity of the quantities for each location (Seppanen, 2014). In the late 1920s, the eradication of glamorous 102 story Empire State Building is a cornerstone for location-dependent repetitive time plans using a flowline diagram to plan and control the work by multiple time-defined work steps (Haghsheno et al., 2016). The construction team established a production line of standard parts controlled by a visual chart of floors and time spent. The horizontal and vertical axes combined activity sequences by short bars. This visualized control system provided completion with $24,5 million (%40 under budget) and 18 months earlier (%25 faster) than anticipated of the tallest building in its era (Lucko & Gattei, 2016).

Researchers locate the first systematic method for location-based planning called Line of Balance (LoB), a combination of mathematical (production rate calculations) and graphical techniques, in the 1940s. The method was first provided by the Goodyear Tire and Rubber Company and it was later embraced in the US Navy to coordinate the mass production in the WWII and Korean War (Frandson et al., 2015; Damci et al., 2013a). Before its full adoption in the construction industry, the idea was to use the Critical Path Method (CPM) in the second step of LoB, which was first coined by the Office of Naval Material in 1962 (Lucko & Gattei, 2016).

Later, the method found a wide area of application and it was fully adopted in the construction industry. For example, Lumsden's (1968) pioneer study adopted LoB for scheduling based on how many units must be completed on any day to achieve the program by explaining and linking activities to network schedules, resource leveling, and cash flow analysis. To implement LoB in the construction industry, first, daily working hours and optimum crew sizes are established after the estimation of the required man-hours for the production of one unit. Using optimum crew size enables the duration of the production to remain constant and efficient. Then, the start and finish times of each activity at each unit are calculated (Damci et al., 2013b). In LoB, work starts from 1 (when the first unit is finished) and the slope of its two lines representing start and finish events gives the delivery rate. Lucko and Gattei (2016) advocated that LoB is misused by intermingling the terminology with linear scheduling methods (LSM), especially in Scandinavian studies. LSM is originally intended for a geometrically linear project like highways and rooted from recent activity-on-node (AON) representation, where Lumsden's LoB was derived from activity-on-arrow (AOA) networks (Su & Lucko, 2015). LoB allows considering different crews to perform parallel tasks, while LSM progresses with one continuous productive resource. The deviations in the assembly of activities and target delivery rate is in the interest of LoB, where LSM embraces constraints such as time, work buffers between activities, floats, and identifying critical path (Lucko & Gattei, 2016). The productivity scheduling method (PSM) employs singularity functions to completely transform LSM to a mathematical model capable of modeling buffers, criticality, and float; which has not yet been adopted for LoB in full sense. At this point, Su and Lucko's (2016) study differentiates between original (manufacturing) and current (construction) LoB methods. The three distinct graphical structure of original LoB establishes a high-production-oriented and detailed workflow for planning. However, this process is time-consuming since potential changes in productivity are shown in the LoB in the form of a column chart for all control points. The current form of LoB focusing on resources, which might portray the cycle of crews in a bar-chart-like form. Conversely, the penalties of interruptions result in idle times and two lines representation creates graphical difficulty in the critical path. The LoB quantity used in Lumsden's (1968) study considered that the productivity is a linear relationship of quantity over time and each activity shall not be lower than the target delivery time. Nevertheless, the assumption of the linear relationship in the production is flawed since the time needed to perform the same job will be decreased by repeating (Arditi et al., 2001). On the other hand, estimation errors will be vulnerable to magnified deviations because of repetition (Arditi et al., 2002a).

Before the translation of Lean concepts into the construction industry (in 1992), Arditi and Albulak (1986) summarized the modified scheduling methods derived from LoB Schedules as Vertical Production Method (VPM), Time-Space Scheduling, Cascade Networks, Velocity Diagrams, Fenced Bar-Charts, Chain Bar-Charts, Construction Management System, and Combined PERT/LoB (Arditi et al., 2001). Dynamic and linear programming methods (Damci et al., 2013a, 2016) and LoB stand out among other process interaction simulation techniques and stochastic approaches with their superior features to balance operations. Each activity is continuously performed and the activities are grasped by their rates of production. This allows production system design be devised with the master plan (Biotto et al., 2017). When the unit network is utilized only, the scheduler is prone to miss noncritical activities, which might become critical later on and disarray the rate of production (Arditi et al., 2002a). Therefore, several researcher studies intended to combine CPM and LoB for more efficient planning (Dolabi et al., 2014). When used alone, CPM algorithm is not designed for special resource constraints of repetitive projects and shows lacuna for resource-leveling and flow of the project. To overcome this challenge, resource allocation is employed to minimize project duration in terms of resource constraints. Moreover, resource leveling is employed to minimize fluctuations without changing project duration (Damci et al., 2013a). The field personnel is found to be more receptive to LoB than arrow networks because of the progress illustration capability (Arditi & Albulak, 1986).

A time-dependent activity is defined as “an activity must be carried out right after the preceding activity” (Hadju, 1997) as frequently used in CPM. In such activities, rate of production is shaped by the dominant time-dependent counterpart activity, which eventually causes one activity to suffer idle times. Also, individual space-dependent activities are required to be brought into the calculation as a combined activity and are calculated by adding up the unit durations. The calculated date of the milestone activity needs to be compared with the required milestone on the specified unit, and if required, compression could be achieved by accelerating the precedence activities (Arditi et al., 2002a). Stage buffers between major phases are introduced than additional safety contingencies for the duration of each activity in a network (Arditi & Albulak, 1986).

The optimum rates for production could be defined by the functions of natural rhythm (Lumsden, 1968). Arditi (1988) defined “Natural Rhythm” as “the optimum rate of production that a crew of optimum size will be able to achieve”. Later, Biotto et al. (2017) used it as the “delivery rate”. Any rate of output difference is doubtlessly yielding to idle time for labor and equipment. The challenge of implementing natural rhythm in real-life projects might explain the reason why researchers who developed different linear scheduling alternatives failed to advance this terminology (Damci et al., 2013b). Yet, the optimum crew size of activity could be easily found by the firm records to establish a multisource leveling model that ensures crews keep the natural rhythm and work without idle time (Damci et al., 2013a) with shifting activities. To shift the start time of activity; first, the activity in question must be assigned with a finish-to-start relationship with its preceding and succeeding activities. Second, if the activity is in the first unit, the slope of two lines must be less steepness than the slope of the preceding activity and greater steepness than the slope of the succeeding activity, and if the activity is in the last unit, the slope of two lines must be greater steepness than the slope of the preceding activity and less steepness than the slope of the succeeding activity. Third, precedence relationships and time intervals must be evaluated to allocate resources between activities (Damci et al., 2013b). This does not affect the duration of an activity, the total project duration, and precedence relationships between activities. Resource leveling can be performed only for preceding and succeeding activities in the first or the last unit according to the natural rhythm principle (Damci et al., 2016). An unbalanced production process by LoB is shown on Figure 1.

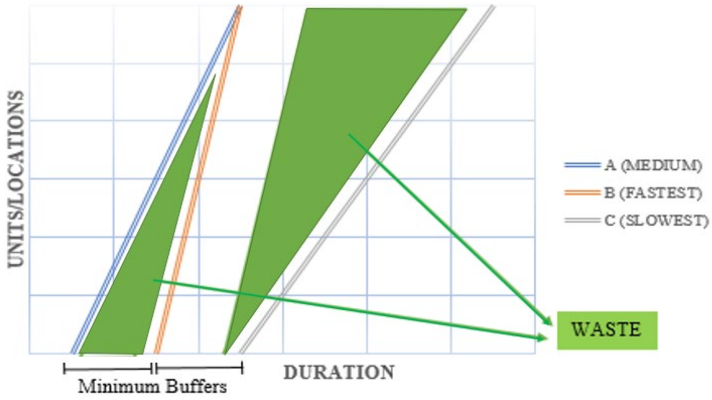

Figure 1: Unbalanced Production Process (Adopted from Yassine et al., 2014).

Increasing the number of crews is the most effective solution to keep the cost constant and accelerate production. The maximum productivity could be achieved by using multiples of the natural rhythm of production rates. Interrelating time and space-dependent activities, sharing the same crew (or equipment) for more than one activity, altering LoB activity criticalness, and generating LoB float might result in better efficiency (Damci et al., 2016). In the LoB analysis, the precedence relationships between activities are used but the production rate is the major parameter for criticalness (Arditi et al., 2002a).

There are several scheduling systems developed using LoB methodology. Arditi et al. (2001) introduced Repetitive Unit Scheduling System (RUSS) to display LoB diagrams in the form of individual paths in the unit networks and implement LoB analysis for typical units. RUSS is designed to optimize resource allocation by using multiples of the natural rhythm of activities. Computerized High-Rise Integrated Scheduling System (CHRISS) is used by Arditi et al. (2002b) utilizing flexible unit networks and multi-level LoB diagrams (three-level) by the "Lobplans" scheduling module to optimize high rise building projects. Minimized idle time results in cost savings and produces flexible unit networks changing depending on the floors (Arditi et al., 2002b). Advanced Linear Scheduling System (ALISS) is used to integrate the learning curve effect to the LoB calculations and lays the groundwork for a multi-user environment and multi-layered security (Tokdemir et al., 2006). Damci et al. (2013a) introduced a genetic algorithm based multisource leveling model for LoB governing the production rate and duration according to the longest duration in completing a unit. The strategy to eliminate idle times was to use multiple crews of optimum size and shifting start times of activities without violating the precedence relationships between activities. The procedure was tested on a pipeline project and provided smoother resource utilization histograms based on the dominant resources. However, different objective functions limit the improvement of the resource distributions in the leveling due to fewness of non-critical activities. Moreover, constraint of natural rhythm hinders solutions to create idle times for crews (Damci et al., 2016).

Takt Time Planning (TTP)

Lean philosophy aims to eliminate so called seven type of waste (overproduction, inventory, repair/rejects, motion, transport, processing, and waiting) in the construction industry. Lean also embraces the principles of value, value stream, flow, pull and perfection (Womack & Jones, 1998). Lean construction provides unique solutions with a clear vision and firm leadership for different cases and these intangible terms are not easy to forge in one frame. Some key success factors of Lean are to get the cross-functional input from all disciplines throughout the process, challenge partners to continuously improve, elite team members selection, identify opportunities earlier and explore solutions. These are possible through the encouragement of the upper management for learning and sharing the failure and the success (transparency). Also, accurate information exchange between departments and customers at the right moment is crucial to establish flow and pull production. Lapinski et al. (2006) highlighted the importance of identifying and understanding the value-added steps. There are various Lean tools and techniques developed for more effective scheduling. Among those, Last Planner System (LPS) is undoubtedly the most widely known and implemented one LPS was created by Glenn Ballard and Gregory Howell, two masterminds in Lean research, in the 1990s for project production control. Ideally, LPS is an integrative process that draws its strength from different project participants to find a pearl of shared wisdom and engage in appointed tasks. At the meetings of LPS, the milestone dates derived from the Master Schedule (MS) are confirmed with Reverse Phase Scheduling which relies on pull system to identify the work that releases work to others. Directives, prerequisite work, and resource constraints should be considered in those meetings (Ballard & Howell, 2003) to enhance quality assignments of definition, size, sequence, soundness, and learning. LPS consists of five elements (1) MS, (2) phase pull planning, (3) make work ready planning, (4) weekly work planning, and (5) learning (Brioso et al., 2017b). Location-Based Management System (LBMS) and Takt Time Planning (TTP) are iterative design methods for planning and controlling construction work for LPS.

The inputs of the calendar for each task, labor consumption rate for each quantity item, Location Breakdown Structure (LBS) according to location and type for location boundaries (with a finish to start relationship), logic between tasks, optimum crew composition quantities for each location and task are used in Location-Based Management System (LBMS) to establish flow. With a top-down approach, responsible engineers track the process, forecast schedule, and identify problems to solve collaboratively at the end. To start, the workflow is optimized by the bottleneck trades (with gentlest slopes) to find a common slope for each phase by changing (1) number of crews or scope, (2) location sequence, (3) soft logic skills or (4) planned breaks (turning tasks to discontinuous) (Frandson et al., 2015; Kenley & Seppanen, 2010). Then the likelihood of delays is analyzed and principally time buffers are added. In LBMS time, space and plan buffers could be implemented but capacity remains constant to utilize the same crew source continuously. If the same crew performs different types of work in the same location, a task can contain multiple quantity line items. Daily/weekly labor production rates are constantly controlled by production engineers and superintendents (Seppanen et al., 2014). In case of deviation in the production rate, work content and overlapping production in different locations could be changed. Transforming quantities in locations and productivity information, buffers, and forecasts could be graphically followed from the flowline method for LBMS which is similar to LoB.

TTP is increasingly used for residential construction projects, highway projects, and hospital projects in different countries. "Takt" is originated from the Latin "Tactus", "meaning touch, sense of touching". In Latin American countries like Peru, TTP is referred to "activity trains" (Brioso et al., 2017a). The German term "Takt" is the translation of "cadence" or "rhythm" into the Lean philosophy, which is used to refer the beat at the demand rate (Frandson et al., 2013, 2015). Unlike the rhythm in music, which can vary within individual "Takts", "Takt" has a predetermined repetition process with the same duration (Haghsheno et al., 2016). To maintain flow and create a pull system, a constant Takt Time (TT) is to be determined for all workstations throughout the project and relevant knowledge is forwarded through a balancing mechanism for the production system. If this particular time interval is falsely set, a high TT could cause many trades to have idle time (insufficient production rate). On the other hand, a low TT could cause a system to suffer from overproduction. In both cases, the project team encounters waste, and concurrency is collapsed. Therefore, at fieldwork, trades underload their production units e.g., 70 or 80% of capacity after evaluating work density. People who finished the work earlier than TT can work on "off Takt" (backlog or leave out work), prepare for the next Takt sequence, or improve their work (Frandson et al., 2015). The TTP eventually enhances output and demand rates to become matched with a steady flow where at each zone, trades identify the scope, means, and crew loading of work (Frandson et al., 2013). TTP is based on the manpower, Standard Space Unit (smallest repetitive part in a project), and the performance factor (Binninger et al., 2018). It provides activities to be separated with the correct size and sequence. However, the TT and zones must be large enough to work productively and small enough to control at a frequent interval. It also maintains a clear outlook on upcoming work and reduces stress on the entire project team ensuring the completion of a precalculated fixed daily batch of work with even intervals conforming with the project objectives. A temporal movement of a task in a given TT sequence does not affect the completion of work within the TT sequence, which is called as Schedule noise, and if this movement shifts into another TT sequence, it is then called as Schedule variance. Schedule variance needs to be handled in the field before it affects the incoming trade or results in rescheduling the work (Frandson et al., 2014). This detailed TT planning sets a pace that meets MS's milestones and serves as a check point. Even though the scale across multiple floors or large areas put a challenge for a balanced TT, the idea of belonging to a collaborative objective increases productivity. According to their unique conditions, some trades may have to perform "off Takt" paces. TTP ideally starts with a common meeting with all project teams to distribute control (Frandson et al., 2015). Frandson et al. (2013) summarized this process in 6 steps; (1) collecting data (identify how, by whom, in what sequence), (2) divide workstations by zones (same production rate for a certain task), (3) order by trade (collaborative planning of all parties to design and execute a certain task), (4) balance work equally (identify bottleneck tasks, balance time interval of tasks), (5) time needed for each trade (first runs are made for future improvements), and (6) plan according to TT (control variations for each task). Binninger et al. (2017) added Takt leveling to shift variable work steps, manpower and buffer) and determined milestones for consumer priority (demand) in accordance with the steps mentioned.

TTP buffers with capacity, plan, and space buffers. In case of TT deviation for a trade, the following steps are applied; (1) work overtime to complete, (2) pick up in future if no work depends on it, and (3) leave out if it is the case is unique (Frandson et al., 2015). Binniger et al. (2016) and Chauhan et al. (2018) proposed improvements in machinery, logistics, prefabrication to reduce waste for ameliorating deviations. However, these improvements are not quite efficient in reducing construction time. Lehtovaara et al. (2019) advised using digital control tools for more efficient control and learning of TT in the interior phase of residential construction. Conceptually, TTP constantly evolves with short-cycled adjustments.

TT and Lean philosophy highly influenced better results in some construction projects. Frandson et al. (2013) reported that a clear daily goal for each activity, daily level production management and a well determined TT allowed production team to finish exterior cladding in 5 months resulting in a time saving of 6 months. In the study of Yassine et al. (2014), a construction task with a repetitive nature was completed in 54 days with a smoother resource allocation curve by TT, where it was expected to be finished in 105 days. Location-Based Management Systems (LBMS) utilize TT in the Kampi Center building complex in Finland saved millions and the project was completed six months earlier than scheduled (Kenley & Seppänen, 2010). Establishing a 5-day TT for a healthcare facility in California put forward the importance of balancing the entire system from the project team to production (Frandson & Tommelein, 2016). Consequently, better quality, increased economic viability, exploitation of incentives, timely completion, better worker comfort are the most important advantages of TTP (Haghsheno et al., 2016).

Discussion

LoB and TT are two intertwined concepts, which have several features in common. LoB and TT suggest that all activities are to be performed with a single rate, turning the work into parallel programming to avoid delays. The mastermind of Lean philosophy, Taichii Ohno, also indicated that synchronization in production is obtained by establishing a single production rate (Ohno, 1988). Both methods include phases of planning, doing, checking, and acting. LoB and TTP allows a clear outlook on upcoming works, considering different crews to perform parallel tasks, activities to be separated with the correct size and sequence, the deviations in the assembly, and aimed to work with a target delivery rate. The zones, the trades sequence, and duration need to be clearly defined for both methods, and if leveling applied in LoB; workflow should be balanced in both methods (Biotto et al., 2017). After the leveling approaches completed for both methods, better task definition, evenly use of resources, minimization of inventories, reuse of crews in different operations, uninterrupted work for a crew, and visual management (to indicate successor ones to pull predecessors) are implemented (Binniger et al., 2016). LoB allows to detect cycle times, therefore, reduces cycle times, which aligns with the continuous development mentality of Lean production theory (Lucko & Gattei, 2016). LoB is a superior tool, overarching Kanban cards, to indicate when materials should be supplied to units or tasks visually. Focusing on resources can portray the cycle of crews in a bar-chart form. Yet, the horizontal bar representation of activities between two parallel lines in LoB might suppress a crew discontinuity due to non-balanced productivities of a predecessor-successor pair in the two back-to-back bars at work units situations. LoB uses buffers between critical activities (Frandson et al, 2015) or the crew's production capacity. Nonetheless, TTP implements buffers in the production capacity of the crew (Biotto et al., 2017). The line slope gives the delivery rate in LoB and it should not be mixed with the production rate in the flowline methodology (Su & Lucko, 2015). In this manner, the slope of the boxes in TTP represents the TT or customer demand rate, which is similar to the delivery rate. These representations are shown on Figure 2.

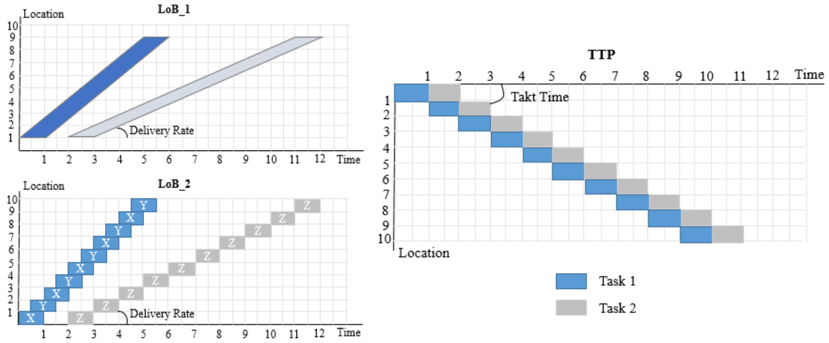

Figure 2: Visual representation of LoB and TTP based on location (Adopted from Biotto et al., 2017).

Seppanen (2014) converted LMBS into TT schedules by removing buffers, adding dummy "Takt line" flowlines based on the bottleneck production rate (TT allowed to change if one specific location had larger quantities), production tasks are linked to Takt lines by start-to-start link and the number of crews changed according to shorter or equal to TT. Moreover, it was found that TT implementation is harder in the high number of varying tasks requiring workable backlogs or locations to absorb periods of low production demand. The comparison of these two scheduling methods could be followed from Table 1.

Table 1. Comparison between LoB and Takt Time (Biotto et al., 2017).

	LoB	Takt Time
Collaboration	Varies according to the level of plan	Necessary
Crew's Workflow Visualization	Yes	Partial (crews can work in two locations at the same time, or executing backlog)
Level of detail of the plan	Flexible	High
Pace Achievement (Balancing the Lines)	Adding or reducing the number of crews to execute an activity; Changing the crews' composition and amount of service inside the work package	Changing the crews' composition and amount of services inside the work package; Distributing the workload among crew's members; workable backlogs
The slope of the line represents	Arditi (1988): Production pace Later: Delivery pace	TT: available production time divided by demand
Task duration per location	Location quantities divided by standard crew's productivity	Equal to takt-time or shorter Start
Tasks representation	Formerly: Start and finish dates of first and last units; Currently: start and finish dates by unit	Start and finish dates per unit
Task Visualization	Formerly: two parallel lines; Currently: boxes	Boxes
Use of buffers	Buffers inside the work package duration; Buffers between critical activities	Buffers inside the work package duration: the difference between takt- time and cycle time

TTP requires crews to work at the same pace without buffers to reduce non-value adding time. This might cause more work backlog in the unique tasks of construction projects and a comprehensive communication plan. But in a well-determined TT with elite project members, people who finish their work earlier than TT can work on backlogs, prepare for the next sequence, and improve the work capacity by innovations. The brilliant philosophy to match demand and supply in TTP with continuous improvement combined with the construction industry experience and mathematical wise of LoB surely will contribute to help construction industry find its true potential.

Conclusions

Planning methods aim to create the best value for construction activities. This study is aimed to compare two distinguished planning methods which are heavily mentioned separately in the literature; LoB and TTP. The authors detailly evaluated these two concepts from a historical and literature-based perspective. Even though LoB is developed before TT, both methods have remarkable similarities. LoB and TT suggest all activities are to be performed with a single rate and turn the work into parallel programming to avoid delays. Planning, doing, checking, and acting is implemented in both methodologies. Moreover, activities aimed to be separated with the correct size and sequence aims to work with a target delivery rate. The cycle times are detected by LoB that aims to reduce these times and aligns with the continuous development mentality of the Lean production theory. On the other hand, LoB uses buffers between critical activities or the crew’s production capacity. TTP implements buffers in the production capacity of the crew. LoB and TTP have different representations visually and it is found that TT implementation is harder in the high number of varying tasks requiring workable backlogs or locations. In future work, the calculations between LoB and TTP can be compared with a case study of repetitive works to combine the strengths of these two methods.

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An Evaluation of Project Communication Management in Turkish Construction Sector

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Abstract

Communication within construction projects is a multilayer phenomenon which involves multiple disciplines and organizational levels, also different perspectives, and interpretations. Communication through project participants has become a critical factor for project success and effective communication can be possible with a communication management. This study focused on project communication management in Turkish construction sector. A comprehensive literature review was done, and it was noticed that there is a very limited number of studies about communication in construction sector in Turkey. For this reason, the value given to communication concept by professionals of Turkish construction industry, the communication perspective of professionals and the communication management practices applied in the sector were investigated with two-stage field studies. Also, needs of the communication principles defined in PMI standards by the professionals were analyzed. As a result of the field researches, although it is seen that construction sector professionals are giving necessary value to the communication and they are considering that communication is an important factor for project success, there is not any standard practice for communication in the project organizations. Also, Turkish construction professionals' need of communication management can be clearly seen in consequence of the questions asked in the survey.

Keywords: *communication, communication management, construction projects, Turkish construction sector.*

Introduction

Construction projects require different communication methods compared to other project types due to their unique characteristics such as complex, one off, immobile, fragmented, temporary, need to be finished limited time period (Prencipe & Tell, 2001).

Communication within construction projects is a multilayer phenomenon which involves multiple disciplines and organizational levels, also different perspectives, and interpretations.

With the increasingly complex structure of the construction industry, establishing effective communication and ensuring the necessary coordination among multiple stakeholders has become a very important factor in terms of project performance.

Construction projects are generally delivered by temporary organizations. New organizations are formed for each project temporarily and the organizations are special to the projects' requirements. Within these temporary organizations, there are various participants as contractors, subcontractors, design offices, consultants, project management offices, suppliers, financiers etc. who are appointed to the projects. These organizations are short-term and multi-partnered organizations. Consequently, the participants of the construction projects maintain their existence in a constantly changing network of relationships according to each project's own characteristics and requirements. At this point, in order for the projects to be completed successfully, it is important to establish a proper communication between the participants from different backgrounds and cultures to work in a harmony. In multidisciplinary and complex projects, a huge amount of information exchange and communication is required for the project to be successful. However, it is impossible for all project participants to know all of the information. For this reason, it should be ensured that necessary and correct information is transmitted to necessary participants at the required time for project success (Butt et al., 2016).

Within the project process, management plans which are aiming to delivery information to the correct individual / groups, at the right time, in the right format with the right effect, also summarize and elaborate stakeholder's needs and expectations are called "Communication Management Plan".

The delivery of necessary and right information to the right audience, at the right time, in the right format can be possible with a "Communication Management Plan" which will be established at the beginnings of the projects, also management and supervision of communication according to "Communication Management Plan" afterwards.

According to the report published in PMI, high performance organizations tend to use standard applications three times more than low performance organizations. Communication Management Plan is a standard application that can be adjusted for each project. In addition, the same report revealed that a formal Communication Management Plan has been developed in seventy percent of the projects of successful organizations, while this ratio is forty percent in low-performance organizations (PMI, 2013). This report shows the importance of the Communication Management Plan for project success.

Although the concept of communication in the construction industry has started to be the subject of researches since the 1960s and has gained importance in the foreign literature in recent years, it has been observed that a very limited number of studies have been conducted in the field of communication in the Turkish Construction Sector. However, the construction sector is considered as one of Turkey's most important sectors. For this reason, with this study, the value given to communication concept by professionals of Turkish construction industry, the communication perspective of professionals and the communication management practices applied in the sector were investigated with two-stage field studies. Also, needs of the communication principles defined in PMI standards by the professionals were analyzed.

Literature Review: Communication Management in Construction Sector

Project Communication Management is defined by the Project Management Institute as a set of processes required for planning, producing, collecting, distributing, storing, reusing, managing, controlling, monitoring and delivering their final positions in a timely and accurate manner (PMBOK, 2013). Communication is considered as one of the most important skills that the project manager should have. Project managers spend most of their time communicating with team members and other project stakeholders.

Kerzner defines Communication Management as the process of controlling the transfer of information from any direction (up, down, horizontal or diagonal) that may be formal or informal. It states that project performance is directly dependent on the project manager's ability to manage communication (Kerzner, 2009).

The authors claim that effective communication creates a bridge between stakeholders with different cultural and organizational infrastructures, different levels of expertise, and different perspectives and interests (PMBOK, 2013).

Effective project communication assumes that the right information is delivered to the appropriate person at the appropriate time, at an affordable cost. These prerequisites are essential for project success (Kerzner, 2009). Efficient project communication means providing only the necessary information (PMBOK, 2013).

Project communication is an exchange of information between project stakeholders to create harmony (Nangoli, 2012). The term project communication refers to all aspects of communication in a project; both external and internal communication, written and interpersonal, formal and informal communication (Ramsing, 2009).

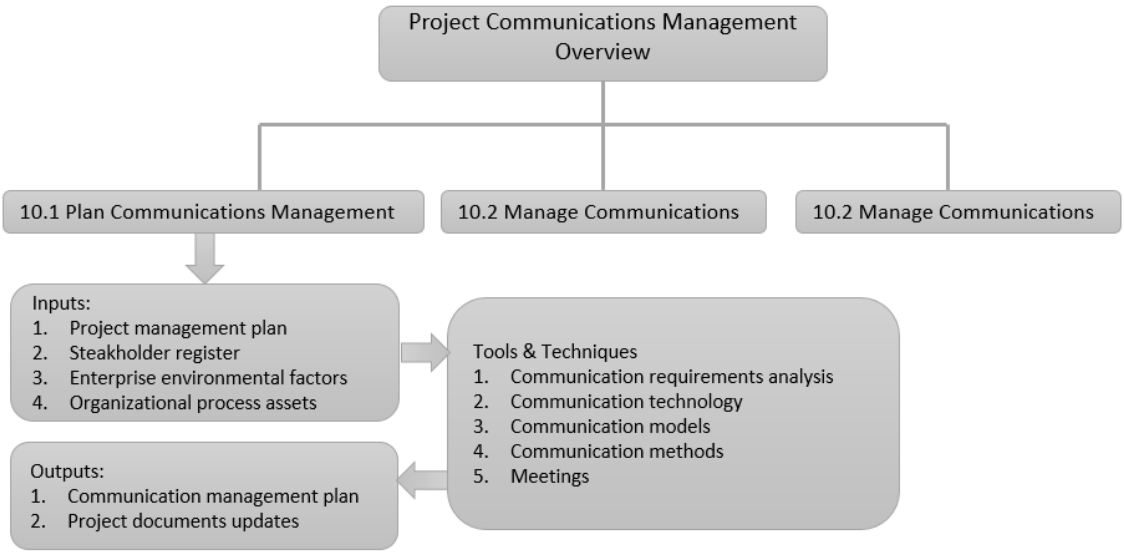

Figure 1: Project communication management overview (PMBOK, 2013).

As seen in Figure 1, the Communication Management process is divided into three process according to PMBOK. These processes are as follows.

1. Plan Communication Management: The process of developing the project communication management plan according to the information needs of the stakeholders and available organizational structure.
2. Manage Communications: The process of creation, collection, distribution, storage, selection and bringing of the project information to their final positions in accordance with the Communication Management Plan.
3. Control of Communications: Monitoring and controlling whether the information needs of stakeholders are met in the project life cycle (PMBOK, 2013).

Lys (2015) created the structure shown in Figure 3.5 on how the communication management plan should be created. Lys (2015) created Communication Management Plan Frame shown in Figure 2 as a result of her field researches.

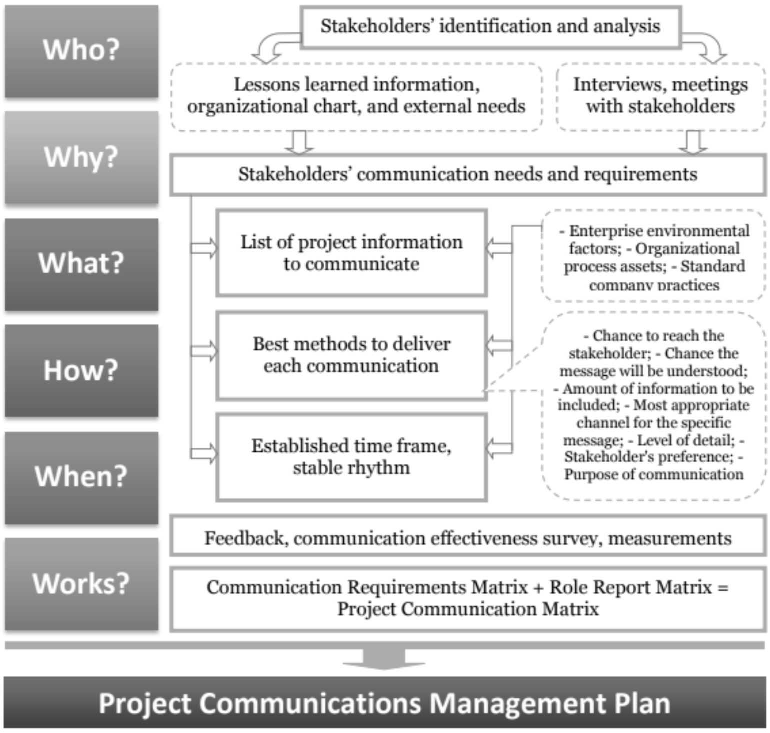

Figure 2: Communication management plan frame (Lys, 2015).

According to Lys (2015) communication Management Plan Content are as follows.

- Stakeholders communication requirements,
- Language, format and detail levels of the information to be delivered,
- Purpose of communicating information,
- Timing and frequency of distribution information,
- List of people responsible for information distribution,
- List of people and groups who receive information,
- Methods, tools and technologies to be used to deliver information,
- Updating methods of project communication management plan,
- Terminology list,
- Information flow charts, reports and meetings, etc.

Method

The purpose of this study is designed as three stages. Firstly, the value given to the communication by the professionals in the Turkish construction sector has been investigated and communication perception of professionals is examined. Secondly, it was researched that whether "Communication Management Plan" is used in Turkish Construction Projects and how it is used. Thirdly, the needs of "Communication Management Plan" and "Communication Management" principles defined by the PMI standards have been analyzed. Field research was carried out in two phases. In the first phase of the field study, a pilot study was conducted with seven professionals who have over ten years of professional experience. Six open ended questions were asked to the professionals. In the second stage of the field research, in the light of the literature survey and the answers received from the pilot study, questionnaire were prepared and the survey was conducted with the participation of 99 professionals working in various positions in different companies in the Turkish construction sector.

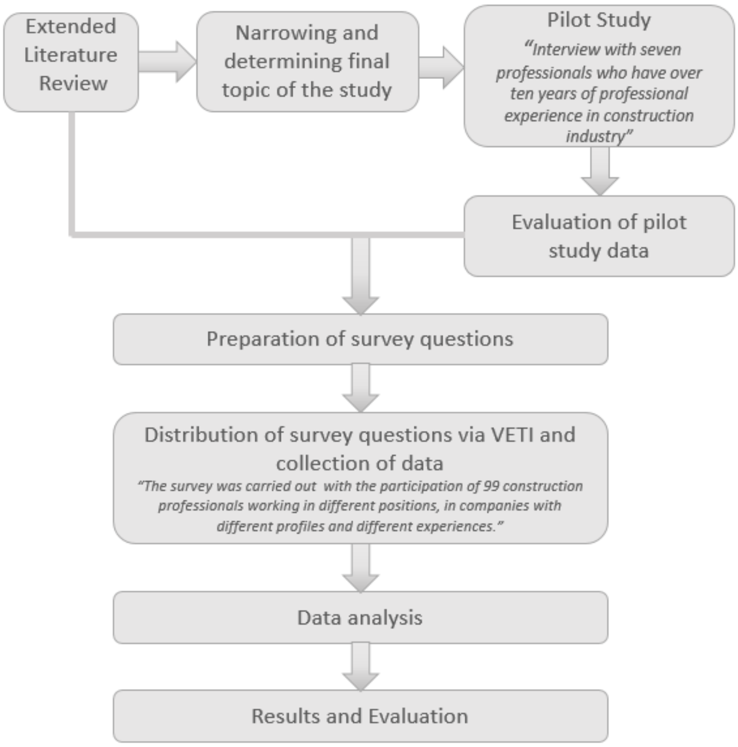

Figure 3: Research method.

Findings

First Stage

Communication Concept

Pilot Study: In the first question of the pilot study, the participants were asked to define the concept of effective communication in order to understand the perceptions of the communication. When the answers were reviewed, it was seen that the definitions of the effective communication of the participants working in international projects in generally match up with the literature. The participants who have worked on projects carried out in Turkey only, also think the communication is an important factor for project success. However, their definition of communication is not totally in line with the literature, their definition formed according to problems they encountered in their professional life.

Questionnaire: In the light of the questions asked in the communication concept section of the questionnaire, it was determined that the participants agreed that communication is a critical success factor for construction projects. Participants were asked whether they agree with given statements, one of the statements is “Establishing effective communication between participants in construction projects is one of the most critical factors for project success”.

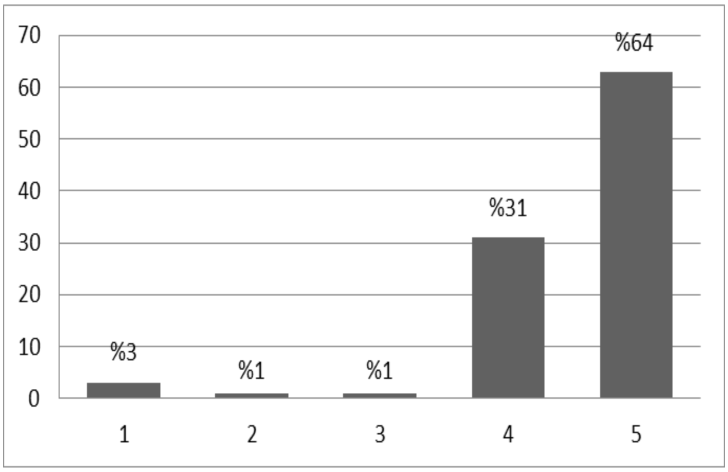

Figure 4: Effective communication – project success (1: Strongly Disagree 5: Strongly Agree).

As a result, it can be said that Turkish Construction Professionals have a high awareness of the importance of communication, based on the field researches.

Communication Barriers

Pilot Study: In the pilot study, participants were asked about the communication barriers that they have encountered so far. The communication barriers encountered by professionals can be listed as follows.

- Verbal communication is not recorded,
- Language barriers,
- It is not known who should be contacted about which subjects,
- Employer / investor requests cannot be transferred correctly to all project participants,
- Stakeholders' locations are not identified correctly in organizational chart and not released to all project participants,
- One-way communication

When communication problems’ effects on project success is asked to participants, it was stated that communication problems would affect project success negatively, especially in terms of cost and time, and different opinions emerged about whether quality was affected negatively.

Questionnaire: In the third part of the survey, the communication barriers listed according to the literature research and the data obtained from the pilot study. Frequencies of the participants to encounter these communication problems were investigated. The frequency values indicated on Figure 5.

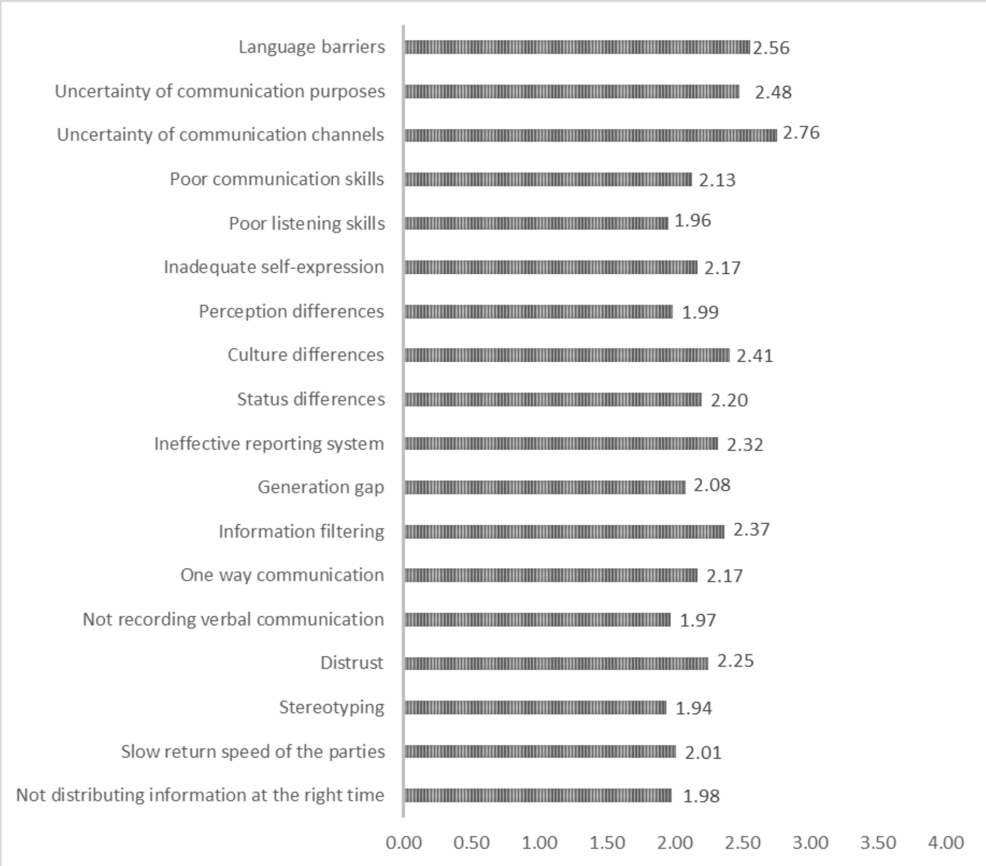

Figure 5: Communication barriers (1:Always 2:Sometimes 3:Seldom 4:Never).

It can be said that participants face with almost all of the listed communication barriers, except from "uncertainty of communication channels","language barriers".

Communication Tools

Pilot Study: In the pilot study, the participants were asked to indicate which communication tools they used in their projects and to rank the communication tools according to their usage frequency and efficiency. When the responses are examined, it is seen that the most commonly used communication tool is "e-mail".

Although almost all the participants agree on "e-mail" as the most widely used communication tool, the most efficient communication tools they specify are different. The importance of face-to-face communication in some urgent matters was indicated, also the necessity of verbal communication should be recorded is strongly specified. Some participants stated that the most efficient means of communication will change in line with the complexity and urgency of the business.

Questionnaire: Communication tools listed according to the literature research and results of the pilot study. Usage frequencies and efficiencies of the communication tools were investigated. Regarding usage frequencies, results of the survey is the same as the pilot study and participants agree that most used communication tool is e-mail. The frequency values indicated on Figure 5.

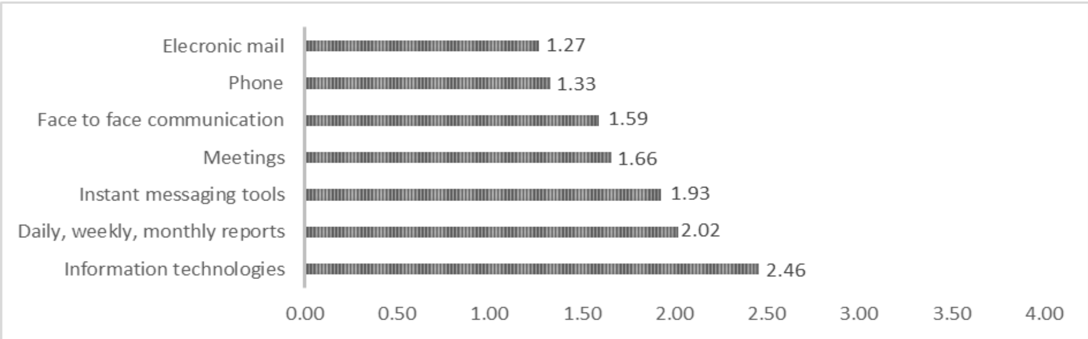

Figure 7: Usage frequency of communication tools (1:Always 2:Sometimes 3:Seldom 4:Never).

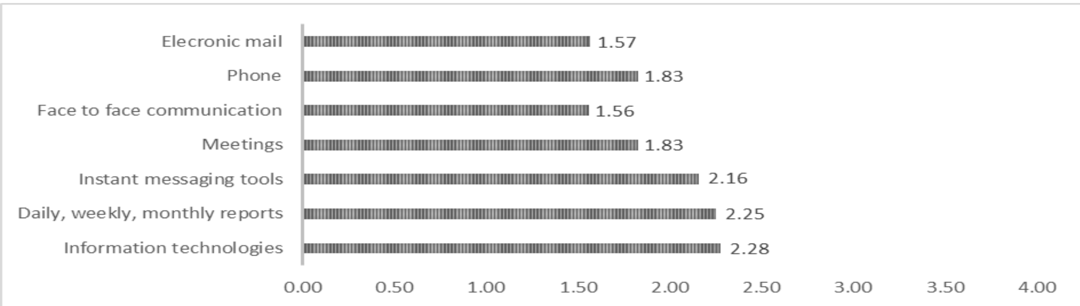

Figure 8: Efficiency analysis of communication tools (1: Very efficient 2: Efficient 3: Less efficient 4: Inefficient).

Regarding efficiency analysis, it is seen that face to face interview and electronic mail has same efficinecy value, also this results match up with the pilot study.

Second Stage

Communication Management

Pilot Study: In the pilot study, the participants were asked whether they used a Communication Management plan and their effects on the project success were investigated. Three participants stated that the Communication Management Plan has been shared with them at the start of the project so far. One of these participants stated that the communication management plan was used only for the "Design" phase. One participant works for international project management and consulting firms, other two participants are working for different project management companies.

As a result, it can be concluded that companies that perform Project Management area professionally in the construction sector are more conscious about "Communication Management".

When the answers were analyzed, it was seen that all participants, except one participant, agreed that the Communication Management Plan, which can be shared at the beginning of the project, will definitely affect the success of the project positively.

Questionnaire: Firstly, it was examined whether the participants are familiar with the concept of "Communication Management Plan", 44 % of participants indicated that they were familiar with the communications management plan. Secondly, it was investigated whether the participants used the communication management plan, the result is indicated on figure 10.

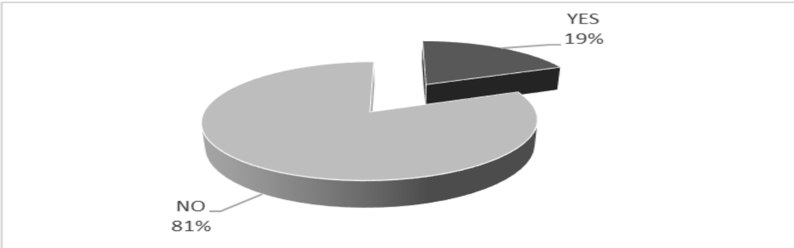

Figure 9: Communication management plan – usage.

Communication management plan contents were asked with open ended question to the participants who indicated that communication management plan is shared. It was determined that only the content information shared by 4 participants corresponded to the definition of communication management plan described in the literature. These 4 participants also works for Project Management company, results are in line with pilot study.

Third Stage

The third stage of the thesis is to analyze the need for "Communication Management" principles defined in PMI standards by professionals in the Turkish Construction Sector. Therefore, thirteen statements were shared with the participants from PMBOK: Communication Management section. The participants were asked to score the thirteen statements.

When the average values of the answers are analyzed, it is seen that the lowest value is given to 9th expression "It is correct to define and explain the communication tools and techniques that will be used and possible at the beginning of the project for each step in the communication process that will take place between the project participants." and the value is (4.31) quite high. The highest value is given to 4th expression "Explanation of who will be responsible for which parts of the communication process at the beginning of the project affects the communication process positively." and is 4.57.

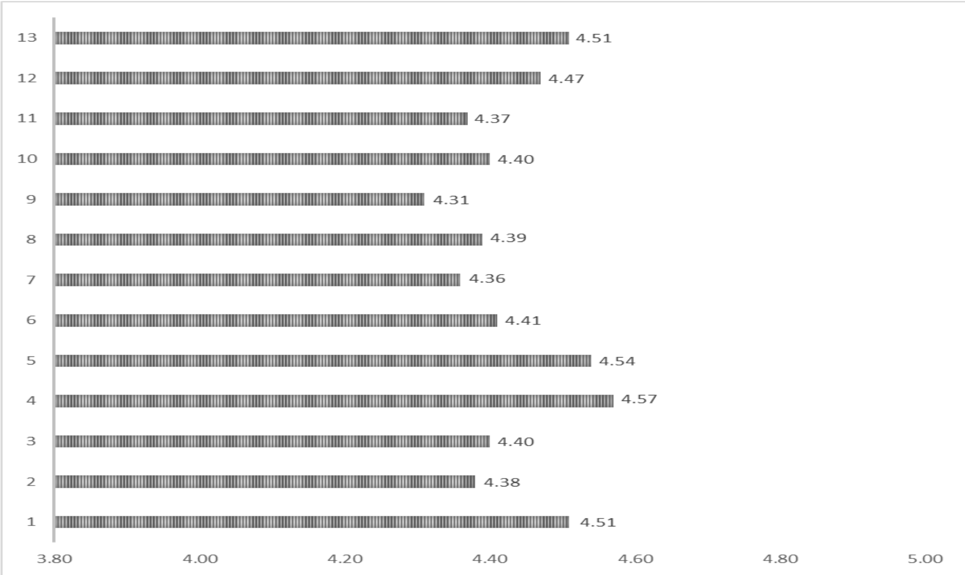

Figure 11: Average values of the answers given to the statements (1: Strongly Disagree 5: Strongly Agree).

Results

As a result of the field studies, it was understood that the “Communication” concept was mostly given the necessary value by the professionals working in the Turkish Construction sector and was regarded as one of the critical factors for the success of the project. It has been determined that companies and professionals in the Turkish construction industry have not yet used the concept of "Communication Management" as a management tool. However, it is thought that the project performance will definitely increase especially in terms of quality, cost and time as a result of the "Communication Management Plan" and "Communication Management" applications by construction professionals. In addition, it can be said that Turkish construction professionals’ needs of communication management plan and communication management can be clearly seen in consequence of the questions asked in the survey.

It is clear that usage of "Communication Management Plan" and "Communication Management" principles as a management tool will positively affect success of the project. The use of Communication Management principles at all stages of the project as a management tool should be supported and implemented by the company owners, project managers in the Turkish construction sector. It can be said that these principles will eliminate project failures due to communication problems.

This study aims to inform professionals who work in the Turkish Construction Sector about the importance of project communication and increase their awareness, and to be a guide for managers and company owners. In addition, it is expected that this study will be a basis for future studies on “Communication Management” and the data obtained will shed light on future studies.

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Identifying the reasons of rework in museum exhibition projects stemming from design representations

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Abstract

Exhibiting is one of the main objectives of a museum according to the International Council of Museums (ICOM, 2008). Focusing on temporary exhibitions we defined their production phases in comparison with the project management main processes and found out possible improvement areas at our previous research. This paper investigates the nature of exhibition design projects and reasons of last minute design changes which leads to costly reworks. Literature review was made to find out the differences between the other 3D design disciplines and the influences of actors involved in the production process of museum exhibitions. We found that the design factors to be involved are much more diverse than architectural or product design. The clients who are mostly without any design education but have control over the design project can't fully understand the construction and installation projects before execution. Traditional representations do lack to transmit the effects of important elements unique to exhibitions like artificial lighting, sound installations and other dynamic multimedia. Not all exhibits to be shown in physical spaces like digital art or multimedia installations can be represented with traditional ways. The adoption of representations that are closer to the "experiential-spatial" human experience in the real world is needed.

Keywords: *design representations, exhibition design, rework.*

Introduction

Exhibition development is a complex activity, which is expanding beyond the design discipline (Dean, 1994) Various kinds of specialists have brought a new perspective to museum exhibitions especially in terms of digital technology, which has had a major impact on the design process in museum exhibition development. Furthermore, traditional museum exhibition design is being increasingly replaced by multi-disciplinary practices that involve a wide range of specialists, such as artists, engineers, architects, designers, curators, museum specialists and educators (Lin, 2002).

In addition to a wide range of contributing professionals to the process, evolving expectations of the visitors and ever developing technological tools to transmit the knowledge; the nature of the genuine production process of exhibitions which do not end with construction but installation of the exhibits. That's why any design change after construction would cost more as it adds not only the cost of rework but also the mobilization and security of the artifacts.

What is a Museum?

Intuitively it is easily understood in its manifold complexity, with a stable core concept of a collection of objects bearing information and transmitting emotions, memory and knowledge to those who view, contemplate and connect with them (MMDP, 2018). Museums grow and multiply, significantly, across the world. Current trends and changes in societies directly and indirectly impact, frame and affect museums and museum work. In adapting to the new conditions and new possibilities museums stretch, bend and reinvent the known institutional formats of what a museum is thought to be. In line with this trend new exhibits and new ways of exhibiting also emerge.

Museum Exhibitions

Exhibitions are mediums where museums communicate the meaning by putting together the collection (objects and archives) and knowledge (fact and stories) with special interpretation techniques and learning sequences. (Ahmad et al, 2014; Desvalles, 2010; Hooper-Greenhill, 1994; Herreman, 2004).

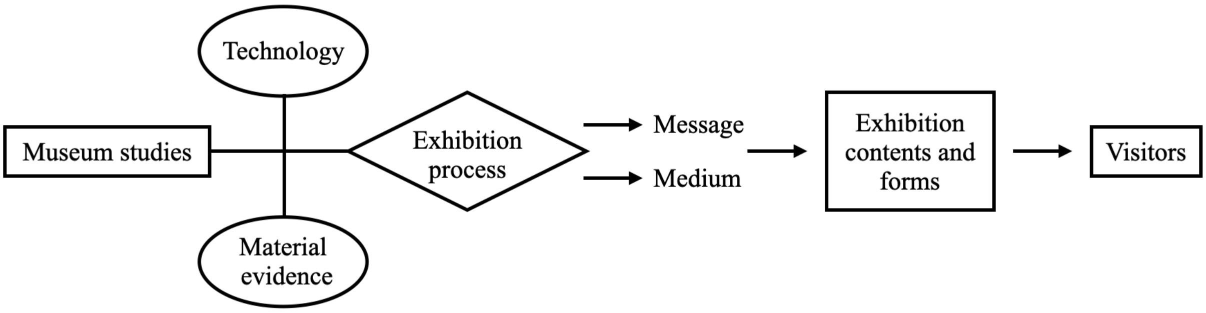

Figure 1: A simple museum exhibition communication model (Lin, 2002).

To Burcaw (1997) exhibition is the presentation of ideas with the intent of educating the viewer or in the case of an art exhibit, a planned presentation of art objects by an informed person to constitute units designed to be meaningful instructionally and/or aesthetically for the visitors who go through in them in sequence.

With overlapping areas, exhibitions can be categorized as follows:

- Content: Art, archaeology and history; science and technology; others (EGMUS)
- Medium: Virtual, physical (building or any other space with physical objects and other information transmitting (digital or not) mediums.
- Interaction: Interactive, unilateral (usually a variable for virtual museums)
- Communication style: Descriptive, narrative, dramatization-based

- Duration: Permanent, temporary (Alexander and Alexander 2008, 237) cited in Davies (2010), Herreman (2004). Herreman (2004) proposes to call permanent exhibitions as "core" exhibitions as this type of exhibitions should use approaches that will not tire the visitor that will not quickly look old-fashioned, and should use materials that will endure time.

Museum Exhibition Production Process

Museum exhibitions are temporary endeavors undertaken to create a unique product, service or result so each should be acquired through specific phases (initiating, planning, execution, monitoring, and closing by PMBOK) as defined in the project management research area. With these in mind we had defined the phases of museum exhibition projects as idea (inception), development, design, construction, installation, demolition (Durmus & Gunaydin, 2016) and pointed out improvement areas for each phase including design. Not always covering the same processes some other phasing are shown at Table 1.

Table 1. Museum exhibition project phases.

Velarde, 2001	Herreman, 2004	Davies, 2010	Durmus & Gunaydin, 2016
Inception	Planning	Initial idea and development	Idea (inception)
Feasibility	Research / Interpretation	Management and administration	Development
Design Principles	Design	Design and production	Design
Techniques	Production	Understanding and attracting an audience	Construction
Production	Installation	Curatorial functions	Installation
Completion and maintenance		Planning the associated program	Evaluation and demolition

In addition to the in house professionals, many museums hire academic expertise (e.g. educators, researchers in exhibition themes) to support their professional knowledge and experience. They generate cross-disciplinary ideas and philosophies to achieve the aims of the exhibition (Lin Chung-Hung, 2002).

"Idea" Phase of Exhibition Process

By the late 1980s exhibitions became popular in the art world, not only to high authorities, but also to the general public. Curators have become more sensitive about visitors' interests and the messages that were communicated through exhibition displays (Hou, 2015). The most recent issues of museological literature (e.g. museum theory, museum planning) indicate that museums need to be communicative and educative, and that museum roles and functions are fundamentally innovative in exhibition design. This has changed the current issue from `displaying the collection' to `exhibiting the idea' in the development of museum exhibition projects (Lin Chung-Hung, 2002).

At the idea phase, the theme of the exhibition is shaped with a planning brief by professionals who have necessary expertise about the content. Curators, consultants, director, conservators, designers, related academics, collectors, professionals from other museums may be involved. According to Davies' (2010) research through 20 exhibitions, there was also evidence of external involvement at the idea phase of 14 cases.

"Development" Phase of Exhibition Process

Once an exhibition brief has been agreed, appropriate members of the team move on to developing the details of the concept, particularly the proposed objects, data and information that will be presented in an exhibition. This will probably involve some special research by curators to update knowledge of and the interpretation of the collections and themes to be included. At the same time the design, education specialists, and perhaps marketing staff also, may need to undertake research into the actual and potential audience and different approaches to interpretation and communication (Herreman, 2004).

"Design" Phase of Exhibition Process

Exhibition design is exceptional in the extent to which it draws upon the full spectrum of the design professions unlike other well-defined sectors in the design field like the design of software and interfaces; two-dimensional design such as graphic design and book design; three-dimensional design such as packaging and industrial design (Bradburne, 1999; Lin, 2002). Therefore it is truly multidisciplinary and includes so many design factors to be taken into consideration (Bradburne, 1999; Herreman, 2004; Lin, 2002; Wang, 2018).

Exhibition design factors (EDFs) have an impact on physical responses, which may directly influence the visitor whether or not stay in and enjoy a particular environment. They are the language to tell a story, in accordance with exhibition design (Wang, 2018). To reflect these factors where necessary, a team of designers from different fields like architectural design, industrial design, graphic design, lighting design, set design, game design, interaction design, multimedia design, programmer for digital design, etc. may work together with related engineering and technical professionals to achieve the right narration and the ambiance which are projected by the curator with a design brief and continuous supervision throughout the whole process.

Through this phase the design project development team;

- evaluate and allocate exhibition space according to storyboard themes and other visual and communication needs,
- determine circulation space needed, including disabled access requirements, security needs and official legal norms such as fire escapes,
- examine and distribute objects by units, sections, subsections that correspond to themes and sub-themes in the script and storyboard,

- design the exhibition furniture system: panels, free standing exhibit showcases, screens, case shelves, block cases, table cases, wall hung panels and other wall mounted elements,
- design lighting and sound system, with the consultation from conservator, curator and necessary professionals depending on the content (Herreman, 2004).

Table 2. Comparison of three design process areas (Lin, 2002).

Museum exhibition	Product design	Architectural design
A number of professionals from different disciplines need to co-operate with each other to sustain the development team.	A number of professionals from different disciplines need to co-operate with each other to sustain the development team.	A number of professionals from different disciplines need to co-operate with each other to sustain the development team.
Each member of the team has an opportunity tı understand the client's requirements when the project starts.	Some members of the team do not obtain product requirements from the client	Some members of the team do not obtain product requirements from the client
Museum curators or design consultants conduct or manage the design process	The product designer conducts and manages the design process	The architect conducts and manages the design process
The client is involved in the design process, providing informations, giving ideas and making decisions, together with all development parties in order tonsure that the full implications of the museum's requirements would be understood clearly	The client is not involved in the design process but provides information and makes decisions	The client is not involved in the design process nor gives information
Client is involved in project development	Client is responsible for manufacture	Client is involved in project development
Produce single or multiple items	Produce multiple items	Produce building/s

Table 3. Exhibition design factors (EDFs) from different researches on the topic (Wang, 2018).

Painting, photography, diagram, lettering, word, architecture, sculpture, tone, light, film, ground-plan, theme, movement, material.	Bayer (1939), pp.17-18, p.22, p.24
Printing, sound, picture, painting, photograph, sculptural media, material and surface, colour, light, movement, film, diagram, and chart.	Bayer (1961), p.258
Object/animal factors (size, motion, novelty, other intrinsic qualities, sensory qualities, interactive elements, and triangulation), architectural factors (visibility, proximity, position of the exhibit object, realism, sensory competition, other design factors), visitor factors (demographic characteristics, special interests, object satiation, social influences, etc.).	Bitgood and Patterson (1987), pp.4-5

Exhibit design factors (size, motion, aesthetic factors, novelty or rarity, sensory factors, interactive factors, and triangulation), visitor factors (visitor participation, object satiation, special interests, demographic factors, other psychological factors), and architectural factors (visibility, proximity of animal/object, realism of exhibit area, and sensory competition).	Patterson and Bitgood (1988), pp.40-47
Exhibit components (objects, communication media, text information; exhibit configuration: spatial relationships, other types of relationships; extra-exhibit factors: social influences, physical influences).	Bitgood (1992)*, pp.4-10
Objective physical factors (lighting, color, signage, texture, material, style of furnishing, layout, wall décor, temperature, etc.), and services cape.	Bitner (1992), p.65
Atmospheric factors: ambient case (lighting and music), social cues.	Baker et al. (1992), p.445
Content (types, issues), objects (types, users, source, issues), floor space (tools, issues), media (types, issues).	Carliner (1998) *, p.79
Primary elements with five senses: color, shape, and typeface (for sight); loudness, pitch, and meter (for sound); material and texture (for touch), etc.	Schmitt (2000), p.97
Value, color, texture, balance, line, and shape.	Dean (2002), p.46
Storyline, design style, exhibits, diorama, graphic concinnity, graphic aesthetic, text readability.	Chen and Ho (2003a, 2003b), p.8
Path, modules, lighting, visual communication, and interactive and multimedia tools.	Legrenzi and Troilo (2005), p.5
Atmospheric, layout, design, social.	Bonn et al. (2007), pp.347-348
Atmospheric factors (color, design, lighting, and layout).	Ariffin et al. (2012), p.380
Media, sociality and space.	Macdonald (2007), p.149
Atmospheric cues (product display features, color, space, layout, lighting, sound, design features, comfort features, employees, and crowding).	Parsons et al. (2010), pp.644-645
Text, artifacts, interaction, images, materials and content.	Topp (2011), p.31, p.67
Lighting, spaciousness, orderliness, style, color strings, texture settings, texture settings, and exhibition proportions.	Fang et al. (2012), p.178
Environment component (ambient factors, design factors, social factors).	Bohl (2012) *, p.6
Color, shape, material.	Zi-qi (2012), p.25
Space, audience, and message.	Wang (2012), p.6
Shape, form, space, color and value, density, form, shape, and texture.	Bogle (2013), p.293, p.317
Exhibits, didactic and graphic panels, furniture, technical equipment, multimedia products, audio-video, etc.	Ciamarra (2013), p.86
Atmospherics, and services cape (external variables, general interior variables, layout and design, point of purchase and decoration, human variables).	Forrest (2013) *, p.206
Orientation and navigation, spaciousness and display density, design and display style, lighting, color.	Forrest (2015), p.126

Lin (2002) defines this team for an exhibition design as a design project development team rather than a design team alone as it incorporates also people without design/build background. Here we could define two types of design communications;

1. Within the Multidisciplinary Design Project Development Team

Designers tend to monopolize the discussion about the formal aspects of the product. They do this by means of their training in the presentation of the design in drawings, sketches, plans and computer renderings. Only designers can 'read' in plan, section and elevation (Bradburne, 1999) so a useful design documentation is required to cope with complexity of museum exhibition design among those teams (Bradburne, 1999; Herreman, 2004; Lin, 2002; Wang and Xia, 2018; Vavoula and Mason, 2017).

The format of representation defines the ease of information understanding and sharing (Chandrasegaran et al., 2013). They are tools for communication, vehicles for exploration (Galle, 1999).

2. Design Communication between the Designer and the Client

Exhibition messages are generated and shaped by the clients such as curator, government, exhibition institution, or company/enterprise (Acord, 2010). Museum curators or the museum director who represent the museum are also involved in conducting the design project usually with full authority including plan, select, change, and control the exhibition design project (Lin, 2009; Wang, 2018).

To Accord (2010), the most important people in the cultural world now are not artists but curators who usually are not able to read in two or three dimensional drawings. Some crucial curatorial decisions are made onsite during installation days rather than the planning stage because there are three things that are hard to plan on paper or on screen from a 3D model; the exact final form of unfinished artifacts, the relationship among artifacts and the connection between artifacts and space (Acord, 2010).

Construction

It is the manufacturing or fabrication processes of the different elements that in the end create an exhibition. These can be divided into building work and specialized production. The first covers such activities as masonry and brickwork, plasterwork, basic electrical, video and audio installation, wiring and fixed furniture manufacturing, while the second includes more specialized work such as graphics, reconstructions, model-making, artwork, etc. (Herreman, 2004).

Many big and well-financed museums have flexible standardized, often modular, exhibition and display systems including showcases, movable walls and display screens and panels which allow multiple use and in different ways. Such museums are likely to design and build much of both their long-term ("permanent") displays and temporary exhibitions around such a system, using the available display elements and modular prefabricated cases. On the other hand, for special occasions or particular requirements, specially designed and constructed exhibition designed systems and furniture may be needed or desired (Herreman, 2004).

Installation

Once all building work has been completed and the free-standing showcases and wall-mounted furniture and exhibit structures are put into place. The working area then has to be thoroughly cleaned, including the glass or acrylic glazing for cases and other display units, and the lighting is tested. Then the fixing of title panels, other text and graphic units, illustrations and photographs can be carried out by the design team or contractor, after which the installation of the original objects by the curators or conservators can begin (Herreman, 2004).

Installation of the objects begins with the condition check of them by the conservator of the host museum and the courier of the guest collection. After the acclimatization of the object packages/boxes in the storage art handlers opens the crate in the presence of representatives of both institutions to witness the condition of both the package and the object. Handlers carefully move the object to a place for the conservator to examine thoroughly and compare the condition of the object with the condition report which comes with the object indicating every detail about the object. If a new damage is found it is added to the condition report with the approval of both parts. With this procedure the object will be under the host institution’s responsibility until reversing it at the end of the exhibition.

Art handler, conservator, courier, curator or the designer places the object to the dedicated space after the condition check. Sometimes, when it is not possible to measure the object beforehand, the supports which hold and secure the object during the exhibition are designed there and fabricated away from the galleries on site or at a close workshop as the exhibition space should always be clean and secure. These supports are made out of materials like stainless steel, acrylic glass, Mylar, acid-free paper, museum wax, silicone etc. with no effect on the object.

Any costume figures are dressed at this stage and finally the lighting is adjusted and tested for both effectiveness in terms of illumination, and of safe lighting levels according to agreed conservation needs. Finally, the curator, conservator, education specialist, designer and any other specialists, and usually the director also, review the display or exhibition and approve the final result. After this, the showcases are closed and there is a further full cleaning of the exhibition space ready for the opening to the public (Herreman, 2004).

Evaluation, Inauguration and Demolition

Evaluation after the opening will identify quickly any major mistakes or problems, such as circulation difficulties so that necessary modifications can be carried out. Even the inauguration day would be a good opportunity for evaluation especially to find out any bottlenecks through the visitor route. Cited in Herreman (2004) one of the leading researchers into exhibit effectiveness, Chandler Screven (1985), has described a method to carry out the process during the exhibition installation, before it is open to the public, and therefore discover and correct mistakes and problems at an earlier date unless another tool is used to do the evaluation through the virtual model at design phase.

Inauguration is usually a date that is set long before. It is an announcement of the opening not only to the invited guests but also the general public through press and social media. Depending on the size and importance of the exhibition it is usually not possible to change the opening date when there is not enough time for the invited guests, sponsors and the press to reorganize their schedule therefore any work related with the exhibition should be finished before the invited guests get in the exhibition space.

Demolition begins with the uninstallation and packaging of the artifacts, continues with dismantling of the technological equipment, exhibition lighting, modular showcases, special installations, artifact installation supports and stage environments. Storage and reuse of those equipment is important therefore museums need storages and professionals to condition them. If the next exhibition's design is set, demolition of the temporary spaces would be done accordingly. If not, it is usually delayed until the next exhibition to see if any of the construction would be necessary to keep.

Findings and Analysis

Reviewing the literature, 3 main reasons for costly reworks has been identified.

Multidisciplinary Process and Wide Range of Exhibition Design Factors (EDFs: Table 3)

Exhibition design draws upon the full spectrum of the design professions unlike other well-defined sectors in the design field like the design of software and interfaces; two-dimensional design such as graphic design and book design; three-dimensional design such as packaging and industrial design (Bradburne, 1999; Lin, 2002).

In addition to this diverse designers and related producers, different professionals that are in-house or not, from different disciplines or even non-professional volunteers, some of who are not used to work within teams and for a one time production, may contribute to the process of exhibition design and construction. This usually leads to communication problems emerging from lacking representation techniques and/or contributors who are not able to read in plan, section, elevation or even 3D visualization.

According to Florio (2011) decision makers' lacking in visualizing the traditional representation formats which might increase the time and cost of the project makes it important to adopt building representations that are closer to the *"experiential-spatial"* human experience in the real world (Paes et al., 2017).

Additional Works to be done which are not Directly Related to the Design Change after the Construction and Pressure of Finishing the Production before the Inauguration Date which is More Often Impossible to Delay

Any design or object distribution change during or after the installation might cost more than the necessary construction or fabrication which are directly related to the change because of the precautions and measures taken to protect the artifacts in the space or repacking and carrying them back to the storage during the rework period. Depending on the type and extent of the change, part of the space may need to be sealed and after the work, a deep cleaning will be necessary to be ready for the objects to reenter.

As the installation is the last phase before inauguration whose dates are usually impossible to change, the cost of rework might either increase compared to before or decision makers lower their expectations from re-productions around the artifacts due to the limited time. As it gets closer to the inauguration "time" constraint becomes more important compared to "quality" and "cost" unlike most of the other types of design and construction projects.

One Time and Special Constructions. High Expectations from the Common Construction Works Which Leads to Rework and Quality Management Issues

The expectation from the paint job and plaster work on e.g. a school wall and a wall on which to hang a precious painting are different even if it could be accomplished with the same type of material and workmanship.

It is usually a new experience also for AEC professionals, as the expected standards are higher than other design and construction projects. Not the productions that are special for museums like showcases, lighting, etc. but more common applications like painting, plastering, floor covering, drywall building, and basic furniture may be subject to rework as the quality standards are higher than other types of sites. The understanding of quality between the contractor and not only the non-AEC project manager but also the designer may end up with rework after or during the production.

As the mentioned types of productions are done before installation of exhibition furniture and related technological equipment, it is crucial to control the process and check the outcome thoroughly before the deep cleaning.

Conclusions

It can be concluded that to adopt building representations that are closer to the *"experiential-spatial"* human experience in the real world is necessary to overcome the communication problems and related rework in the museum exhibition projects.

Virtual reality (VR), as proposed for construction projects (Bouchlaghem et al., 1996; Issa, 2005; Dunston et al., 2011; Moura et al., 2012; Paes et al., 2017; Boton, 2018) may help to solve those problems. With this immersive tool, the feeling of presence in the designed environment, can be created through simulations that are done by computers and transmit to the user by a series of output devices that are aiming for the five senses.

Cultural organizations like museums are already in the process of adopting digital strategies (Johnson et al., 2016) which include the use of virtual environments both for online applications and a new way of transmitting the knowledge at physical exhibitions (Arrigoni et al., 2019). So adopting the VR tools also to the production process could easily be a part of the strategy.

Further research should be made to look for the efficiency and user acceptance of VR tools in the process of museum exhibition design and production.

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Understanding the Driving Factors of Cost Overrun in Highway Projects in Nigeria: A Systems Thinking Approach

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Abstract

In recent years, cost overrun was one of the most significant concerns for infrastructure development and understanding the triggers of cost overrun is vital in delivering critical infrastructural projects within the contractually agreed budgeted cost. Although, existing studies have focused on identifying and understanding critical risks factors impacting project cost performance, limited efforts have investigated the complex and dynamic interactions that exist among the triggers. Hence, this study adopted a holistic perspective to investigate and understand the impact of the dynamic interactions of the various triggers on project cost performance based on the philosophy of systems thinking. Based on a data compatible coding framework, qualitative data based on stakeholder interviews was analyzed to identify the contextual key factors and their causal relationships, complemented by textual data from existing literature. Subsequently, causal loop diagram was developed based on the underlying interactions among the key drivers to describe their complex and dynamic nature. The finding shows that the relationship of the cost performance risk factors is reciprocal and looped and thus, captured the dynamics of typical context-based system. The developed conceptual model can be used to identify system improvement points to enhance project performance and form the basis for a formal simulation model.

Keywords: *causal loop diagram, cost overrun, highway projects, qualitative data, system thinking.*

Introduction

Highway infrastructures plays a vital role in the socio-economic growth of every country, including emerging countries such as Nigeria and its contribution to the overall gross domestic product cannot be underestimated (Famiyeh et al., 2017). However, the uniqueness, dynamic, increasing complexity of highway infrastructure projects and the highly competitive and fragmented nature of the construction industry has resulted in construction projects and highway infrastructure projects in particular continually facing uncertainties that render cost management very difficult and thus, leads to poor cost performance. Hence, poor cost performance has been regarded as one of the most serious issues during the implementation of publicly funded highway infrastructure projects (Flyvbjerg et al., 2003).

In practice, cost overruns occur in most of highway projects and the magnitudes significantly varies with geography, empirical studies and the individual project (Famiyeh et al., 2017). In total, 258 infrastructure projects (including 167 highway projects) that covers a range of countries across North America, Europe and Japan, were studied (Flyvbjerg et al., 2003). The study found that only 1 in 10 projects were successfully delivered within budgetary provision. It was further revealed that cost overruns are evident and prevalent in highway infrastructure projects. Similarly, of the 142 highway projects Federal Capital Territory, Nigeria constructed between 2004 and 2014, only 10 projects were completed within the agreed budget (Anigbogu et al., 2019).

Several empirical studies have tried to identify and understand the potential triggers responsible for cost overruns in highway infrastructure projects, but most of these studies focused on general construction and transport infrastructure in general as demonstrated by the works of (Flyvbjerg et al., 2003); (Park & Papadopoulou, 2012); (Huo et al., 2018); and (Andrić et al., 2019). Although, highway construction cost overrun contribute significant risks financially, in most of these studies, highway infrastructure cost overruns and its triggers, especially in Nigeria are understudied. More so, they are largely survey-oriented employing a range of conventional statistical techniques including but not limited to index analysis and regression analysis-based methods. For instance, Mansfield et al. (1994); (Leo-Olagbaye & Odeyinka, 2018); and (Anigbogu et al., 2019).

Although, the existing studies investigated the triggers from conventional statistical methodological lens, they tended to document the triggers without necessarily incorporating the dynamic and complex nature of these factors. However, the triggers of cost overrun has been revealed to have a complex interaction with each other, consisting of multiple feedbacks, delays and non-linear relationships (Ahiaga-Dagbui et al., 2015). As such, an approach that takes a holistic perspective by considering the complex and dynamic characteristics of the drivers is required to understand the interrelationship of the key drivers. These drivers could be identified from prior empirical studies or through engagement with the stakeholders that have knowledge about the nature of the problem or a combination of both. Systems thinking provide a means to understand and work with this intricate complexity. Systems thinking as a branch of system dynamics is an approach that takes a holistic view of a problem as a complex system (Sterman, 2000). It is based on understanding the dynamic behavior of the whole system i.e. how a factor in a system interact with another and how a change in one variable affects the other overtime which in turn affects the original variable (Boateng et al., 2012); and (Leon et al., 2018).

This study aimed to contribute to this timely debate by exploring how system thinking tools, more specifically, causal loop diagrams (CLDs) can help better understand the complexity underlying the triggers influencing cost overruns in highway infrastructure projects. Overall, the goal is to offer an all-inclusive and holistic approach to examine the dynamic interactions and feedbacks between the various contextual-based triggers and thus, be adopted to other sectors of the construction industry and contexts.

Literature Review

The Concept of Cost Overrun

Cost overruns in projects are one of the most serious issues during the execution of construction projects, particularly, highway infrastructure projects Anigbogu et al. (2019) with Flyvbjerg et al. (2018) concluding that highway infrastructures projects record substantial cost overruns. However, Mahamid and Bruland (2011) conceded that highway projects in some emerging economies, including Nigeria are completed above the original contract budget by about one-third.

Cost overrun has been defined by several researchers as the variance between the final actual cost and the original contract cost of a project. However, the key difference in the description lies in the baseline of the initial estimate considered by the authors within the project execution process i.e. baselines as time of formal decision to build, project definition, contract award (Flyvbjerg et al., 2003); (Cantarelli et al., 2012c); and (Love et al., 2015) and the variance is a defining reason to the magnitude of cost overruns.

Empirical studies worldwide have thus recognized the generality of cost overrun phenomena by revealing varying magnitude ranging from 7.9% to over 450% (Flyvbjerg et al., 2003); (Odeck, 2004); (Okon, 2009); (Cantarelli et al., 2012c); and (Locatelli et al., 2017). For example, Okon (2009) cited an extreme high cost overrun figures of 500% associated with some completed highway projects in the region of Niger Delta, Nigeria. This is far more substantial compared to (Amadi, 2016). He revealed a mean cost overrun of 216.47% based on a sample of 61 completed highway projects from 2002 traversing the swamps of Nigeria's Niger delta region. Looking at individual projects cost performance, the channel tunnel project commonly known as "BIG DIG" in USA experienced a substantial cost overrun of over 400% (Olivio & Shaver, 2014). Several studies on highway infrastructure projects have consistently reported enormous cost overruns over the years (Creedy et al., 2010). These positive variations are attributed to numerous factors that are dependent on the changing culture and practices of different countries which are mostly evaluated from a statistical perspective.

Causes of Cost Overrun

Over the years, many researchers have been inspired to inquire about the various triggers influencing poor cost performance in highway infrastructure projects in different countries. This is essentially due to the inability of a significant proportion of highway infrastructure projects to be completed within the established cost target and indeed the differences in the culture, practices and institutional structures of the various countries (Johnson & Babu, 2018). For instance, Mansfield et al. (1994) explored the causes of cost overrun in Nigerian highway projects from the perspective of key industry stakeholders i.e. client, consultant and contractors based on questionnaires. The retrieved data was analyzed using index analysis method (i.e. severity index). They found that, the most severe causes of cost overrun were attributed to finance and payment for completed works by the client, inaccurate estimates or forecasts, poor contract management and fluctuation in prices of materials as unanimously agreed by the stakeholders. Leo-Olagbaye and Odeyinka (2018) conducted a study on the risk factors that affect the financial performance of highway projects in Osun state, Nigeria using questionnaire survey. The questionnaire responses of 115 experienced professionals involved in about 34 highway projects was analyzed using index analysis method (i.e. mean score) and found changes in scope, defective design, changes in initial design, delay in the availability of design information and adverse weather conditions to be the most significant risk factors. Anigbogu et al. (2019) examined and analyzed questionnaire responses from key industry stakeholders involved in highway infrastructure development in Federal Capital Territory, Nigeria using index analysis method (relative importance index) complemented with analysis of project documents and interviews in order to identify the significant factors. They found that, inflation, fluctuation of prices, exchange rate, government related issues like changes in policies, variation, delays in payment, design changes, corruption and unforeseen ground conditions were the key contributory causes.

Alinaitwe et al. (2013) conducted a study based on analysis of questionnaire survey responses of project stakeholders involved in public projects in Uganda and used a case study of civil aviation authority projects to validate the results. The retrieved data was analyzed using index method i.e. importance index based on combined effect of the frequency and severity of each factor. They found that scope changes, payment delays to contractors, poor project monitoring and control and high inflation and interest rates are the five most significant factors impacting negatively on project cost performance. Similarly, Kaliba et al. (2009); Nasir et al. (2011); Hazim and Abusalem (2015); Zafar et al. (2016); Al-Hazim et al. (2017); Sohu et al. (2017); and Pai et al. (2018) used similar data analysis technique i.e. index analysis method though, adopting diverse variants of the method.

Based on the global study by Flyvbjerg et al. (2003); and Flyvbjerg et al. (2004), the data retrieved from project documents was analyzed using regression analysis to establish the relationship between cost overrun and some descriptive project variables i.e. project size, length of implementation phase and type of project ownership. Similarly, Odeck (2004); Cantarelli et al. (2012a); Cantarelli et al. (2012b); Cantarelli et al. (2012c); Huo et al. (2018); Andrić et al. (2019); and Creedy et al. (2010) used similar data analysis technique i.e. regression analysis, though in a different context.

Hence, from the foregoing, it is apparent that significant effort has been made to understand the causes of cost overrun globally. However, most of these studies including Nigeria, adopted a positivist orientation towards data collection and statistical approach to data analysis (index and regression analysis methods), thus, ignoring the contextual circumstances in which these factors occur as well as the dynamic and complex nature of these factors. Though, methodologically, the existing studies provide a valid contribution and thus add to the existing body of knowledge relating to cost overrun triggers, it is however inefficient in evaluating the systemic and complex nature of the phenomena. These approaches appear to be one-dimensional and unable to explain the complex interrelationship among the different contributory factors of cost overrun (Ahiaga-Dagbui et al., 2015). As such, the need to conduct a study that acknowledge the systemic and complex characteristic cannot be overemphasized.

Research Methodology

Considering the nature of the research study, which is based on developing a causal loop diagram to understand the triggers of cost overrun in highway projects in Nigeria, a hybrid approach to data retrieval and utilization (textual and mental data) was employed in line with the recommendation of (Sterman, 2000). Therefore, the study adopted a qualitative case study approach employing a two-stage interview process. The interview participants were selected based on their ability to provide the most relevant and reliable information that is related to the problem under investigation. This point has been emphasized by Creswell (2013) on the need to recruit interview participants that will willingly and honestly share their knowledge related to the investigative phenomena. In this regard, interview participants were selected purposively complemented by chain-referral technique. The significance of both approaches have been emphasized by (Collis & Hussey, 2009); and (Sargeant, 2012). Combining purposive and chain-referral techniques afforded the opportunity to achieve equivalence in representativeness between the stakeholders that were accessed through referrals from the purposively selected stakeholders and those that were purposively selected. In particular, the participants for the interview were key stakeholders i.e. client, contractor and consultant organizations charged with the responsibility of delivering the highway project in Nigeria. First, semi-structured interviews with 16 key stakeholders involved in highway infrastructure development in Nigeria in form of mental data was utilized in line with the observation of Ghauri and Gronhaug (2002); Bryman (2015); and DiCicco-Bloom and Crabtree (2006) supplemented by grey and empirical literature in form of textual data in line with the recommendations of (Forrester, 1992) and (Sterman, 2000). De Castro and Salinetti (2006) reiterated the need to consider other sources of data in research (such as newspaper articles and government documents) that are not empirically rooted, and evidence based, because they often contain highly valuable and unique information that are rarely found elsewhere (Smith, 2009); (Lawrence, 2012); and (Tanacković et al., 2014).

Secondly, interviews were conducted with key stakeholders (experts) to validate the conceptual model and ensure that it really captures their mental models about the system structure. Nine (9) experts who participated in the first stage interviews were contacted and used for the validation. During this stage, the stakeholders were asked to state whether all the variables represented in the CLD and their causal relationships existed and whether there were any significant causal factors that were missing. In case there were missing causal factors, the participants were asked to list them. Furthermore, the stakeholders tested whether the direction of each of the links were correct or required to be reversed (implying that the effect is the cause and vice versa) and were asked to state whether there were other effects that could be observed resulting from the causes in the CLD. Based on the responses and comments obtained from the stakeholders, the suggestions were incorporated into the CLD for improvement together with further qualitative analysis of the collected data in response to the questions raised by the researcher, leading to an improved CLD based on the recommendation of (Rwashana et al., 2014).

Furthermore, to analyze the qualitative interview data, a coding framework was developed based on case study approach, principles of inductive thematic analysis and saliency analysis and also considering the key elements of a recommended coding framework of Turner et al. (2013) which is compatible with asynchronous data. The procedure included steps 1-5 of the thematic analysis framework of (Braun & Clarke, 2006). The interviews were analyzed using the 5-step developed framework to support the development of the conceptual model as presented in Fig. 1.

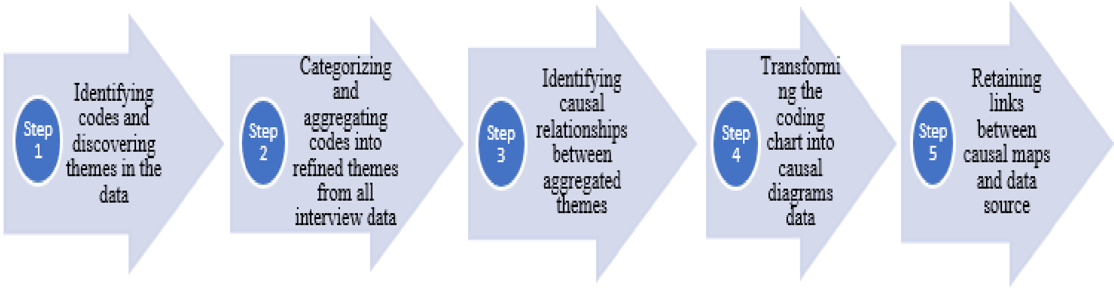

Figure 1: Coding process.

Analysis of Results and Discussion

Coding Process

Step 1: Identifying Codes and Discovering Themes in the Data

The first stage of the coding process corresponds to steps 1-3 of the thematic analysis framework (Braun & Clarke, 2006). During the first step of the coding process, the interview data was coded to identify the important information relevant to the research question. However, some of the codes were representation of the original terms from the interview transcripts while others were clues from the literature which resulted in the generation of numerous codes. Understanding the context of the study is very important in order to code the concepts that are not explicitly stated in the extracts as emphasized by (Kim & Andersen, 2012); and (Eker & Zimmermann, 2016). The data often include open statements that clearly hint to a concept i.e. original terms from the interview transcripts. However, there are some statements that do not disclose a concept with clear references and which the codes were then borrowed from the existing empirical literature.

At this stage, the idea of which themes represents the coded extracts begin to become apparent and the coder begins to have some initial ideas of the themes that will emerge as a result of observed dominant patterned relationships of the various codes or codes of similar status as recommended by (Braun & Clarke, 2006). The process of coding was supported by CAQDAS such as Nvivo 12 which has a special feature to assist of maintaining the link between the coded extracts and the identified codes as suggested by (Eker & Zimmermann, 2016); and (Yearworth & White, 2013).

Step 2: Categorizing and Aggregating Codes into Refined Themes

This step corresponds to steps 4-5 of the thematic analysis framework (Braun & Clarke, 2006). This step involves examining the codes and assessing if they really fit into a particular theme and the theme indeed reflect on the research question and also assess the essence of the theme and what it really means (Braun & Clarke, 2006); and (Eker & Zimmermann, 2016). The nodes that are referring to similar concepts are linked to each other and then forms a theme which was done in a hierarchical manner. However, the final coding tree formed from this step is expected to be formed iteratively. However, further revisiting and regrouping and analysis of the sifted data extracts was done, and the refined themes of the aggregated relevant coded information identified.

The framework of saliency analysis advocated by Buetow (2010) which considers the salient information within the data as well as prevalence of information was adopted to further support the identification of the key themes which are both important and prevalent. The themes that had statements of emphasis about the importance like “this is a big issue, the major reason………etc.” were considered salient and highly important even though they are not prevalent and those statements that had frequently occurring codes were identified and regarded as frequent. However, themes that were neither frequent nor important were ignored as recommended by (Buetow, 2010); and (Anigbogu et al., 2019).

Step 3: Identifying Causal Relationships between Themes

This step corresponds to steps 4-5 of the thematic analysis framework (Braun & Clarke, 2006). The data were further analyzed rigorously and the causal relations were recorded at any instance that is mentioned in the data source i.e. the causal relations was recorded at any instance within the different data items and using a unit of analysis of a statement that represent a causal relationship between two codes within the same paragraph in a data source which basically comes from a participants mental model as suggested by (Nguyen et al., 2015); and (Yearworth & White, 2013). The established causal relationship is irrespective of the category of the drivers, but rather, based on a representation of causal attributions clearly identified in the data which represents the mental models of the key stakeholders. This step was assisted by establishing the relationships in Nvivo and linking them to the data source based on the recommendation of (Kim & Andersen, 2012); (Turner et al., 2013); and (Eker & Zimmermann, 2016). However, in establishing a causal relationship, indicators that infer causal relation about a system behavior such as because, then, if, so, so as etc. were located and also considered a general understanding of an expressed causal relationship by the interviewer from an interviewee as recommended by (Eker & Zimmermann, 2016).

Further analysis was carried out and coding chart created based on the established causal relationship. These charts were given reference identification codes (signifying the categories of the themes and the causally related themes) and data source identification codes based on the variable causal relationship and all relevant information sources were given to represent the interviewee(s) that made the statement. Using a coding chart as suggested by Kim and Andersen (2012), the data is broken down into small segments that contain one causal relationship within the same paragraph (Yearworth & White, 2013). In line with Turner et al. (2013), the data extracts supporting those relationships were provided which further enhance the confidence and transparency in the coding process. For instance, a coding chart demonstrating a causal relationship together with reference identification code and data source identification code and also the data extracts that support the causal relationship is presented below:

Table 1. Coding chart.

<table>
<tr><td colspan="3">Data Source ID: [C_CQS] [C_HPM]</td><td>RIC: L:-POP-PInt</td></tr>
<tr><td colspan="4">Main Argument: There is always a conflict of interest between the various arms of government when it comes to budget approval and which project should be accorded priority due to diverse nature of representation of various elected officers</td></tr>
<tr><td>Causal structure</td><td>Cause variable:</td><td>Political opposition to project</td><td rowspan="5">Leadership Related Drivers</td></tr>
<tr><td></td><td>Effect variable:</td><td>Political interference</td></tr>
<tr><td></td><td>Relationship type:</td><td>Positive</td></tr>
<tr><td>Variable behavior</td><td>Cause variable</td><td>Strong opposition</td></tr>
<tr><td></td><td>Effect Variable</td><td>Continued interference</td></tr>
<tr><td colspan="4">Information Source: Comments observed from all the interviewees relevant to the causal relationship about the leadership related drivers of cost overrun with indicators such as if, and the general understanding of a causal expression by the interviewee
Themes: Political opposition to project, Political interference</td></tr>
</table>

"You know, there is always this tense relationship between the various arms of government because, you have politicians from different political parties representing different constituencies, and they are more interested in what project represents their interest. Most times, the parliament are against a project because majority are not happy with it, they (national assembly) interfere and frustrate the project. It is very typical across the country, and this particular project is no exception because, it has been affected by series of interference from politicians and that is why little progress has been made. I think this is the main problem" [C_CQS- POP-Pint]

Step 4: Transforming the Coding Chart into Causal Diagrams

The coding chart showing the relationship between variables and also the system behavior was transformed into causal links and eventually, causal loop diagrams. In this step, the coding chart were utilized to develop a causal loop diagram. To achieve this, each causal relationship from the coding charts were analyzed individually to draw the identified causal links. Furthermore, cause and effect links identified for all the causal relations irrespective of the category of drivers were generated to represent the collective interpretation of the individual mental models about the various categories of key influencing drivers of cost overruns. For instance, the causal links for leadership related drivers is presented in Fig. 2. Then, a composite causal loop diagram was created by merging all the cause and effect representation in order to understand the overall factors that influence cost overrun in highways projects as shown in Fig. 3. This step was performed using Vensim Software.

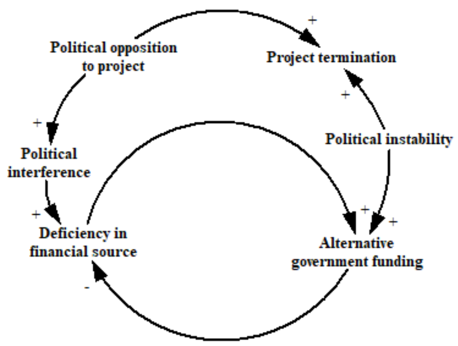

Figure 2: Transformation of coding charts into causal loop diagram (leadership related drivers).

Step 5: Retaining Links between Causal Maps and Data Source

To establish a strong linkage between the causal loop diagram and the data source and thus establish confidence in the resultant causal loop diagram, a data source reference table was created as emphasized by (Kim & Andersen, 2012). This step was assisted by initially defining a relationship in Nvivo and linking them to the data source, so that the references to the data are maintained as suggested by (Eker & Zimmermann, 2016). In order to avoid a disconnect between the causal loop diagram and data sources due to the transformation, reduction and simplification of the data into causal links and subsequently causal loop diagrams, there is a need to rigorously link the two together. Although, as suggested by Kim and Andersen (2012), that there is no one best way to do this task, though, it is vital to ensure that the linkage is transparent and systematic. To ensure strong data connection, a reference identification code and data source identification code were assigned to the data. RIC was attached to each data segment that represented a causal relationship, category of drivers and its coding chart such as *"L:-POP-Pint"*, signifying the causal relation between political opposition to project and political interference from the leadership related category of drivers. Data Source ID code was assigned to each causal relationship that was represented by a data segment of a participant's mental model such as "*[C_CQS]"* indicating that, the source is from the consultant i.e. chief quantity surveyor. Furthermore, a data source reference table was then created as suggested by Kim and Andersen (2012) where all causal relationships are represented in each column and linked with the data source ID code and RIC on different columns and using the table, the causal relationship could be matched with the DS ID and RIC by checking on the corresponding cells.

Causal Loop Diagram

The integrated causal loop diagram representing all categories of drivers i.e. project management related, leadership related, macroeconomic related and societal related was based on qualitative data analysis process using the developed coding framework, grey and empirical literature and the outcome of the model evaluation process as presented in Fig. 3. The discussion below described the process and its outcome.

Causal Relations and/or Structures from Mental Database (Interviews)

The starting point of the study was the identification of causal relations from mental database of key project stakeholders involved in provision of highway infrastructure projects in Nigeria. The causal relationships emerged from the analysis of qualitative interviews based on step 3 of the coding process.

Causal Relations and/or Structures from Textual Database (Literature and Project Documents)

In addition to the causal relations identified from the analysis of data from mental data base of project stakeholders, causal relationship were obtained from existing empirical literature on cost overrun in highway projects in Nigeria, grey literature reporting on challenges relating to highway projects as well as documents obtained from the client organization on highway infrastructure projects across Nigeria which covers the six geopolitical zones were also used to complement the relationships obtained from mental database. This is in line with the recommendation of (Sterman, 2000) and Forrester (1992). The relationships were identified by reviewing through the text sentence by sentence and documenting the relationships existing between variables thus forming a list of variables and their existing relationships with regards to the various categories of driving factors i.e. project management related, societal related, leadership related and macroeconomics related drivers. However, the selection of variables was conducted with due diligence to ensure that only the relevant variables and their relationship were selected to establish an existing relationship. For instance, the following causal relationship in Table 2 was identified from textual sources.

Table 2. Causal relations from textual sources.

Causal Relationships	Literature Reference (Empirical and grey)	Project documents supporting statements
Delay in payments to contractors —+→ Delay in work progress	(Akoh, 2018; Nnodim, 2017)	The work was suspended because the contractors were not paid

Causal Relations and/or Structures from Mental Database (Stakeholder Evaluation)

In addition to the earlier causal relations established from interviews, literature and project documents which established the basis on which the causal loop diagram was developed based on the technique of causal loop diagramming Sherwood (2002) and (Sterman, 2000), the second phase of interviews in form of stakeholder evaluation was utilized after the development of the conceptual model to refine, enhance and validate the existence of the relationships. Hence, some variables and their relationships were affirmed, others were rephrased, and new ones suggested. Therefore, based on these suggestions, the causal loop diagram was revised and amended to incorporate the comments observed. For instance, the comments by some of the stakeholders are presented below.

Stakeholder P_03 highlighted that *"delay by the contractors to received payment" from the client which is a norm in Nigeria is considered significant in "demotivating the contractor" particularly when it takes a very long time to make a payment towards the contractors and it became persistent.*

Furthermore, Stakeholder P_01 has indicated that*, "work progress" as against delay in progress of work reflects on the progress of work because it will then capture the progress made towards achieving significant work effort and I think that is what is usually used in a real project scenario.*

Based on the above comment, "*delay in progress of work"* was replaced with "*work progress"* in the conceptual model as presented in Figure 3.
From the comments of the stakeholders, the revised causal relationship is presented below with the data source code as P_03 indicating the comment is made by participant 3;

Delay in progress payment —-→ Motivation of contractor and workers

High-Level Conceptual Model

The high-level conceptual system model integrates the project management related, leadership related, societal related and macroeconomic related drivers of the system based on all data sources as shown in Figure 3. These interrelationships and interconnections produced seven (7) feedback loops including three (3) reinforcing or positive loops and four (4) balancing or negative feedback loops, signifying the complex feedback structure that determines the dynamic behavior of the system. Hence, based on the complex nature of the system, one (1) feedback loop as highlighted in the high-level model in Figure 3 is thus selected for further detailed discussion and analysis, because it captures some of the vital structural elements of the integrated conceptual model and has significant implications for understanding the contextual dynamics of the system in line with the recommendation of (Kotir et al., 2016).

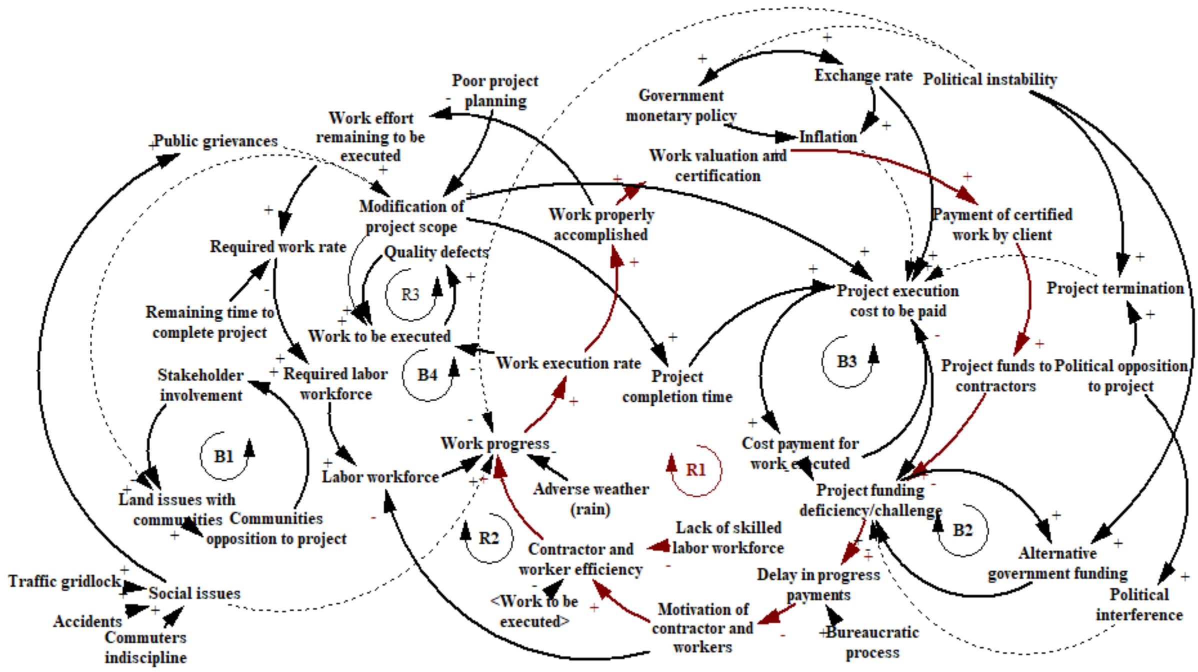

Figure 3: High-level conceptual model.

Loop R1 illustrates the interaction between work progress, political instability, social issues, work to be executed, work valuation and certification, payment of certified work by client, project funds to contractor, project funding deficiency, delay in progress payments, motivation of contractor and workers and contractor and worker efficiency. The loop tries to explain how the performance of a project is strongly impacted by the attitude of the client towards fulfilling the contractual agreement on progress payment which often significantly impact on the progress of work. From the perspective of the stakeholders, the delay in payment of work progress particularly, when the process of obtaining approval requests and payment for certified works takes longer than contractually agreed period, has significant adverse consequence on the contractor such as lack of motivation. In this case, the contractor's motivation to continue working at site is significantly impacted as the confidence they have in the client is degraded. Although, they continue to work to a certain point by committing fewer financial resources and thus affecting their efficiency particularly, in circumstances where the labor workforce has limited experience in the development process, the inability of the client to make payment result in suspension of the work thereby affecting the progress of work and the completion rate of project.

It is evidenced from the stakeholder's viewpoint that, political instability i.e. changes or transition in government, social issues due to attitudinal influences and adverse weather all influences the progress of work in highway construction projects. The impact of political instability is viewed from the viewpoint of the country's political leadership and often affect the project particularly, an on-going project throughout its lifecycle. Because of the shorter time horizon of political leaders which often is shorter than the completion period of most highway projects in Nigeria, the political uncertainty is exacerbated as a result of transition in government through elections or otherwise because it takes time for the new leadership to decide on its priorities with regards to on-going projects. Although, in most construction practice, the anticipated impact of unfavorable weather condition such as rain is usually estimated and incorporated into the project program, the severity of such conditions beyond the anticipated impacts significantly slow the pace of work. Work progress is impacted by issues resulting from the interaction between people through their attitude and the impact of the construction work on the people. This is often the case during the construction phase on highway projects, particularly, a reconstruction project. As a result, social issues arise when people are affected by the construction work. For instance, due to the capital intensity and significance of highway construction or reconstruction projects, they often require diversion of traffic which often has significant impact on existing road users and restricts access to some parts of the road sections. Thus, in most instances, the construction or reconstruction of highway projects particularly in developing countries unavoidably causes substantial commotions in usual vehicular movement and operations during the construction phase, often creating unease and delays for motorists and compelling them to consider using alternative routes such as using opposing lanes which in most cases compound the traffic issues.

Sometimes, accidents occur due to diversions, predominantly, when there are no adequate construction diversion signs to make people or motorists aware of the dangers of the diversions. Furthermore, it is often a common practice that, significant effort is made by the contractor and law enforcement agencies to clear off disrupted sections of the road to allow for most essential material delivery vehicles to access the construction site. Hence, a completion of a practical amount of work by the contractor is a strong indication of a reasonable performance and has committed reasonable amount of resources. On the contrary, when the rate at which work is accomplished is decreased or impacted, it means that the work done or completed will be decreased. Furthermore, because of the physical nature of highway construction, there are visible milestones that are employed to measure the performance of work achieved i.e. based on the amount of work that is certified to have been completed by the contractor. Hence, when the amount of completed work decreased, the work to be certified by client which is based on the attained milestone, will be impacted and decreased. Based on the form of contract used, the measured accomplished work forms the basis on which the contractor receives payment of work certified to be executed based on pre agreed payment schedule.

More so, when the payment based on the certified completed work is decreased, the income that the contractor will receive will be decreased. However, by the completion of a significant portion of work, if the gap between the funds or income paid to the contractor by the client as certified and the project execution cost to be paid is substantial, then the funding issues of the client is further compounded, because, it means that the cumulative backlog of funds due to the contractor will be significant, and one of the most common reaction to funding issues experienced by clients particularly public sector clients in developing countries is that the payment of work due to contractors is further delayed because they often face significant burden particularly when the client is committed to delivering other important infrastructure projects, thereby closing the loop.

Conclusion

Cost overrun in highway infrastructure projects, particularly in Nigeria is a challenge that is being increasingly experienced. Hence understanding the key triggers of poor cost performance is of paramount importance. This study adopted a holistic approach utilizing systems thinking philosophy, specifically, CLD to analyze and understand the feedback structure or interactions between the project management, leadership, macroeconomic and societal related drivers, thus providing a broad integrated perspective of the dynamics associated with the drivers from different stakeholder viewpoints. To do this, a developed coding framework based on case study and the principles of thematic analysis was utilized to analyze and establish the causal relations of the various drivers supported by literature-based sources. Based on the established causal links, CLDs were used to capture the interacting elements and feedback loops that contributed to the poor cost performance of highway projects in Nigeria. Furthermore, evaluation of the conceptual model with experts ensured that the model variables represent that of a real system and thus, can be utilized to support management decision making. Finally, the analysis of the CLD will support in identifying key action points which can effect significant improvement in the cost performance of highway projects in Nigeria, and indeed other settings of similar characteristics and settings.

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Sustainable Construction Projects: Students' Personality Perspective

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Abstract

One of the significant ways of improving productivity in construction projects is creating appropriate project teams by considering personality characteristics as a way of predicting job performance. As such, this paper aims to recognize the appropriate personality types in creating a project management team for sustainable construction projects. For this reason, defined knowledge areas and skills which are necessary for dealing with the challenges of sustainable construction projects are used in this research. To achieve this, a questionnaire survey was conducted. The Enneagram Personality Model was employed to indicate the different personality types of respondents. The selected Enneagram test for use in this study is Riso-Hudson Enneagram Type Indicator (RHETI). This model specifies the respondents' personality type by allocating them in one of the nine personality types. In addition, respondents were asked to give scores to knowledge areas and skills according to their character. The respondents of this survey were undergraduate students of architecture and civil engineering. The results of this study demonstrate that respondents with each Enneagram personality type have tendencies to specific knowledge areas and skills. Also, provides reasonable results to help architects, civil engineers, and human resource managers in creating teams for sustainable construction projects.

Keywords: *architecture/engineers, construction project management, enneagram personality model, personality characteristic, sustainability.*

Introduction

Managing a project is challenging, as project managers and project teams deal with both internal and external challenges. Like information technology, management consulting and many other industry sectors, construction is project based, however, construction sector considered as the largest and most complex one (Meng & Boyd, 2017; Sydow et al., 2004; Cheng et al., 2005; Whitley, 2006). The complexity of the construction sector is due to its undeniable impacts on the environment, economy, and surrounding community (Hwang et al., 2015; Zuo & Zhao, 2014).

In construction projects, there are many challenges that project managers have to deal with; they have to ensure that projects are completed on time, within a certain budget, and to an acceptable level of quality (Akhavan Tabassi et al., 2014). They also have to manage stakeholders apart from various resource constraints (Xie et al., 2014; Zhao et al., 2012).

Overcoming all these challenges are the tasks of project managers that are necessary to achieve project success (Zuo et al., 2018). According to Anantatmula (2013), project managers have the daunting task of completing a project successfully and meeting the expectations of all its key stakeholders who perceive project success or failure differently.

As stated by Hwang and Ng (2013), "successful construction organizations now focus on ensuring that project managers acquire the core competencies required to be successful in their assignments". Researchers have long argued the most beneficial skills and competencies for the project manager role that may increase project success (Bevilacqua et al., 2014; Gillard & Price, 2005). According to Yang et al. (2011), "the success of construction projects is affected by the management style of construction project managers". Each project manager has a unique personality profile which leads to distinctive character and tendencies (Ling et al., 2020). The personality profile of project managers directly affects persons' behavior and values (Rashid & Boussabiane, 2017; Fischer & Boer, 2015), project decisions (Rashid & Boussabiane, 2017), and their job performance in projects (Carr et al., 2002) and also plays a significant role in the projects' outcome (Saade et al., 2015; Aitken & Crawford, 2008; Purcell & Hutchinson, 2007; Müller & Turner, 2007).

Several researchers explored the influences of project managers' personality on project performance (Bevilacqua et al., 2014). Some of the studies have investigated the impact of personality on team work (Xia et al., 2017; Spatz, 2000; Carr, 2000). Some other researchers highlighted the importance of personality traits as one of the main factors affecting risk propensity (Rashid & Boussabiane, 2017; Zuckerman, 2007). In another research, Yiu and Lee (2011) asserted that the type of personality characteristic of negotiators is one of the critical factors in construction dispute negotiation outcomes. Therefore, selecting an appropriate project manager with a personality profile that matches the project he or she will be heading can reduce the challenges and increase the rate of success (Cohen et al., 2013; Turner & Müller, 2006).

In this study, it has been tried to create the most appropriate project management teams for sustainable construction projects considering the personality perspectives of architecture and civil engineering students. For this reason, the results of the study of Hwang and Ng (2013) were used in this study. Hwang and Ng (2013) determined ten fundamental challenges in sustainable construction projects. After determining the challenges, they defined the five most important knowledge areas that are essential in managing sustainable projects, including cost management, communication management, schedule management and planning, health and safety management, and risk management. Moreover, Hwang and Ng (2013) determined the five crucial skills in managing sustainable projects which are: analytical skill, decision-making skill, team working skill, delegation skill, and problem-solving skill.

Therefore, the aim of this research is to investigate the relationship between different personality types and the knowledge areas and skills which are essential in sustainable construction projects. There are many personality indicator tools that have been established and used in studies (Ling et al., 2020). Some of the most used tools are: Myers–Briggs Type Indicator (MBTI) (Cohen et al., 2013), Multidimensional Personality Questionnaire (George & Zhou, 2001) and the five-factor model of personality or "Big Five" (Cobb-Clark & Schurer, 2012). However, among various personality frameworks, the Enneagram Personality Model was preferred to use in this study. This has been the first time that the Enneagram personality model was used to investigate the personality characteristics of architects and civil engineers.

This instrument classifies different personality characteristics in 9 categorize that allows us to allocate persons in one of these nine personality types.

Enneagram

History and Background

The Enneagram (pronounced "any-a-gram") is an impressive instrument for determining and identifying nine different personality types and views on life (David, 2001). Riso and Hudson (1999) describe the Enneagram as "a geometric figure that maps out the nine fundamental personality types of human nature and their complex interrelationships". In Greek, the word "ennea" means nine and "gram" means model, point or something drawn or written (David, 2001; Palmer & Brown, 1997; Wagner, 1980).

The history of the Enneagram dates back to oral tradition, particularly Sufism (Islamic mysticism) (Bland, 2010). In about 1915, the Greek-Armenian philosopher Gurdjieff presented the Enneagram to the modern world (Riso & Hudson, 1999). After comprehensive researches on the elements of the Enneagram, in 1950, Oscar Ichazo found common aspects between the ancient Enneagram symbol and Pythagorean mathematics (Bland, 2010). This foundation created a bridge between ancient form of the Enneagram and the modern form of it. Later, Palmer (1991) and Riso and Hudson (1996) transformed the ancient model of the Enneagram to the modern and usable form of it.

Structure

The Enneagram model has a circle shape which divided into nine points. Each point represents a specific personality type. These types are: 1-The Performer 2-The Helper 3-The Achiever 4-The Individualist 5-The Investigator 6-The Loyalist 7-The Enthusiast 8-The Challenger 9-The Peacemaker. The Enneagram types and some of their workplace characteristics are represented in Table 1.

Table 1. Enneagram types and their workplace characteristics.

Enneagram Types	Some Workplace Characteristics
Type 1	Ones give a lot of importance to product quality and standards (Palmer & Brown, 1997), and health and safety of the employees (Goldberg, 1999). Sense of responsibility more than usual, delegation without confidence, high expectations of co-workers, indignation, and judgment (David, 2001).
Type 2	Twos give more attention to communication, human relations, and personal growth (Goldberg, 1999). Highly qualified and inventive, but do not tend to control and manage others and resist being leaders (Palmer & Brown, 1997). Place more emphasis to people rather than achievements (David, 2001).
Type 3	Threes are hard-working, efficient, short term results-oriented, and give more importance to result than people (David, 2001). Give more importance to decision-making roles, and do not want to work on a

	project which has a vague work plan (Palmer & Brown, 1997).
Type 4	Fours attach high importance to the aesthetic and quality of the products (Goldberg, 1999). They treat sensitive and personally to their employees rather than officially (Goldberg, 1999). Also, Fours are weak members of teamwork activities (David, 2001; Palmer, 1995).
Type 5	Fives want to work alone and in their personal place (Goldberg, 1999). They also do not like surprises and need predictability, escape from conflicts, and give importance to decision-making especially unemotional decision-maker roles (Palmer, 1995).
Type 6	Sixes pay attention to the organization‘s security, developing future strategies, taking reasonable risks, being faithful, and so on (David, 2001). They have strong analytic power (Palmer, 1995) and have the ability to be leaders and unite everyone to achieve a common goal (Goldberg, 1999).
Type 7	Sevens want to work with their employees like a team and friends (Goldberg, 1999). They are creative during hard times, quick in thinking and acting under pressure, and planner rather than implementer (Palmer, 1995).
Type 8	Eights are dominating, self-confident, aggressive, strong, self-sufficient, and self-reliant (Riso & Hudson, 1999). So, in management style they tend to control everything by their own and want to be informed about everything in every moment (Palmer, 1995)
Type 9	Nines are cautious in taking risks (Palmer, 1995), slow decision-makers, and average time managers (David, 2001). They have talent in conflict resolution; Nines can be good negotiators and good human resource managers (Williams et al., 2008).

The Wing

In the circle of the Enneagram each type is bounded on both sides by its contiguous types and has tendency to one of these types that surround it. In another word, no person is a “pure” personality type, and each personality type is influenced by a number on one of its flanks called “wing” (Kale & Shrivastava, 2001; Palmer, 1995). According to the Enneagram Institute (2020), “your wing is the ‘second side’ of your personality, and it must be taken into consideration to better understand yourself or someone else”.

Research Methodology

This study aims to investigate the relationship between the Enneagram personality types and determined knowledge areas and skills. For this reason, a survey was designed. In the first part of the survey, respondents were asked to answer some questions about their fields and level of education. Also, there were questions about interests and talents in different skills and knowledge areas in the first part. Respondents should evaluate them according to the suitability of these skills and knowledge areas for their personality characteristics by giving a quantitative value from 1 (not suitable for their character), to 5 (very suitable for their character).

In the second part of the survey, participants were asked to answer the Enneagram personality type indicator questions to determine the personality type of each. Among some Enneagram type indicator tools, the scientifically validated Riso-Hudson Enneagram Type Indicator (RHETI® version 2.5) tool was selected for this study. The selected Enneagram type indicator consists of 144 paired statements, which require respondents to choose the statement that best describes those (Riso & Hudson, 2000).

The unit of analysis was bachelor and master students of architecture and civil engineering from different universities. The participants of this research were selected from the students who did not have any work experience.

Analysis of Results

There were a total of 58 surveys issued in this study. Among the 58 successfully completed surveys, 52 of them were effective and had the required conditions for analysis. For the other 6 surveys, 2 or 3 different personality types were recognized, which exclude them from the analysis process. According to the results, 34% of respondents were civil engineering students and 66% of them were studying architecture. Also, 58% of them were at the undergraduate level, whereas 42% of them were master students.

As previously discussed, each respondent answered two major sets of questions: (1) questions related to skills and knowledge areas that respondents had to score according to their personality characteristics; (2) questions related to the Riso-Hudson Enneagram Type Indicator tool. The results of the obtained data for Riso-Hudson Enneagram Type Indicator (RHETI® version 2.5) were analyzed and represented in Table 2. Findings indicate that the highest rate of respondents (21%) were type Two, while the lowest rate of them (5%) were the Enneagram type Three.

Table 2. Distribution of the Enneagram types.

Enneagram personality types	Percent
Type 1: The Reformer	14%
Type 2: The Helper	21%
Type 3: The Achiever	5%
Type 4: The Individualist	7%
Type 5: The Investigator	11%
Type 6: The Loyalist	11%
Type 7: The Enthusiast	7%
Type 8: The Challenger	12%
Type 9: The Peacemaker	12%

Further, the scores of the respondents in the first part of the survey were computed. For this part, the average of the scores given by each personality type to the questions was calculated. The reason is to understand which personality type found which of the knowledge areas and skills more suitable for their characteristics. Table 3 represented the knowledge areas and skills and the means of the scores given by each personality type to them. For example, for the knowledge areas type One respondents gave the highest scores (with the mean of 5) to "Schedule Management and Planning". This means that they gave more priority and found it more suitable to their personality characteristics. The reason for this choice can be the idealistic characteristic of type One persons; therefore, they do not like mistakes and want everything to be done right (Palmer, 1995). Also, type One respondents gave the lowest score (with the mean of 3.4) to the "Communication Management". This determines that it is the lowest preferred knowledge area for Enneagram type One respondents in the workplace.

This table also reveals which of the skills were preferred more by which of the personality types. For example, type One respondents gave the highest scores (with the mean of 4.8) to "Analytical Skill". This means that type One respondents believe that they have more talents in analytical skill and can do it better than other skills. On the other hand, type One respondents gave the lowest scores (with the mean of 3) to "Team-working Skill" which means it is the least preferable skill for type Ones in their workplace.

As a result, Table 4 was performed to easily reveal the Enneagram types and their perceived priorities of skills and knowledge areas. In another word, this table presents the highest scores of each personality type. As it is obvious in the table, some of the knowledge areas and skills were preferred more, while some others were not preferred by respondents at all. For example, 5 types out of 9 types preferred "Health and Safety Management" and 7 types out of 9 types preferred "Analytical Skill" as the most appropriate knowledge area and skill for their personality characteristic. On the other hand, "Decision-making Skill" and "Team-working Skill" were not preferred and got lower scores than others.

In order to find out the most appropriate personality types for knowledge areas and skills, Table 5 was performed. This table represents the personality types that gave the highest score to each knowledge area and skill. In this table, 2 or 3 most appropriate types for each knowledge area and skill were specified. For example, the most appropriate types for implementing "Cost Management" in projects are type One and type Three.

Table 3. Enneagram types and the mean of the scores they gave to knowledge areas and skills.

Enneagram Types	Cost Management	Communication Management	Schedule Management and Planning	Health and Safety Management	Risk Management	Analytical Skill	Decision-making	Team-working	Delegation	Problem-Solving
1	✓		✓			✓				
2			✓			✓				✓
3			✓			✓				
4				✓					✓	
5				✓		✓				
6		✓			✓	✓				
7		✓		✓					✓	
8			✓	✓	✓	✓				
9				✓		✓				

Table 4. Enneagram types and their perceived priorities of skills and knowledge areas.

Types	Cost Management	Communication Management	Schedule Management and Planning	Health and Safety Management	Risk Management	Analytical Skill	Decision-making Skill	Team-Working Skill	Delegation Skill	Problem-Solving Skill
1	4.8	3.4	5	4.6	4.4	4.8	4.2	3	3.6	4.6
2	3.33	4.33	4.44	4	3.88	4.44	3.77	3.88	4	4.66
3	4.5	4	5	3.5	3.5	5	4	3	2.5	4
4	3.33	2	3.66	4	2	3.33	3	2.66	3.66	3.33
5	4.2	3.4	4.2	4.8	4.4	5	3.6	2.6	2	3.6
6	3.8	4.6	4	4	4.6	4.8	3.6	3.8	3.8	4
7	3.33	4.66	3.66	4.66	4.33	4.33	3.33	3.66	5	3.66
8	4	4.4	4.6	4.6	4.6	4.6	4	2.8	3.2	4.4
9	3.8	4.6	3.8	4.8	3.6	4.6	3.4	3.8	3	4.2

Table 5. The most appropriate types for knowledge areas and skills.

Knowledge areas and skills	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7	Type8	Type 9
Cost Management	✓		✓						
Communication Management						✓	✓		✓
Schedule Management and Planning	✓		✓						
Health and Safety Management					✓				✓
Risk Management						✓		✓	
Analytical Skill			✓		✓				
Decision-making	✓		✓					✓	
Team-working		✓				✓			✓
Delegation		✓					✓		
Problem-Solving	✓	✓							

Concluding Discussion

Personality characteristic is one of the significant key factors to create teams, especially project management teams. Nowadays, successful construction organizations focus on considering the personality characteristics of employees when creating project management teams. Our study was an effort to explore and find out the most appropriate personality types to create a project management team for sustainable construction projects. For this reason, a survey study was conducted in this research. Answers of the respondents were analyzed and the results presented. It should be noted that the sample size may be relatively small to make any statistically significant conclusions. Hence, many of the conclusions drawn from the research are obviously limited by this sample.

Analyzing the results showed that the Enneagram types One and Three gave the highest scores to cost management. This indicates that these types place special emphasis on estimating and managing cost in projects. The idealistic characteristic of type One persons and success-oriented personality of type Threes (Riso & Hudson, 2000) can be the reasons that these types pay more attention to cost management than other types.

According to results, the most appropriate types for communication management are types Six, Seven and Nine. The common characteristics of these types are their friendly and talkative personalities. On the other hand, it is indicated that the lowest scores for communication management belong to the Enneagram type Four, which makes them the most inappropriate type for this area. The reason for this score is their low self-confidence, which makes Fours fully embarrassed and depressed persons (Williams et al., 2008; Palmer, 1995).

Types One and Three respondents gave the highest scores to schedule management and planning. According to Goldberg (1999), type Ones are the best schedulers and organizers. Also, Threes are success-oriented peoples (Riso & Hudson, 2000) and do not want to work in a project which has a vague work plan (Palmer & Brown, 1997); so, they tend to spend more time to have the best plans for achieving success.

The Enneagram types Five and Nine respondents believe that they are the most appropriate types for implementing health and safety management in the workplace. The reason for this may be the friendly and humanitarian personality characteristics of type Nines.

By giving the highest scores to risk management, type Six and Eight respondents showed that they found it more appropriate to their personality characteristics than other types. Sixes are security-oriented (Riso & Hudson, 2000) and have worried and anxious personality (Williams et al., 2008), which forces them to anticipate everything before happening. On the other hand type Four respondents gave the lowest scores to this area. Fours are Romantic and sensitive peoples and have a tendency to break out from the real world.

In the analysis of skills, the tendencies of the types were determined for each skill area. According to the results, except type Four respondents the other types gave high scores to analytical skill and the most appropriate personality types for this skill are types Three and Five. Type Four respondents gave low scores to this skill because they are more emotional than logical.

For decision-making skill, the most appropriate types are types One, Three and Eight. Ones suffer from the mistakes of other people and want everything to be done right (Palmer, 1995); Threes are success-oriented persons (Riso & Hudson, 2000); and Eights are dominating, self-confident and self-sufficient peoples, who want to control everything on their own (Riso & Hudson, 1999; Palmer, 1995). So, these types tend to make important decisions of their workplaces by their own.

The three types that gave highest and approximately the same scores to team-working skill are types Two, Six and Nine. According to the literature, Twos are sincere, warm-hearted, energetic, and intimate, which make them the best team members (Riso & Hudson, 2000; Palmer, 1995). Also, types Six and Nine persons have friendly and welcoming characteristics. On the other hand, types Four and Five respondents gave low scores to this skill because Fives are deeply private persons and want their privacy and work alone in their personal place (Goldberg, 1999). Further, Fours are weak in teamwork because they may see other members more talented and more valued (David, 2001; Palmer, 1995).

As presented in the results, types Two and Seven are the most appropriate types for delegation skill. Whereas type Five respondents gave the lowest scores that make them the most inappropriate type for this skill.

Also, results indicate that Types One and Two respondents believed that they have talents in problem-solving skill. According to Bland (2010), Twos tend to attend and solve the needs, feeling, and problems of people. This characteristic makes them willing to be good problem solvers.

The remarkable issue in this research is the Enneagram type Four respondents who do not tend to almost any area (knowledge area and skill) and gave low scores to all of the them. Knowing employees' Enneagram types is important in understanding each person's strengths and weaknesses and can help managers in creating teams which can work more productively to achieve common goals. In this study, it was tried to find logical reasons from literature to describe the importance given by the respondents to knowledge areas and skills.

Limitations and Future Research Directions

The other knowledge areas that defined in PMBOK and other skills have not been investigated in this study. The other knowledge areas and skills play critical roles in creating a project management team that should be studied in future research. It is recommended to increase the number of respondents of the survey to obtain more reliable results (statistically significant results).

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Investigation of Energy Loads in Different Window-To-Wall Ratios for Different Orientations of a Building Model

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Abstract

Upon the significant energy consumption of the buildings and the importance of their efficiency, factors such as local climate, geometrical aspects, material properties, and HVAC systems are of great importance in the design of the buildings. In this study, the effect of the window-to-wall ratio on energy efficiency based on the building's orientation has been investigated. Istanbul is chosen as the study area and a building model is prepared with an energy simulation program. Heating-cooling energy loads are calculated by considering the properties and climate data of the structure that is examined in this model. According to the simulation results, the directions and window-to-wall ratio (WWR) in buildings affect energy consumption. According to the simulation results, with an increase from 20% to 80% for the ratio of WWR, the heating load of the building decreases in the maximum amount on the south side of the building and reduces in the minimum amount on the north side of the building.

***Keywords**: building orientation, energy load, parametric design, window-to-wall ratio.*

Introduction

After the industrial revolution, urbanization, and population growth, which can be regarded as the beginning of the process, affected the building construction. Increasing housing demands has raised housing supply and also has increased the comfort characteristics of them. Energy requirements pertinent to this, on the other hand, the high cost of energy production and consequently energy shortage, increase the importance of energy conservation worldwide. Considerable amount of energy consumption is related to consumers' performance, thus, special attention has to be paid in order to improve it and prevent energy waste (Faizi et al., 2011). Nowadays energy is a challenging issue in developing countries which made new era in energy efficient architecture in contemporary architecture of developing countries (Mahdavinejad et al., 2017) such as Turkey that is dealing with energy shortage problem similar to other countries and as a result as of 2007 imports 75% of its required energy supply (Türkiye Enerji Raporu, 2010). Thus, this has doubled the necessity of optimizing energy consumption in this country. Fig. 1 shows energy supply and demand changes in Turkey.

Provided that housing and commercial buildings are responsible for nearly 37 percent of the energy consumption, designing an optimum pattern for openings or WWR for buildings is of great importance (Mahdavinejad et al., 2012).

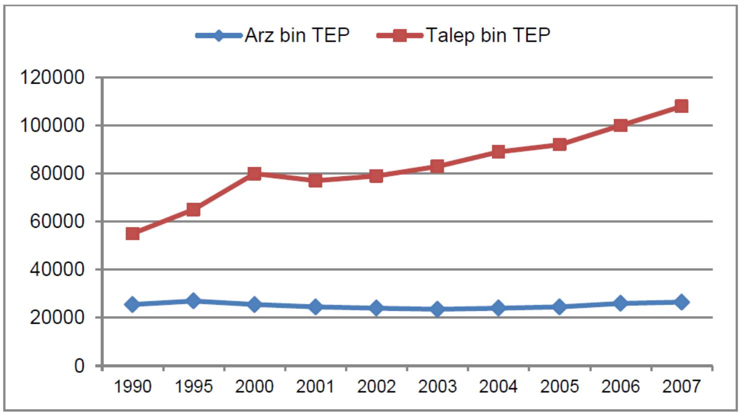


Figure 1: Energy supply and demand changes in Turkey.

Nowadays, it is encouraged to use computer-based simulations from well-known organizations to accomplish energy-efficient projects (American Institute of Architects, 2013). It is accepted that making energy-efficient design decisions in the early stages of the building design process has the most influential and cost-effective results (Paulson, 1976). It is also an undeniable fact that solar energy is one of the most important factors affecting energy consumption in buildings which is gained via radiation, conduction, and convection inside of the building. Windows exposed to high levels of sunlight, especially in hot climatic regions, negatively affect the internal thermal comfort conditions. Some of the problems that this unpleasant condition might create could be increasing stress on people, decreasing people's working efficiency, and reducing the working efficiency of electrical equipment inside of the building (Bojic & Yik, 2007). Therefore, building envelopes that include the WWR and transparent surfaces, play an important role in the energy requirements of the building (Yildiz et al., 2011). Energy conservation in the building shell is common to the design of transparent areas following energy-efficient or passive design principles, i.e., dependence on the opaque-transparent surface area, window system, and materials to be used, airtightness, capability of controlling the flow of heat, providing the necessary thermal conditions in the interior space, and having a functioning that decrease the consumption of fossil fuel energy.

In this study, the effects of different window-to-wall ratios according to different orientations on heating and cooling loads were investigated in the city of Istanbul. Given the conditions for this city, it is aimed to increase the energy performance of the building by determining the appropriate WWR and orientation in moderate-humid climates. With the effective use of controllable design parameters, it is possible to increase the indoor thermal comfort and reduce the negative impact on the environment due to energy consumption.

Methodology

This research is based on modeling and simulating via Rhino 6, an architectural modeling program, Grasshopper (a software inside of the Rhino) to parametrize the Rhino model, plugins named Ladybug 0.0.68 for examining environmental data and Honeybee 0.0.65 for energy simulation. Simplifying the process of analysis effectively allows the architects to develop an efficient design and have a logical choice. Different WWRs were selected on two opposite sides of the examined building model and the total energy loads of heating, cooling, and lighting were calculated and compared via energy simulation by rotating 45 degrees on the central axis of the building. In these calculations, the thermal transmittance value (U) of the building was chosen 0.57 W/m²K that is suitable for Istanbul (Table 1). The total energy load is calculated and compared with various window-to-wall ratios and orientations. With the data acquired as a result of the simulation, the changes in the heating, cooling, lighting, and total loads were observed.

Table 1. U values according to climate regions.

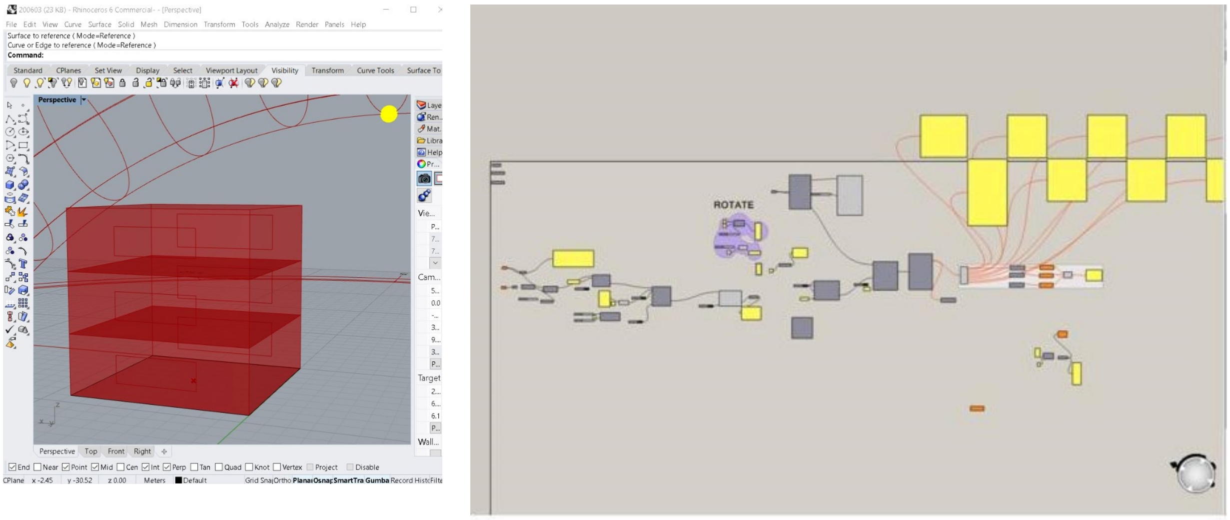
Climate zone	UD (W/m²K)	UT (W/m²K)	Ut (W/m²K)	UP (W/m²K)
1.zone	0,66	0,43	0,66	1,8
2.zone	0,57	0,38	0,57	1,8
3.zone	0,48	0,28	0,43	1,8
4.zone	0,38	0,23	0,38	1,8
5.zone	0,36	0,21	0,36	1,8

Properties of the Examined Building Model and Climate of Its Location

Utility costs for a building can be decreased when passive energy systems are properly designed to replace active energy systems. To determine the effect of WWR on energy efficiency, "Istanbul", which is one of the cities where the new building production speed is highest within the scope of urban transformation, has been chosen as the case study. Istanbul, which is a transition area between the Mediterranean and the Black Sea climates, has a temperate climate. However, due to high humidity, the effect of hot and cold air conditions are significant. June is the hottest month and January is the coldest month during the year.

Algorithmic Programming

Although various parameters i.e., materials, urban context, and energy consumed by occupant appliances affect the energy use of buildings, in this study authors consider only the exploitation of window-to-wall ratio and building orientations. These are recognized as an effective means to reduce the energy requirements of buildings. The algorithm of energy analysis provides acceptable progress in the research development plan. The design model is considered an office building with dimensions of 10*10*10 m. The building has only two windows on two opposite facades. The algorithm of energy simulation and calculating process and result is shown in Fig. 2.

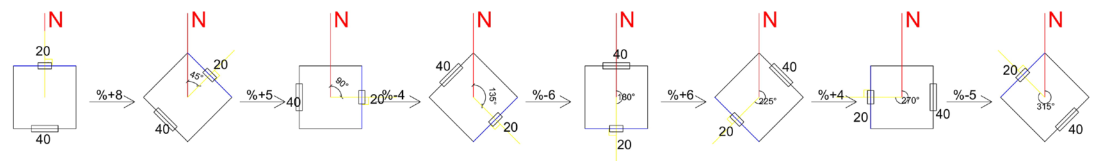
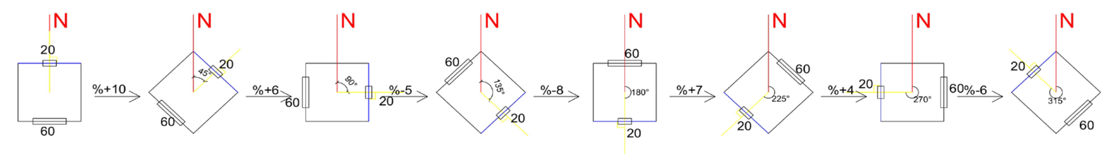
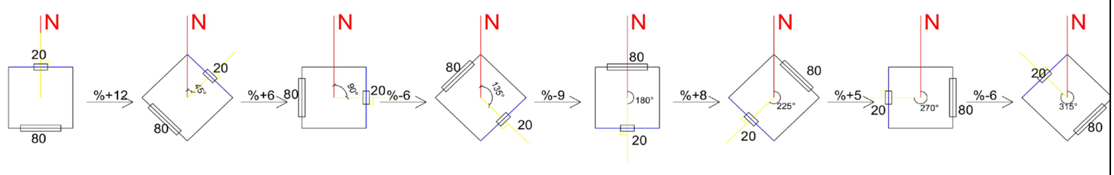


(a) (b)

Figure 2: (a) Building energy model. (b) Algorithm of energy simulation.

Determination of Window-To-Wall Ratios That Provide Optimum Energy Consumption Based On Directions

In the four-faced model, the two sides are deaf walls, while the other two facades have WWR alternatives 20-40%, 20-60%, 20-80%, 40-60%, 40-80%, and 60-80%. Heating, cooling, lighting, and total energy loads for these alternatives are calculated and compared with each other by rotating the angle of the building repeatedly with 45° around the center axis (Fig. 3).

Transp - arency rate	Steps of rotating the alternatives around their axis
20-40%	
20-60%	
20-80%	

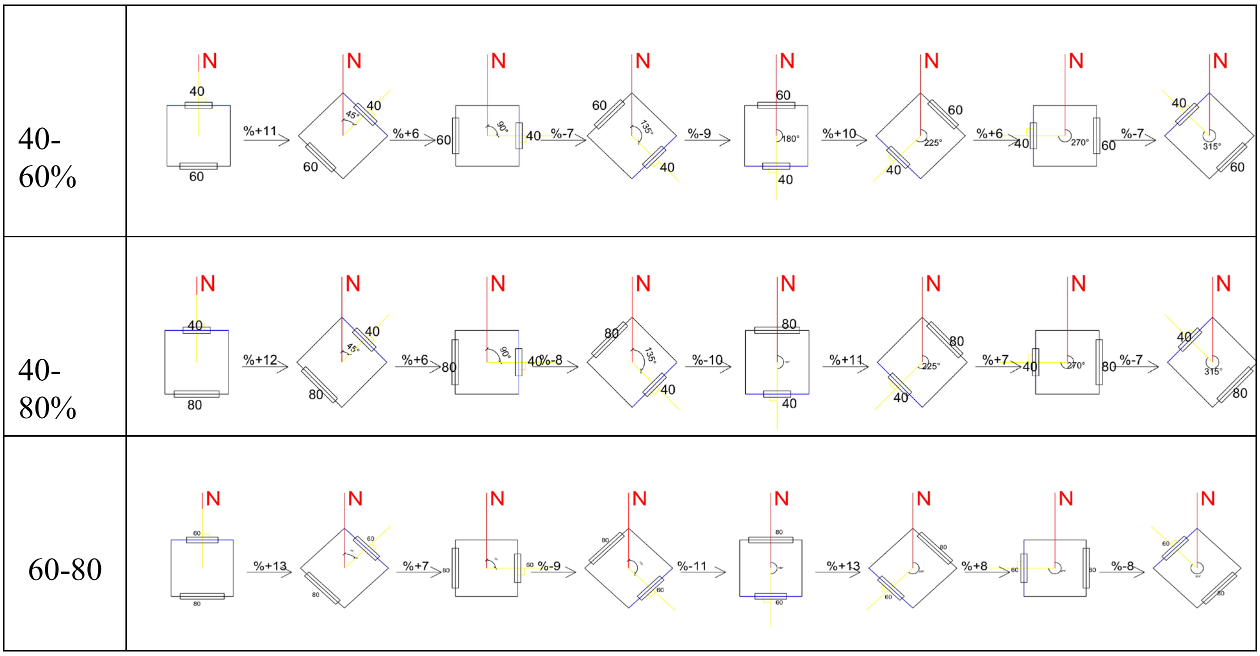
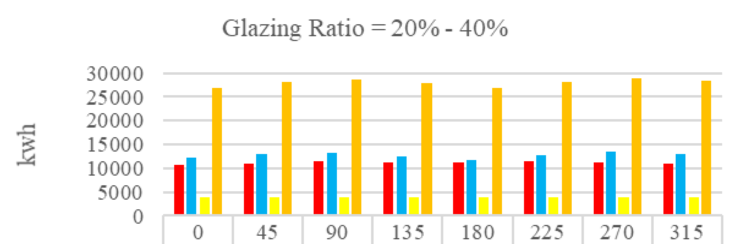


Figure 3: Steps to rotate building alternatives derived from different WWR around their axis and percentage changes in total energy loads between these locations.

Results and Discussion

The window-to-wall ratio of the building in different directions was gradually increased between 20% and 80%. The effects of the WWR were examined on the energy performance of the building in winter and summer periods. The comparative analysis was performed in 8 steps by changing the angle between the vertical axis passing through the north facade and the north axis. Energy consumption for the 20%-40% WWR alternative with 8 orientations of the building (X-axis) is shown in Fig. 4. In this figure energy use for heating, cooling, and lighting in different orientations (from 0˚ to 315˚) is shown. Total energy use in 0˚ which WWR is 40% and 20% for the south and north sides respectively, is 26887 KWh, whereas in 270˚ with WWR 40% and 20% for the east and west sides respectively, is 28876 KWh.



	0	45	90	135	180	225	270	315
HEATING	10743	11071	11366	11327	11266	11375	11333	11065
COOLING	12279	13062	13254	12515	11602	12644	13413	13105
LIGHTING	3865	3852	3844	3853	3865	3865	3860	3865
TOTAL	26887	28030	28554	27830	26913	28109	28876	28350

Building orientation

Figure 4: Effect of different orientations for 20%-40% WWR alternative.

Results indicate that the effects of window-to-wall ratios according to the building orientation is undeniable in the building total energy consumption. As Fig. 5 illustrates, the increasing window-to-wall ratio on the building facades increases total energy consumption in this building. The 20-40% WWR indicates the minimum total energy consumption of 223549 KWh, whereas the 60-80% WWR condition indicates the maximum total energy consumption of 276364 KWh.

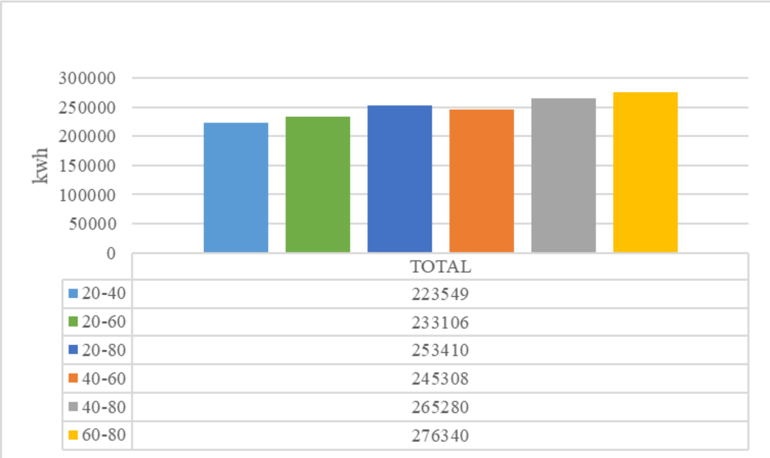


Figure 5: Total energy loads for all orientations of building with different WWR.

As it is illustrated in Fig. 3, in all alternatives, except for the northwest and northeast sides, increasing the WWR from 20% to 80% is effective in reducing the heating load. In Fig. 6 assuming the window-wall ratio remains constant at 40% on the opposite side of the specified facades. The WWR increases from 60% to 80% on the discussed facades. The heating load of the building decreases in the maximum amount on the south side of the building and reduces the minimum amount on the north side of the building. However, in the northwest and northeast sides, when the window-to-wall ratio is increased from 20% to 60%, the heating load of the building increases (Fig. 6).

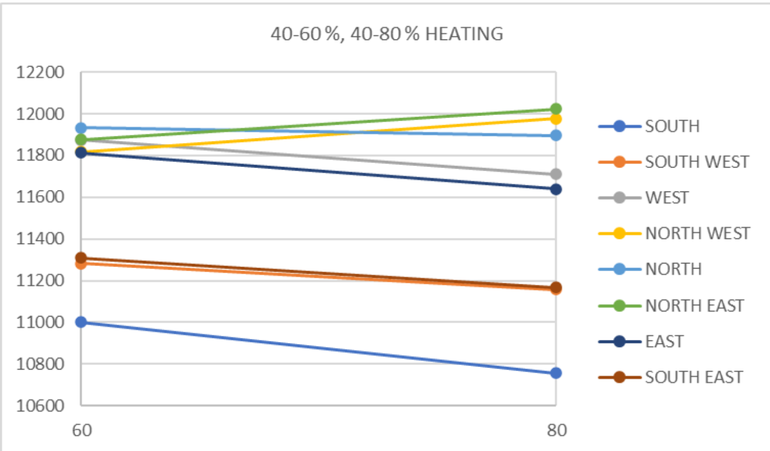


Figure. 6: Comparison of the effects of WWR in different building orientations on energy consumption (heating load).

In Fig. 7 and 8 assuming the window-to-wall ratio remains constant at 20% and 40% respectively, on the opposite side of the specified facades. Investigating summer cooling load

(Figs. 7 and 8), by increasing the window-to-wall ratio from 20% to 80% on the discussed facades, energy consumption (cooling) is increasing. While the highest increase in energy consumption (cooling) is found on the southwest and the south side %38 and 33%, respectively, the north side with a 19% energy consumption increasing is minimum.

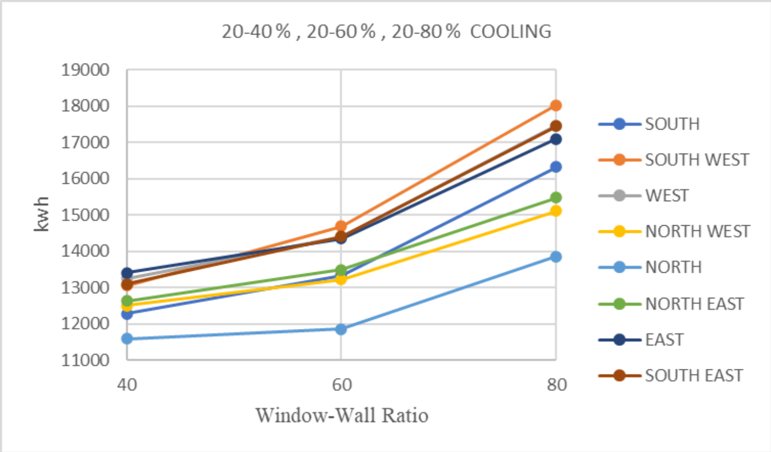


Figure. 7: Comparison of the effects of WWR in different building orientations on energy consumption (cooling load).

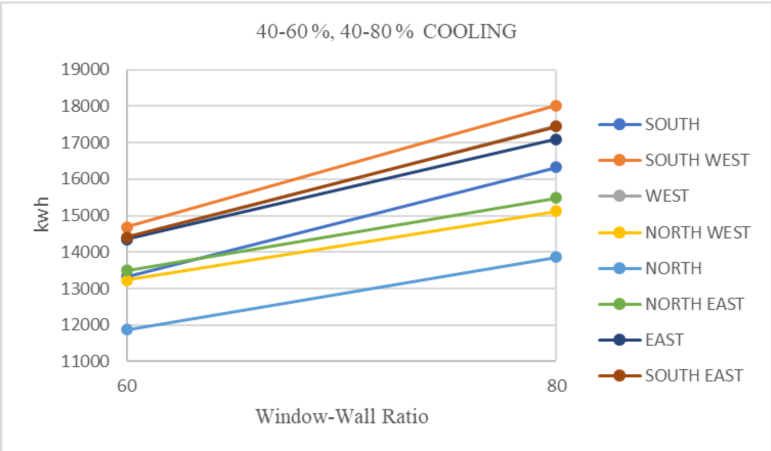


Figure. 8: Comparison of the effects of WWR in different building orientations on energy consumption (cooling load).

Fig. 9 and 10 illustrate total energy consumption for each specified facades when assuming the window-to-wall ratio remains constant at 20% and 40% respectively on the opposite side of the discussed facades. The effect of changing the WWR on the total annual energy consumption is different than the amount of heating or cooling load. According to Figs. 9 and 10 the southwest side with 17.6% and the west side with 15.4 % have the largest total effect, whilst the north side has the smallest total effect.

Figure 9: Effect of WWR on energy consumption (total).

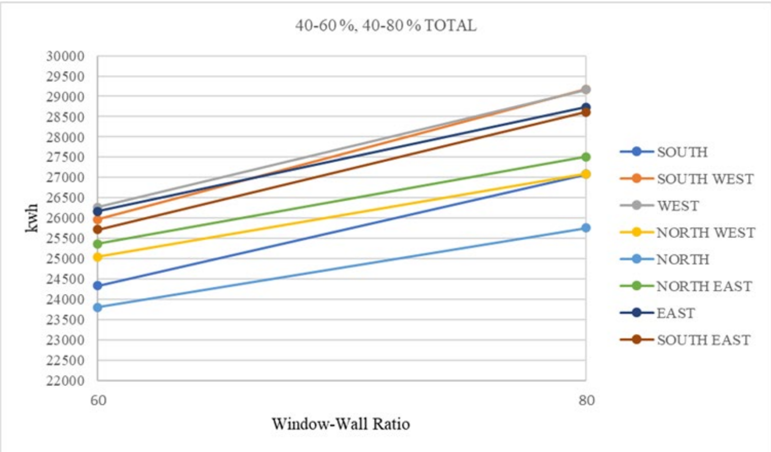


Figure 10: Effect of WWR on energy consumption (total).

Conclusion

In the concept of energy, the importance of the early stage of building design is undeniable, thus, heat gain or loss from transparent surfaces should be analyzed in detail in this stage by considering building function and local climatic conditions. In this paper, parametric modeling and energy simulation analysis was introduced to obtain an optimized orientation and window-wall ratios for a building to minimize energy consumption. Depending on the climate analysis observed via Ladybug plugin, the energy requirement for annual heating, cooling, and lighting were calculated via Honeybee plugin which both work with parametric modeling software named Grasshopper in Rhino 6. The heating and cooling energy consumption values were calculated with arranging window-to-wall ratios in opposite directions as 20-40%, 20-60%, 20-80%, 40-60%, 40-80%, 60-80 by rotating in the main and intermediate directions.

The results indicate that the most optimized alternative regarding energy consumption, according to the functional and climatic characteristics of the building, is south-north orientation with a WWR of 20-40%, which the highest rate of the window is on the south-side. In the optimized alternative, occupants will use less energy for heating in winter and less energy for cooling in summer. While the worst case is west-east orientation with an opening rate of 60-80%. Additional studies would be required to investigate the effects of exterior and interior wall materials, heat transfer coefficient when choosing windows (U values), building geometry, and wind speed on the energy performance of the building..

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International Steps on Climate Change and Transition to the Paris Agreement under the Effect of Covid-19

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Abstract

Sustainability and climate change concepts have been discussed and kept on the agenda for a long time because they are directly related to many sectors such as energy, construction and manufacturing. Due to this reason, International negotiations were held, and agreements were signed. The Kyoto Protocol, which came into force in 2005, and the Paris Agreement, which will come into force at the end of 2020, are among the biggest steps in climate change. In this context, the commitments of the Kyoto Protocol and the Paris Agreement were examined in this paper. The performance in the period between these two agreements and Turkey's status about this issue has been stated. In addition, the effects of the Covid-19 outbreak in this process were examined in terms of climate change. This paper, prepared for the basic perception of climate change rather than a sectoral perspective, aims to raise awareness about international steps towards climate change, the commitments of these steps and the advantages of compliance with commitments. Beside that, by evaluating the data obtained from the Covid-19 epidemic in a climatic sense, more conscious transition to the post-epidemic period and the Paris Agreement implementation at the end of 2020 was aimed to be ensured.

Keywords: *carbon trading, climate change, covid-19, Kyoto protocol, Paris agreement, United Nations framework convention on climate change (UNFCCC).*

Introduction

The Industrial Revolution is considered the beginning of industrial developments in many respects. These developments are so important and powerful that some of the effects of this process, which started in the middle of the 18th century, have just begun to be felt in terms of its effects on human life. Technological developments emerging after industrialization, production supply-demand balances and globalization are the links that are interconnected in terms of cause-effect relationship. All of these are visible things of this process. The invisible thing revealed by the process is global warming.

Global warming and climate change, which is one of the biggest actors threatening the future, grow for reasons such as increasing fossil fuel use, increasing energy production with wrong sources and decreasing the amount of forest clearing the atmosphere. Due to the economic developments that people see as growth and the increase in the number of living people, the increase in global warming and climate change is accelerating (Akkaya & Uzar, 2012). According to the IPCC (2016) report, if the subject is considered numerically, a change of 0,74 ± 0,18°C has occurred in the global warming amount positively between 1906 and 2005. According to the IPCC (2018) report, if this situation progresses in the current manner, this increase value is expected to reach 1,5°C by 2040. Although the direct or indirect reasons of the numerical change are seen as fields such as energy, construction, industrial processes and product use, agriculture and transportation, it is necessary to look at the subject from a much broader perspective before addressing the issue in a sectoral manner (TUIK, 2020). According to the study conducted between 1951 and 2010, the biggest cause of global warming with 95% reliability is human activities (IPCC, 2014). In other words, human beings are responsible for all of global warming. For this reason, a basic change of perception is needed instead of focusing on various sectors.

The predictions show that damages that will prevent the sustainability of life will arise. The solution of climate change caused by global warming is no longer deferred. Countries cannot solve this issue alone. It is necessary to find a global solution to this global problem. In this context, the United Nations Framework Convention on Climate Change was opened for signature at the World Summit held in Rio de Janeiro in 1992 and came into force in 1994. In this way, the first step towards raising awareness of the international public on climate change has been taken. The second main development is the Kyoto Protocol, which was agreed in 1997 but could come into force in 2005 for various reasons. The last big step is the Paris Climate Summit held in 2015. The decisions of this summit will come into force at the end of 2020 with the postponements. The Paris Agreement can now be regarded as the last chance for environmental intervention. For this reason, it is necessary to analyze the previous step, the Kyoto Protocol very well, and to comply with the new decisions by correcting the missing aspects of the protocol and strengthening the positive aspects of the protocol.

In this paper, the process from the Kyoto Protocol to the Paris Agreement was examined in terms of global warming and climate change. In addition, legislation and commitments was put forward, and the current status in Turkey about these issues was evaluated. On the other hand, the effects of the Covid-19 epidemic, which is a current global development, within the scope of climate change were examined. This paper is important in terms of making a situation assessment by analyzing the current data on climate change, which has become irreversible. Also, this evaluation is extra important, as it was made in the transition year to the Paris Agreement, which is the last big step. Moreover, since the Covid-19 virus is very new, a paper examining its environmental impacts is almost nonexistent. For this reason, this paper is very valuable in terms of providing the most up-to-date data to the literature and paving the way for future studies on this subject.

International Steps on Climate Change

There are periodic interviews in the international context of climate change and the global warming caused by climate change. The first serious step taken in this regard can be accepted as the United Nations Framework Convention on Climate Change (UNFCCC). This contract is the first environmental contract that was opened in 1992 under the leadership of the United Nations and came into force in 1994 with the approval of the European Union as well as 188 countries (Çetintaş & Türköz, 2017). Correct diagnosis must be made before the measures to be taken on the subject. It is important that the contract begins with the acceptance that human activities have major impacts on climate change. Diagnose is totally correct and important. The main purpose of the contract is to control the greenhouse gas density and reduce it in the following process (TUSIAD, 2012).

Kyoto Protocol

The provisions set out in the UNFCCC have been insufficient on many issues. The second biggest step taken to eliminate the deficiencies and create a more feasible system is the Kyoto Protocol, approved on 11 December 1997. The protocol came into force at the beginning of 2005. The reason for this delay is two conditions set for the protocol to take effect. Fist condition is the protocol acceptance of at least 55 countries. The second condition is the total emission amount of the accepting countries should be more than 55% of the total emission amount of Annex-1 countries established in the framework of UNFCCC (Binboğa, 2014).

According to rule-3-1 of the UNFCCC (1998), the countries that are included in Annex-B within the scope of the protocol will reduce the amounts of greenhouse gas emissions defined in Annex-A by at least 5% of their emissions in 1990. This is the clearest numerical declaration. Also in rule-2/1.a of the protocol, it is stated that in order to promote sustainable development, it is necessary to increase energy efficiency in related sectors, to ensure afforestation and reforestation, to promote sustainable agriculture types, to develop and use renewable energy types and environmentally sensitive technologies, and to implement appropriate reforms in the relevant sectors.

Although the Kyoto Protocol contains notifications with environmental targets, some of countries that we can call advanced are reluctant to approve this protocol. According to the protocol, countries are divided into two as have completed the industrialization process and developing countries. While the countries that have completed their industrialization are responsible, the industrializing countries are not under any responsibility. Some countries in the world in terms of greenhouse gas emissions such as China and India are not under any obligation because of being in the category of developing countries (Öztürk & Öztürk, 2019). However, according to the available data, the mentioned countries are the leading countries in terms of greenhouse gas emissions. In global leadership race, it can be said that countries are advancing by ignoring certain issues. Therefore, the fact that the countries in the leadership race are not evaluated under the same category and not being in equal responsibility creates a deep discomfort. The success of the protocol will be with the success of these countries. So, this problem needs to be eliminated.

Flexibility Mechanisms of the Kyoto Protocol

Reduction targets in CO_2 emissions set in the Kyoto Protocol mean serious measures to be taken for some countries. Every precaution is seen as an economic burden because it means a system change. For this reason, flexibility mechanisms, namely Clean Development Mechanism, Joint Implementation and Emission Trading, were introduced in order to ensure that countries achieve these targets and even to make bigger progresses (UNFCCC, 1998).

Clean Development Mechanism (CDM): The Clean Development Mechanism, defined in rule-12 of the Kyoto Protocol, offers great opportunities for cooperation between developed countries and developing countries. As a matter of fact, when the projects and the greenhouse gas reduction potential of these projects are evaluated, it can be said that the most used flexibility mechanism is the Clean Development Mechanism (Can, 2018). According to this mechanism, the investor country is a developed country (Annex-I and Annex-B country) defined under the protocol, and the country where the investment is made is a developing country according to the protocol. The developed country develops a project for emission reduction in one of the non-Annex-I countries. Thus, the developed country earns a certificate and credits named Emission Reduction Unit (CER), and the developing country achieves a carbon emission reduction since the project is carried out in its own country. In addition, the country that has earned credits will have the right to emit as much carbon as this amount (UNFCCC, 2007). Considering that the costs are lower in developing countries, it can be estimated that the number of projects developed within the framework of CDM is quite high in order to reach the target figures. Because of this situation, when it is evaluated between 2010 and 2020, it is foreseen that the carbon emission reductions in developing countries will be higher compared to developed countries thanks to the projects carried out in developing countries (Çetintaş & Türköz, 2017).

Joint Implementation (JI): Although the Joint Implementation defined in rule-6 of the Kyoto Protocol is a project-based mechanism similar to the CDM, it is an implementation that takes place between Annex-1 countries. The investing countries earn credit as Emission Reduction Units (ERU) with the projects implemented. These countries can use their credit to both fulfill their greenhouse gas emission commitment and sell it to countries that have problems in complying with its commitment (UNFCCC, 2007). The JI prepares the environment for a large trade formation among Annex-1 countries. According to the data of Binboğa (2014), at the end of May 2013, 758 projects worth 738.332.000 ERU were made. 42% of these projects will be completed in Ukraine. The example given by Akkaya and Uzar (2012) conforms exactly to this specified data. The investment costs of the projects to be realized in Germany and Ukraine are different from each other. Ukraine is more suitable for investment costs. Thanks to the Joint Implementation, Germany can fulfill its greenhouse gas emission commitment specified in the Kyoto Protocol with the project or projects in Ukraine.

Emission Trading (EI): This system, which is a kind of exchange between the countries within the scope of Annex B of the Kyoto Protocol, is defined in the rule-17 of the protocol. Countries that comply with the committed greenhouse gas emissions reduction targets and even achieve more reduction can sell their rights to countries that do not achieve this goal as credits call Assigned Amount Unit (MEF, 2008). The measures to be taken for climate change with the Emission Trading comply into the world system where everything is measured with money. Thanks to this system, the possibility of cost effectiveness is offered and the idea that investment costs increase by making environmental investments in countries can be eliminated.

The Kyoto Protocol has led to positive results with flexibility mechanisms. In Fig. 1, there is a graphic prepared between 2008 and 2012, when the Kyoto Protocol was applied. In this graph, it can be seen that most of the European countries complied with the commitments made under the protocol and even had very successful results.

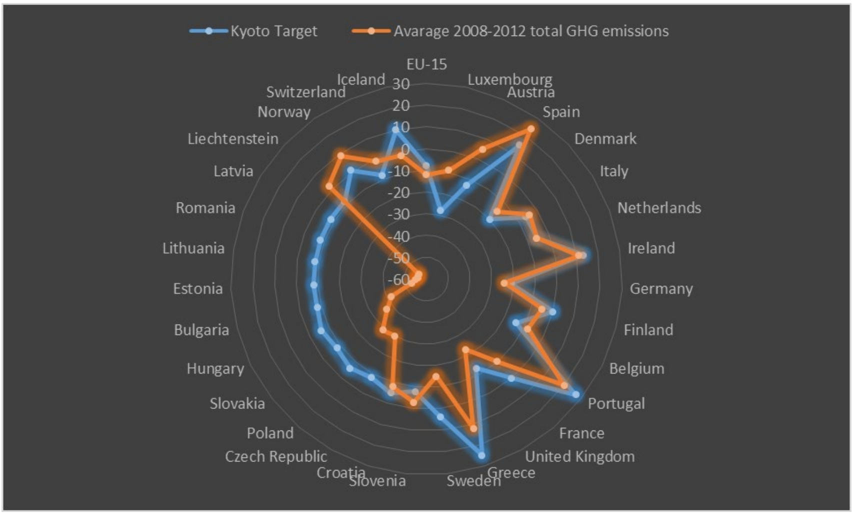

Figure 1: Compliance with the Kyoto Protocol targets for European countries, 2008-2012 (EEA, 2014).

Carbon Trading

The concept of "carbon trade" has emerged with the purchase and sale of credits obtained in line with the targets set for reducing carbon emissions. This trading system, on the one hand, made it easier for countries to progress to their targets, and on the other hand, it enabled developed and rich countries to expand their carbon quotas without changing their production systems.

Not all countries can benefit from the flexibility mechanisms in the Kyoto Protocol. However, the growth in the prevalence of carbon trade in parallel with the environmental sensitivity increases the appetite of the countries day by day. For this reason, countries try to enter the system in some way. It is stated in Uysal Şahin (2016) that some countries do not aim to contribute to the prevention of climate change. The reasons for signing the Kyoto Protocol are to direct decisions to be taken in the future and to benefit from the advantages of flexibility mechanisms.

The voluntary Carbon Markets and the Current Situation in Turkey

Although the countries in the Kyoto Protocol had different thoughts other than environmental benefits, they basically had a goal to prevent global warming. More cooperation is made, and the more participants are involved in the process, the greater the chances of success. In this regard, voluntary carbon markets were created besides the flexibility mechanisms of the Kyoto Protocol. These markets are not government initiatives, but are systems designed to provide a carbon balance in which everyone from local governments to individuals can participate, regardless of the plans to combat climate change. Projects created for reducing greenhouse gas emissions in this system are certified under the name of Voluntary Emission Reduction (VER) certificate (MEU, 2012).

The biggest difference of the voluntary markets with the flexibility mechanisms is the absence of national obligations. However, awareness of countries and local organizations increases day by day. For this reason, the prevalence of volunteer markets increases with the participants who are not the main parties of the Kyoto Protocol. Turkey is in Annex-I list according to the UNFCCC. However, since it was not listed in Annex-B in the Kyoto Protocol, it could not find a place in flexibility mechanisms. Therefore, Turkey participated in the voluntary market. In this way, it both increases environmental and social responsibility awareness and tries to ensure compliance with the system for the possibility of being subject to flexibility mechanisms in the future.

Turkey carried out many projects in the field of energy, mainly hydroelectric and wind in voluntary carbon markets (MEU, 2014). According to the data of 2015, Turkey implemented projects worth $4.2 million. The carbon equivalent of these projects were 3,1 $MtCO_2e$ (Binboğa, 2017).

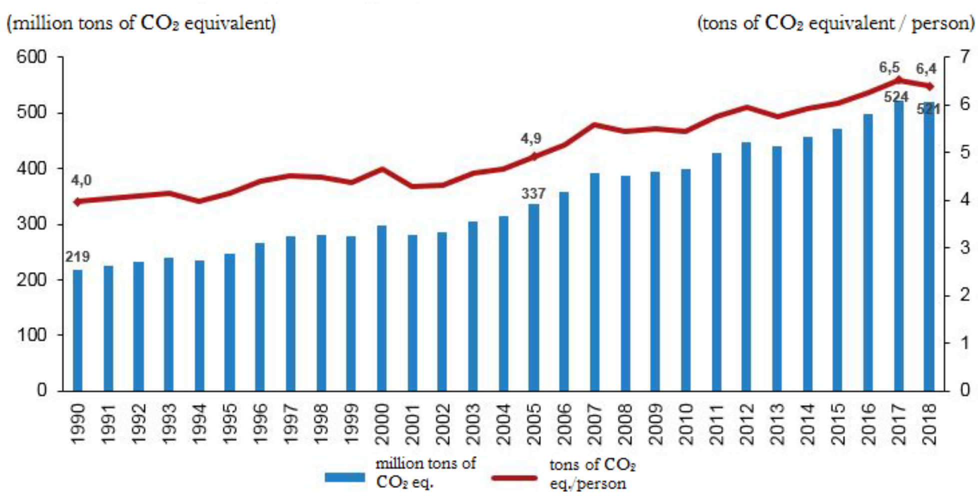

Figure 2: Amounts of carbon emissions in Turkey, 1990-2018 (TUIK, 2020).

Turkey is in the category of countries being industrialized. Besides, considering its population size, it is at a lower level in terms of primary energy consumption compared to other countries. When we look at the total amount of carbon emissions in the world Turkey has a share of only 0.9% (Çetintaş & Türköz, 2017). Therefore, it is thought that there are no emissions problem in Turkey. For this reason, carbon emission limitation does not apply in Turkey. However, it is realized over time there is enormous growth in carbon emissions in Turkey. Compared between 1990 and 2009, it is seen that the amount of emissions increased by 98%. (Çelikkol & Özkan, 2011). The increase continued even more sharply. According to the TUIK (2020) report published on March 31, 2020, compared to 1990 and 2018 data, an increase in the amount of carbon dioxide equivalent greenhouse gas emissions occurred by 238%. As seen in Fig. 2, Turkey's amount of emissions equivalent to carbon dioxide reached 521 million tons by the end of 2018. In addition, the amount of greenhouse gas emissions per capita has reached 6,4 tons. Contrary to the stated bad figures, there were some positive evaluations in the transition from 2017 to 2018. Throughout the country, there was decrease in the total carbon emission amount by 0,5% and decrease in the amount of emission per person by 0.015%.

It can be said that the reason for the increase in the amount of greenhouse gas emissions, especially carbon dioxide, is the development of the industry and increasing energy need depending on the development of the country. Considering the greenhouse gas emissions amounts in the sectoral sense, the energy sector has the biggest share with 71.6%. Industrial processes, waste and agriculture sectors are listed with a share of 12.5%, 12.5% and 3.4% respectively (TUIK, 2020). In 2011, 45% of Turkey's foreign trade deficit was caused by energy imports. This rate increased to 62% in 2012 (MD, 2013). Therefore, we can say that the growth of the industry increased the need for energy. After this need, oil, natural gas and hard coal, which are primarily responsible for the increase in the amount of greenhouse gas, were imported.

Actions begun to prevent graphics that show a negative increase in environmental aspects. The project called Partnership for Market Readiness was signed with the World Bank in 2011 and action plans were put forward. Also, Turkey has made a progress in the way of EU membership with fulfilling the requirements regarding carbon emissions. (Can, 2018). In addition, Turkey is a country having quite high potential in terms of energy resources. For this reason, it can be found in much better places with the right policies. According to the report of the Ministry of Energy and Natural Resources of Turkey, Turkey has an annual value of 160 TWh of hydropower, 48000 MW of wind, 1500 kWh/m^2 of solar power potential (MER, 2016). Despite this great potential, reports published up to the last 3 years contained superficial information on the budget information of studies on renewable energy sources. Thanks to the increased awareness, it has been seen in the reports of the last 3 years that renewable energy sources are considered as installed power, targets and potentials (MER, 2014; MER, 2015; MER, 2016).

Paris Agreement

The shortcomings of the process starting from the UNFCCC and continuing with the Kyoto Protocol are constantly discussed. The biggest problem seems to be the classification of developed and developing countries and that these classified countries have different obligations. The countries that continue the development process argue that based on the statistical data of the previous periods, the source of today's problem is developed countries. However, some of developing countries such as China are rapidly increasing carbon emissions as clearly seen in Fig. 3. This leads to conflict of countries such as the USA, which is at the forefront of emissions and has a strong industry, and China, which is growing fast. This dispute causes these countries to stay away from the protocol. If they stay away from the protocol and do not take responsibility, it will be a miracle to reach the final goal. Countries that are the main responsible for the current situation should not be left out of the process (Yılmaz, 2019).

Another problem is the misuse of flexibility mechanisms created in Kyoto Protocol in order to reach targets more easily. Some of the developed countries try to fulfill their obligations directly through mechanisms, without the need to take measures in their own internal dynamics. (Uysal Şahin, 2016).

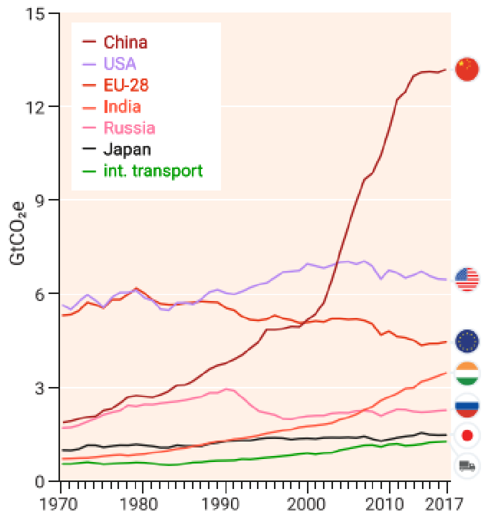

Figure 3: Change in carbon emissions of some countries, 1970-2017 (UNEP, 2018).

There are deficiencies in the process naturally. The important thing is to continue by solving these problems. In this context, the Paris Agreement, the biggest step after the Kyoto Protocol, was signed in order to prevent climate change and find a global solution. The Paris Agreement, signed by 196 countries that are parties to the UNFCCC at the end of 2015, will come into force by the end of 2020. Turkey prepared a national statement of intent and submitted to the commission before acceptance of the Paris Agreement. According to this statement of intent, reduction commitment was made by 21% in the scenario of amount of the greenhouse gas emissions prepared for between 2010 and 2030 as seen in Figure-4. However, despite all attempts, the decisions expected from the Paris Agreement were not taken. Countries in the same category with Turkey such as Mexico, Brazil, India, China, Qatar and etc. will receive technological and financial assistance. But Turkey is not considered as equal with these countries (Binboğa, 2017).

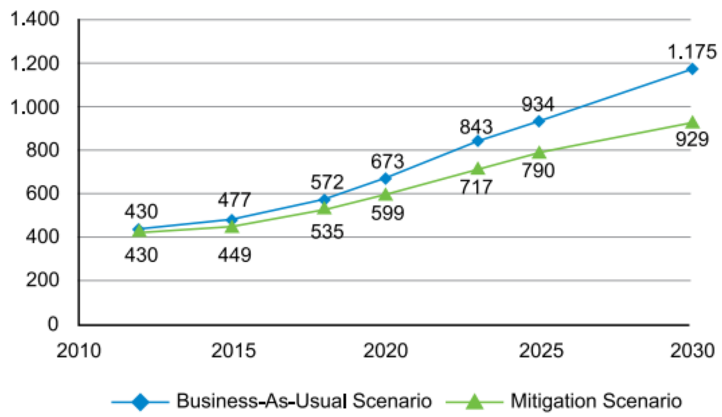

Figure 4: Turkey's national declaration of intent, 2010-2030 (RTMEU, 2019).

One of the developments in the Paris Agreement is that all the countries will be under obligation according to rule-2/1.a. It is expected that all the countries will keep the temperature increase below 2°C until 2100, compared to the pre-industrial period. In addition, the way of using the flexibility mechanisms, which is also one of the criticism points, is regulated. With the new regulation, 3 new mechanisms are introduced. Many projects have been put forward with the Clean Development Mechanism of the Kyoto Protocol and both developing and developed countries have benefited from the system with win-win principle. According to rule-6 of the Paris Agreement, it is understood that one of the mechanisms will be similar to the Clean Development Mechanism. (UNFCCC, 2015).

Covid-19 Effects on Climate Change

According to 1st case report on Covid-19, the Covid-19 virus, which started on December 31, 2019 with the notification of the Chinese Office of the World Health Organization, has spread rapidly in the world due to globalization, which seems to be an advantage in normal conditions (WHO, 2020a). With the spread of the virus, studies in many areas have been slowed down. Even official work has progressed to a minimum. According to the Official Gazette published on March 22 in Turkey, it was reported that it would be sufficient to have a minimum number of personnel in the offices so that the activities and service would not be disrupted. All the gates between the countries were closed over time. Despite all these efforts, according to the 182nd case report dated 20 July 2020, viruses called Covid-19 have spread and 14,348,858 cases were detected, and 603,691 deaths were recorded (WHO, 2020b).

As with the effects of Covid-19 in many areas, it can be mentioned enormous environmental effects. The slowing or stopping of work in all sectors means a decrease in energy demand. It is certain that there will be a change in the amount of greenhouse gas emissions during the pandemic process as the energy demand constitutes a large part of the greenhouse gas emission causes. Many independent organizations working in this field made assessments and started to work on what should be done in the future according to these assessments. According to the report of International Energy Agent, which includes many European countries and developed countries such as America and Japan, a net restriction period of approximately 2 months was experienced in China in the first quarter of the year. Energy demand decreased more than 7% in the first quarter of 2020 compared to the first quarter of 2019. While the decrease in energy demand was over by 6% in the USA, the decrease exceeded over by 5% in the EU countries. From the carbon emissions perspective, the decrease exceeded by 5% in amount of CO_2 emissions in the first quarter of 2020 in the world compared to the same period of 2019. This decline is much sharper in countries where the Covid-19 effect was the first and the most widespread. These effects were 8% in China and EU countries and 9% in the USA. Depending on the continuation of the process, it is expected that the amount of carbon emissions at the end of 2020 will decrease by approximately 8% compared to the end of 2019. Similar intervals can be seen in the paper of Corinne Le Quéré et al. (2020). According to the forecast made with the data obtained until April, if the conditions are returned to time before the pandemic in mid-June 2020, the amount of carbon emissions is expected to decrease between 4% and 7%. This decrease is estimated from the data received from the end of 2019 to the end of 2020.

In the period when Covid-19 is effective, there is a decrease in transportation as well as a decrease in energy demand. In the paper focused on the USA, vehicle travels were checked using mobility data of mobile phones. It was determined that a decrease of approximately by 40% has been achieved in the period until mid-April of 2020. According to the data received from the electricity distribution company, there was a decrease of approximately by 16% in electricity consumption until the middle of April. The reduction in fossil fuel-based transportation and energy demand led to a noticeable positive change in air quality. It was determined that the deaths due to air pollution decreased by approximately 25% with various models (Cicala et al., 2020).

According to the IEA (2020b) report published in February, total CO_2 emissions of the world were around 33 gigatons at the end of 2019. According to the forecasting studies for the Covid-19 pandemic process, drops ranging from approximately 1,3 to 2,6 gigatons are expected. This drop will take the world to levels about 10 years ago in terms of carbon emissions. As can be seen in Fig. 5, there are similar examples in world history. Looking at the examples, it can be seen that the effects of Covid-19 are equivalent to two times of the sum of all the declines after World War II in terms of ecosystem and environmental impact.

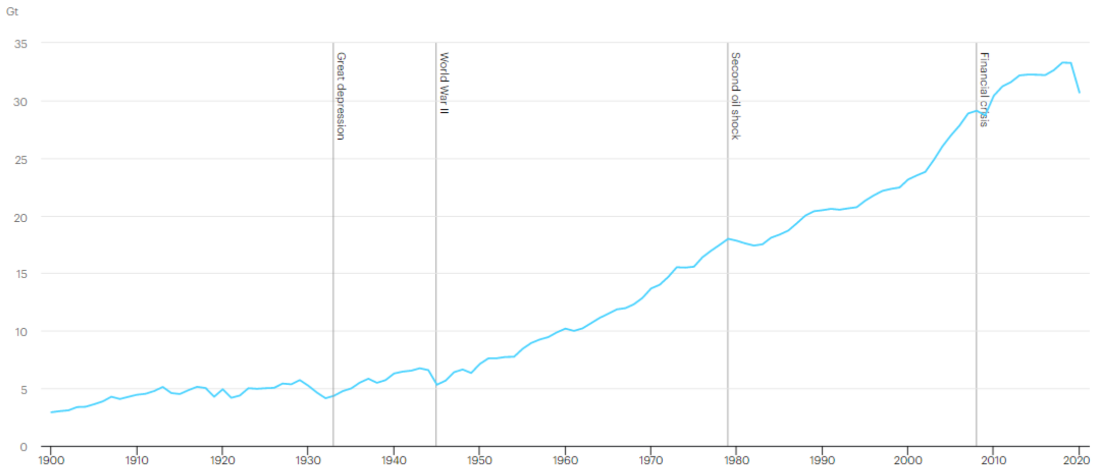

Figure 5: Global energy related-CO_2 emissions, 1900-2020 (IEA, 2020a).

Besides to the environmentally positive effects of the epidemic process, there are also negative effects such as weakening of the recycling system and increase in the amount of waste. Recycling programs were suspended in some cities in the US since it is concerned that virus spread from the recycling centers. In some European countries, such as Italy, infected people were forbidden to separate their waste in accordance with waste management (Zambrano-Monserrate et al., 2020). Disposable products are increasing due to the more difficult disinfection conditions. Disposable products also increase the amount of waste. In this process, it is seen that the demand for simple products such as sachets has increased as well as the materials used for one time such as mask and gloves.

Many environmental and positive effects of Covid-19 virus can be mentioned, but it should not be forgotten that all developments are temporary. When the virus is controllable and life returns to the pre-epidemic period, works in all sectors will continue and everything will be as before. The important thing is to learn new things for ourselves and our environment from this process. In the history, sharp rises were observed after the decreases in carbon emissions. Peters et al. (2012) mentions this situation. Due to the global economic crisis between 2008 and 2009, amount of the carbon emission decreased by 1.4%. However, the state investments, the high growth rates of the developing countries and the reduction of the price pressure put in order to limit the energy consumption caused an increase in the amount of carbon emissions. The amount of carbon emissions grew by 5.9% and tolerated the previous year's decline as seen in Fig. 6.

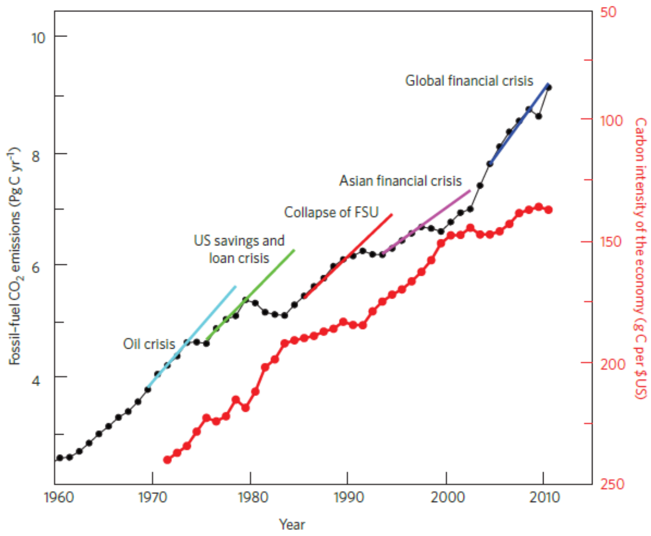

Figure 6: Change in carbon emissions before and after global crises (Peters et al., 2012).

Conclusion and Suggestions

If people know the whole process of a topic and experience it, they will pay more attention to that topic. The issue of climate change has been completely excluded from its important category on people due to its long-term effects. After decades of measurements, a temperature change below 1 ° C is measured, although the effects are very large. Although the impact of this change is huge, this situation that takes place in a long time does not scare people. However, the issue has passed into a period when temperature changes grow at an uncontrollable speed. For this reason, studies on climate change should be evaluated in the category of "cannot be postponed" and "must be done immediately".

The first big step of the studies on climate change was taken in 1992 with the UNFCCC. The existence of the problem and the necessity to take precautions for the problem were accepted. In the Kyoto Protocol, which was signed in 1997 and came into force in 2005, flexibility mechanisms were put forward. As time went on, different claims emerged. The most important of these was the unbalanced distribution claim between the countries that are obliged and not obliged according to the protocol. Other important claim was that flexibility mechanisms are used for commercial purposes rather than the main goals. Therefore, it was clear that new regulations are needed. The Paris Agreement, which offers new system proposals, was signed in 2015. The agreement will come into force at the end of 2020.

Amount of the total carbon emissions have reached 33 gigatons with an increase of 43% from 2000 to 2020 in the world. The biggest reason for the increase is fossil-based fuel consumption, which is mostly used to meet energy demand. Besides, the development of the industry is one of the reasons. Turkey constantly attempts to complete its industrialization. For this reason, while the amount of carbon emissions was around 300 million tons in 2000 in Turkey, this figure increased over 70% and reached 521 million tons in 2018. Turkey entered the recession period with a small amount of decrease in the amount of emissions in the last measurement. It is clear that Turkey will be on much better position after its renewable energy resource potentials are usable.

At the beginning of 2020, a global epidemic occurred with the effect of Covid-19. In a short period of 6 months, the epidemic had great effects on climate change from different perspectives. Energy demand decreased as industrial facilities were slowed down or shut down. In addition, due to curfew restrictions, there was great reduction in the transportation area. All this means that fossil-based fuel usage and carbon emissions were reduced. Therefore, it is anticipated that the decrease in amount of the carbon emissions will approach by 8% at the end of this year. The important issue is what kind of a return will be encountered after this temporary process.

New information about Covid-19 is encountered every day. For this reason, scientists have begun to study on how Covid-19 affects their working areas. In this context, the scope of this paper is quite important and valueable. In this paper, the information obtained so far in terms of the great epidemic before starting the implementation of the Paris Agreement was evaluated. In addition, international steps taken on climate change and the successes achieved thanks to these steps were evaluated. Therefore, this paper is a compilation for the people who will study on climate change, which examines the situation before the transition to the new period.

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Investigation of BIM-FM Integration Approaches

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Abstract

Facility management (FM) is one of the main stages in the building lifecycle and it covers about 70-80 percent of the entire life cycle of a building in terms of both time and cost. Multiple studies have examined the usage of BIM in the design and construction phases. However, less number of studies focused on the integration of BIM with facility management. The aim of this study is to illustrate how a project can be integrated with BIM in the facilities management phase. To achieve this aim, two pilot studies were conducted for BIM-FM integration by utilizing two main methods: (1) using BIM authoring tool, and (2) using BIM-FM platform. Each method was evaluated and the advantages and disadvantages were identified for each method. In the first method, capabilities of BIM authoring tools (i.e. Autodesk Revit) were used for some FM related purposes (e.g. using parameters and colors to filter). In the second method, BIM-FM platform (i.e. EcoDomus) was used for some FM activities such as creation of work-orders and inspection forms.

Keywords: *Building Information Modelling, BIM-FM, Facilities Management*

Introduction

Facility management (FM) is one of the main stages in the building lifecycle (National Science Foundation (NSF), 2003). It covers about 70-80 percent of the entire life cycle of building in terms of both time and cost (Lewis et al., 2010; Akcamete et al., 2010). Although the facility management phase is three to four times more than the cost of all other stages, project stakeholders focus more on initial investment costs (Becerik-Gerber et al., 2012).

Building Information Modeling (BIM) is a digital representation of the building and aims to ensure the flow of information in the digital environment and can be used in all phases of the building life cycle (Eastman et al., 2011). Many studies have examined the usage of BIM in the design and construction phases and have been widely used by companies in the sector at these stages. Although it is the main approach that the information produced in the previous stages was accessible throughout the entire life cycle, only a small part of the studies was focused on the integration of BIM model with facility management (Akçamete et al., 2010; Becerik-Gerber and Kensek, 2010; Parsanezhad and Dimyadi, 2014; Volk et al., 2014; Korpela et al., 2015). These studies have demonstrated the potential benefits of using BIM at the FM stage. However, when the practices in the sector are examined, it is seen that BIM is applied in design and construction stages rather than the facility management stage (Eastman et al., 2011; Becerik-Gerber et al., 2012; Eadie et al., 2013; Volk et al., 2014). It was observed that the information required for the management of the facility could not be collected effectively and collected information was distributed to many different platforms. Studies stated that BIM's structure and graphic interface based on intelligent building elements could be used to combine this information and to provide easy access from a single point. (Becerik-Gerber et al., 2012; Motawa and Almarshad, 2013; Motamedi et al., 2014; Ilter and Ergen, 2015). BIM, also, is seen as a useful tool for effective transferring of FM data to decision-makers. Although the need to develop an integrated system with BIM is often emphasized in the literature, these are only suggestions (Ozturk et al., 2012; Motawa and Carter, 2013; Hua et al., 2014; Göçer et al., 2015). Numerous studies focused on identifying the requirements and challenges of BIM-FM integration and performed opinion-based studies, such as surveys and interviews (Sattenini et al. 2011; Becerik-Gerber et al. 2012; Tian and Liu 2014; Orr et al. 2014; Liu and Issa 2016; Mayo and Issa 2016). Pishdad-Bozorgi et al. (2018) highlighted that these opinion-based findings should be supported with the case studies.

Within the scope of this paper, the studies on BIM-FM integration were examined and the current challenges of this approach were determined by the literature review. Afterward, how BIM-FM integration can be performed is investigated by utilizing two main methods at small-scale pilot projects: (1) using BIM authoring tool, and (2) using BIM-FM platform. Each method was evaluated and the advantages and the disadvantages were identified for each method. The findings of the pilot studies showed that the size of the project and the size of the data would affect the process negatively.

Literature Review

As stated in the previous sections, the positive effect of the BIM in the FM phase has not been seen yet, while it is used mostly in the design and construction phases (Teicholz, 2012). The researchers performed previous studies on identifying the required information in the FM phase and determining related approaches to capture, store, and use this information. These studies can be grouped into two categories: (1) opinion-based studies that conducted surveys, interviews and group discussions with practitioners and experts, and (2) case studies that investigated BIM implementation in real-life projects or pilot projects. The former method was more commonly used (Sattenini et al. 2011; Becerik-Gerber et al. 2012; Tian and Liu 2014; Orr et al. 2014; Liu and Issa 2016; Mayo and Issa 2016). For example, Becerik-Gerber et al. (2012) surveyed and interviewed industry professionals to determine the potential usage areas and challenges of BIM-FM integration. Mayo and Issa (2016) collected information by conducting a Delphi panel with experts to determine the product information needs for BIM usage in the FM phase. In another study, a survey was conducted with sector practitioners to capture the requirements of facility managers and maintainability problems of the BIM-FM database (Liu and Issa 2016). Pishdad-Bozorgi et al. (2018) suggested that these opinion-based findings should be supported with case studies of BIM-FM implementations.

The literature review on the barriers encountered during the integration of BIM and FM, demonstrated that the most important problem is the data transfer among the software packages used for the FM activities and BIM process (Becerik-Gerber et al., 2012; Migilinskas et al., 2013; Kiviniemi and Codinhoto, 2014; Kassem et al., 2015; Terreno et al., 2016; Korpela et al., 2015). Another mostly encountered barrier is the lack of BIM knowledge and experience of FM members since BIM is a new approach for the FM phase (Motamedi and Hammad, 2009; Migilinskas et al., 2013; Kassem et al., 2015; Korpela et al., 2015). In addition, there is no proof that shows the positive results of a real BIM-FM implementation (Becerik-Gerber et al., 2012; Migilinskas et al., 2013; Kassem et al., 2015).

Most of the examples of BIM-FM integration are related to operation & maintenance (O&M) activities. In a study, work orders are managed by using a 3D BIM model (Akçamete et al., 2010). Performed O&M works are saved on the related building components as text information such as “installed” or “replaced”. After giving some specific geometrical shapes according to their status, work orders are tracked on the 3D model. In another study, Kassem et al. (2015) created models of some buildings inside the Northumbria City University Campus by following the existing blueprints to use the visualization of the models for some FM activities. For example, building components are given colors according to their specific properties to follow them on the model. Also, interior furniture renovations are simulated on the model to make a decision. Another study focused on tracking fire equipment with the help of an RFID system (Motamedi and Hammad, 2009). O&M works of fire equipment are tracked with an RFID system. Besides, they have easily located in the model with RFID tags. Kim et al. (2018) used the common data file format, IFC, to follow the work orders by relating O&M works with the building equipment. They have exported the BIM data from the IFC file with their algorithm and link them with FM activities. Another study aimed to sort work orders in optimum order for an effective O&M process (Chen et al., 2018). The work orders are related to building components with their emergency and process duration data. After, the system used the components location data to arrange the order of the work orders. Davtalab (2017) tried to establish the profit of the BIM usage at O&M activities compared with traditional methods. He used the BIM-FM platform EcoDomus for the O&M works. Same maintenance works are simulated by using both the traditional method and the BIM approach. The study shows that using the EcoDomus platform, which is in accordance with BIM, saves nearly 80% of the time when compared with the traditional method. In a health facility, Lucas et al. (2013) aimed to develop a prototype that includes several O&M scenarios to help the technicians solve the problem. Occupants use the system to send the problems they have encountered to the FM team by linking the related building component. The problems are solved and tracked by technicians with the help of previously saved scenarios and the BIM model.

There are also studies aside from operation and maintenance purposes. For instance, Ploennigs et al. (2011) aimed to show sensor data on the BIM model. The temperature sensors inside the rooms send the real-time data to the BIM model. The colors of the rooms inside the model are changed according to their temperature interval and it is easily established if any of the rooms is out of the determined temperature interval. Some of the studies are focused on simulating emergency and disaster situations to analyze. In Germany, a model of a fire training house was created and send to a game engine to simulate several fire disaster situations (Rüppel and Schatz, 2011). By using virtual reality technology, firemen are trained inside the 3D model. Another study aimed to see the possible effects of a flood disaster by integrating geographic information system (GIS) and BIM (Amirebrahimi et al., 2015). Building data coming from BIM is combined with flood data coming from GIS and it is determined that which buildings will be affected in which level by simulating the flood. Bruno et al. (2018) defined the methodology of BIM usage for the sustainability of a historical building. The defined methodology explains the processes starting from collecting the data of historical building to the renovation of the building.

Pilot Studies

In this section, two methods of BIM-FM integration are investigated. These methods are: (1) using a BIM authoring tool, and (2) using BIM-FM platform. They were not used to compare their capabilities for the same purposes but used to show their capabilities for different purposes. In the first method, capabilities of BIM authoring tools (i.e. Autodesk Revit, Navisworks, Dynamo) were used for some FM related purposes (e.g. using parameters and colors to filter). In the second method, the BIM-FM platform (i.e. EcoDomus) was used for some FM activities such as the creation of work-orders and inspection forms.

A university office, which is located at the Istanbul Technical University, was selected for the pilot studies. It is an office to support the start-ups inside ARI-3 building which includes Research & Development (R&D) departments of technology companies. Figure 1 shows both real-world and model appearance of the ARI-3 building and İTÜ Çekirdek office. Autodesk Revit 2019 was used to model the office. While modeling, as-built construction drawings, photos, and on-site measurements were used as reference data. There were 897 elements in the model and 31 rooms and spaces were defined. Since the model will be used for FM purposes, mostly architectural details were included. Only the visible mechanical elements were modeled, such as air diffuser and lighting, and the mechanical systems were not included.

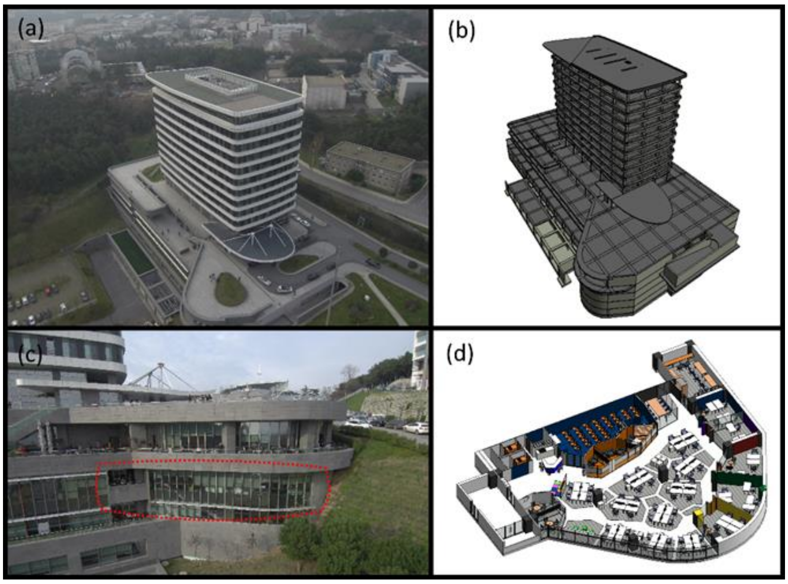

Figure 1: Real-world (a-c) and model (b-d) appearance of ARI-3 building and Çekirdek office.

Using BIM Authoring Tool

BIM authoring tools can be used for basic FM purposes. Revit has the capability of filtering elements according to defined rules and giving them visual differences such as color and transparency. Also, defining parameters to the building elements would be effective to follow the FM information. These parameters can be enriched by using software platforms for computational design and BIM (i.e. Dynamo). Since it is a 3D model, renovations can be simulated on the model to support the decision-making. In addition, add-ins can be used for several FM purposes such as exporting the model to a gaming engine to walk inside the model.

The aim of this part of the study is to show what could be performed by using the BIM authoring tool (i.e. Revit) for FM purposes. It was tested in five categories: (1) Assigning parameters to the elements, (2) filtering elements, (3) using software platforms for BIM (i.e. Dynamo), (4) renovation simulation, and (5) using add-ins.

Firstly, parameters were assigned to building elements to create work orders. Most of the FM related information can be stored inside the model as values of parameters. Then, building elements were filtered according to the parameters for understanding the differences (Figure 2). Highlighting the desired elements on the 3D model can be helpful to understand the situation of the specific area easily. For instance, all the chairs inside the open office zones and office rooms were planned to be changed. An instance parameter, named “Changed?”, was defined and its value type was selected as boolean to represent “Yes” or “No” options. Since it is an instance parameter, it defines each element individually. Some of the chairs entered as “Yes” and others remained as “No”. To visualize the situation of chair renewal activity, rule-based filters were created to represent the changed chairs with green and the others in red. These filters were applied from the “Visibility/Graphics” options (Figure 2).

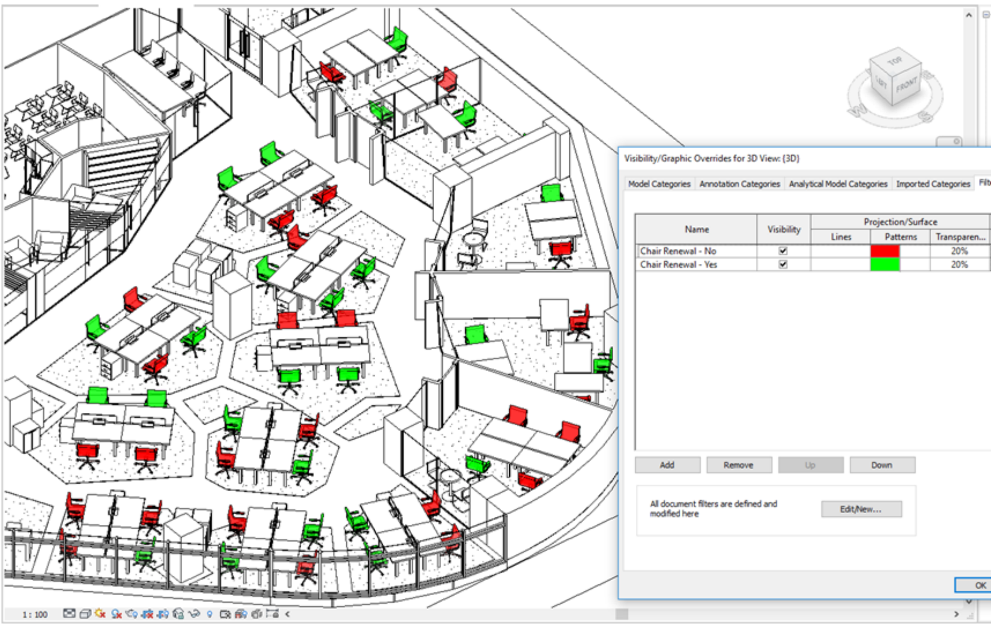

Figure 2: Visualization of chair renewal by filtering.

In the third method, a software platform for Revit (i.e. Dynamo) was used to transfer the live data from the database to parameters of building elements in Revit. Some of the commands can be performed in less time and effort with the support of using such software platforms. For example, temperature data collected by the sensors installed at the rooms and zones can be automatically uploaded in the model. In the first step, the “Temperature” parameter was assigned to rooms and zones as an instance parameter. Then, the rule-based filters were created for the temperature intervals: (1) If the temperature is less than 22, rooms or zones will be blue, (2) if it is between 22 and 25, they will be green, and (3) if it is higher than 25, they will be red. Dynamo was used to write a script for uploading temperature data inside the BIM model (Figure 3).

The fourth method showed how Revit can be used to design simulations by rendering the image. Since visualization is one of the advantages of BIM models, they are very useful for decision making of design issues. For example, an office room was designed with different paint colors and different combinations of furniture. It allows the decision-maker to see the possible design alternatives in the model. Captured screens can also be rendered for a realistic view.

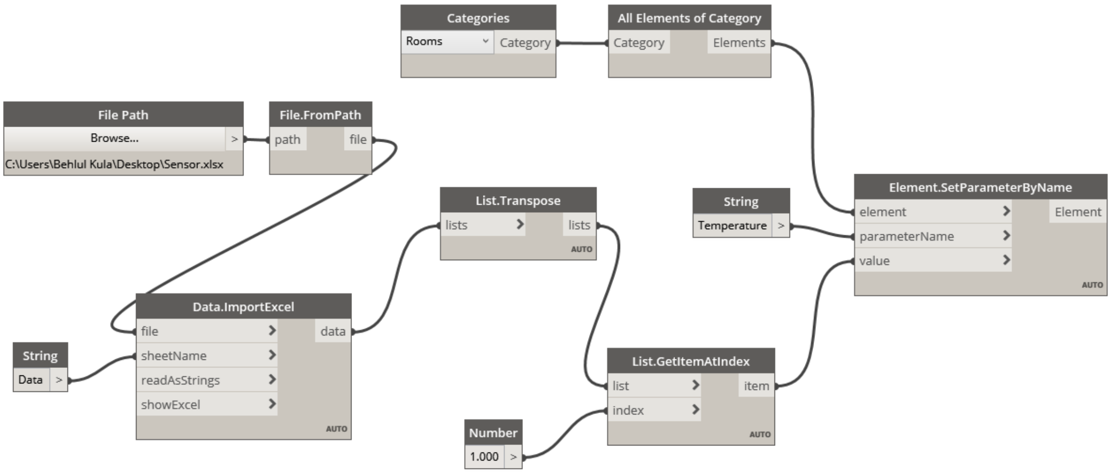

Figure 3: Dynamo script for uploading temperature data.

Lastly, an add-in was used to export the model to a gaming engine (i.e. Unity) for using it in a virtual reality environment. There are various add-ins developed for BIM authoring tools to perform the export. For example, the "Walk-Through-3D" add-in for Revit can export the BIM model as a first-person view game by using the Unity gaming engine (Figure 4). When the model is exported to a gaming engine, it can be used for multiple purposes. Models can be used for understanding the building or for training the new workers by allowing them to walk inside the model. It can also be integrated with virtual reality devices.

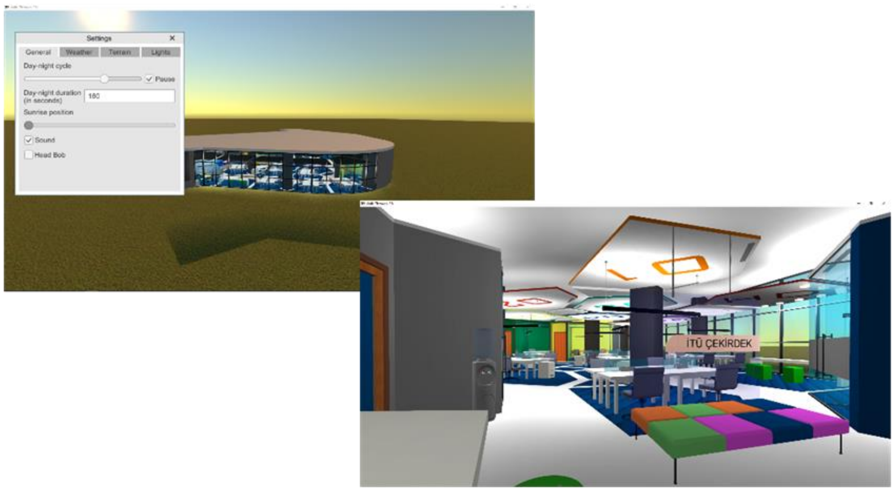

Figure 4: Revit model at Unity gaming engine.

The BIM authoring tools have the capability of performing most of the basic FM issues. However, the size of the project and the size of the data would affect the process negatively. Besides, since BIM authoring tools are designed mostly for model creation, they are complex software packages and have complex interfaces. The one who will use a BIM authoring tool in the FM phase should have background and experience with that tool. Finally, BIM authoring tools can be used for basic FM purposes for a short time, however, professional software packages for the integration of BIM and FM should be used in a continuous FM phase.

Using BIM-FM platform

In this section, the ITU Çekirdek model was uploaded to a BIM-FM platform (i.e. EcoDomus) to understand the capabilities of this platform for FM purposes. EcoDomus software is a platform that provides a common data environment, which can be integrated with a 3D BIM model of the buildings for the operational phase. For integration, the BIM model of the structure is uploaded to the platform and building elements inside the model are saved into the database with its parameters. A user account was created on the EcoDomus platform.

EcoDomus platform has a viewer that allows the user to walk around the 3D model and select a building element (Figure 5). Users can combine both 2D and 3D views to understand the exact location inside the model. On the 2D plan, a location can be selected and the system automatically will open the 3D view on that location. By selecting a space or zone of the model from the list, the desired area can be easily isolated inside the model (Figure 6). When a building element is selected, the properties of that element will be listed. Properties of the building element can be changed or new information can be added to the element. Documents such as photos and Pdf files can be uploaded to the system and linked with the building elements. Besides, a work-order can be created for a specific element. For inspections, forms can be created and tracked.

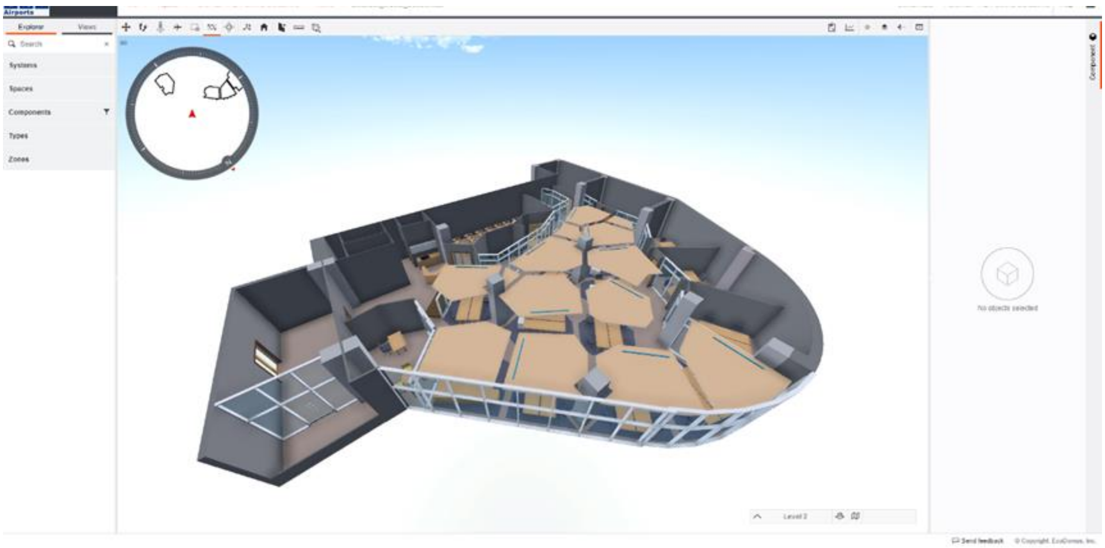

Figure 5: EcoDomus platform.

The BIM-FM platforms have many modules that allow the users to perform their FM activities according to their purposes. It also combines the BIM model by linking building elements with related activities. The visualization of the BIM model can also be used inside the platform with the help of model viewer mode. Usually, BIM-FM platforms are customized based on the requirements of the project. If there is a functionality that is needed is not included in the modules of the BIM-FM platform, it can be added by communicating with the BIM-FM platform vendor. Since they are mostly customizable, project needs should be well defined and necessary modules should be activated by considering the scope and budget of the project.

To conclude, two different methods were used for different FM purposes. It has been observed that BIM authoring tools could provide a quick and easy way to perform some basic FM activities. However, it is only effective when the project size is small and it is used for a specific part of the project. A better way to integrate the BIM in FM phase is using BIM-FM platform which is specifically developed for this purpose. The important point is that project needs should be well defined to select the suitable software platform.

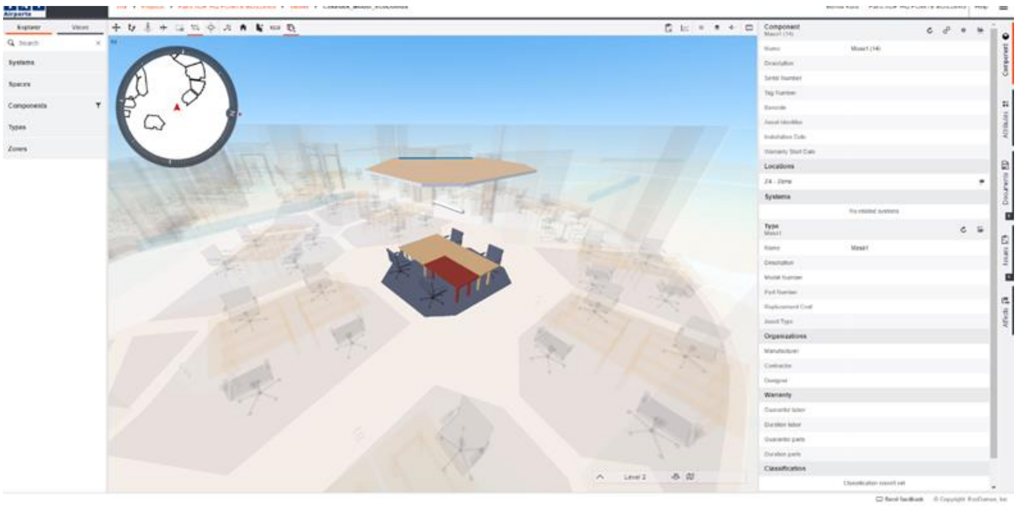

Figure 6: EcoDomus platform.

Conclusion

The aim of this study was to illustrate how a project can be integrated with BIM in the facilities management phase with advantages and disadvantages. To achieve this aim, two pilot studies were conducted at a small size university building for BIM-FM integration by utilizing two main methods: (1) using the BIM authoring tool, and (2) using the BIM-FM platform. Each method was evaluated and the advantages and disadvantages were identified for each method.

The results highlight that BIM authoring tools have the capability of performing most of the basic FM issues. However, BIM authoring tools will not be enough in terms of software capabilities when the project is large-scale. A BIM-FM platform is needed when the size of the project and the size of the data is large. The BIM-FM platform has many modules that allow the users to perform their FM activities according to their purposes. BIM authoring tools can be used for basic FM purposes for a short time; however, professional software packages for the integration of BIM and FM should be used in a continuous FM phase. The findings of the study can be used by academicians that would like to work on BIM-FM integration and by the practitioners that would like to implement BIM-FM integration.

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A Methodology to Facilitate PPP Project Selection Decisions

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Abstract

Public private partnerships(PPPs) have been extensively used to provide public services especially in developing countries. Investment companies evaluate attractiveness of alternative PPP project options considering various factors affecting their risk-return structures. Compared to traditional construction projects, selection of PPP project is more complicated as it involves not only design and construction stages but also the operation stage. As the selection process is performed with respect to several criteria, it is always challenging for decision makers to select the best alternative. This paper offers a methodological approach that assists the decision makers to select the best PPP project among possible alternatives. The selection criteria were determined as a result of an extensive literature review and a workshop conducted to understand decision-makers' priorities. Then, a network structure was developed to simulate factors affecting project selection decisions. A case study, in collaboration with an investment company was conducted to demonstrate utilization of analytic hierarchical process (AHP) to compare the attractiveness of three potential PPP project alternatives. Finally, benefits of this approach were determined as well as its shortcomings.

Keywords: *AHP, PPP, project selection*

Introduction

Public-private partnership (PPP) is long term agreement between public and private entity for the purpose of delivering public infrastructure or services, especially in the energy, transport, health or education sectors (Neto et al., 2016). Developing countries especially use this procurement model for meeting the growing demand for new public services (Nguyen et al., 2018). For instance, Turkey as a developing country, applied this model more than $139 billion worth of PPP projects in different sectors (Presidency of The Republic of Turkey, 2019). There are several PPP based investment opportunities for the investors, however, it is difficult task to select the most suitable investment as it involves more complex structure compared to traditional project selection. This research offers a methodological approach that assists the decision makers to select the best PPP project among possible alternatives.

Literature Review

Project selection have been widely discussed in the literature over the past decades. As the project selection is Multi-Criteria Decision-Making problem, the first and important step in the project selection is to determine the critical success factors or key performance indicators for associated project. Several researchers identified critical success factors and key performance indicators for different types of PPP projects. Amovic et al. (2020) investigated critical success factors for sustainable PPP projects in Bosnia and Herzegovina. Chan et al. (2010) identified critical success factors for PPP projects in China. Ishawu et al. (2020) examined the success factors for PPP-based waste management projects in Ghana. Chileshe et al. (2020) conducted a survey questionnaire with 27 Kenyan stakeholders to identify critical success factors for PPP housing projects in Kenya. Ramli et al. (2019) prepared a CSF list for PPP toll expressway in Malaysia by means an extensive literature review. Kavishe and Chileshe (2019) identified critical success factors in PPP housing projects in Tanzania. Zhao et al. (2013) clarified critical success factors for PPP thermal power plant projects in China. Marzouk and Elhesnawi (2019) presented key performance indicators in PPP infrastructure projects in Libya. Hashim et al. (2017) highlighted performance indicators for PPP projects in Malaysia. Villalba-Romero and Liyanage (2016) clarified performance measurement for PPP road projects in Europe.

The next step for the project selection is to rank projects by using one of the multi criteria decision approach. Several researchers performed project selection with the help of different multi-criteria decision approaches. Osei-Kyei and Chan (2019) developed a pragmatic model by creating project selection index, this model assisted decision makers by comparing the viability of the PPP projects. Wibowo and Kochendoerfer (2011) proposed a methodology to select most suitable PPP project by using the chance-constraint goal-programming technique. Fallahpour et al. (2020) developed a fuzzy decision support system for sustainable construction project selection. In this research, they used Fuzzy Analytical Hierarchy Process as a multi-criteria decision making (MDCM) approach. Abdel-Basset et al. (2019) used hybrid neutrosophic multiple criteria group decision making approach for proper project selection. Han et al. (2019) used hybrid approach (fuzzy AHP and TOPSIS) to rank different type of projects. Taylan et al. (2014) proposed hybrid methodology to evaluate the construction projects. In this research, an AHP based approach for PPP project selection has been developed to assist decision makers to select the best PPP project among alternatives.

Research Method

The research procedure includes three main steps:

- Identifying criteria to select the best PPP project
- Developing an AHP based approach
- Testing the approach through a case study

Identifying Criteria to Select the Best PPP Project

This procedure involves two stages. In the first stage, literature studies associated with critical success factors and key performance indicators were conducted to create a potential criteria list to select the best PPP Project among possible alternatives. In this stage, 16 potential selection criteria were identified. The next stage is finalizing the potential criteria list by administering a questionnaire survey. The questionnaire which was created using potential criteria list, was carried out with 10 experts from 4 different investment companies. It should be noted each expert has experience in PPP projects more than ten years. The questionnaire requested experts to finalize the potential criteria list. Table 1 depicts the selection criteria for PPP projects.

Table 1. Selection Criteria for PPP projects

Selection Criteria
Complexity of the project
Credit rating of the country
Scope of the project
Political stability
Political support
Laws and regulations
Experience in different types of PPP project in this country
Economic feasibility of the project
Experience in similar type of PPP projects in other countries
Experience in similar type of PPP projects in this country

Developing an AHP Based Approach

AHP which was proposed by Saaty in 1976, is one of the powerful multi criteria decision-making method that develops priorities for criteria to compare the alternatives. In this method, first step is to construct the hierarchical structure of the problem. For this purpose, the selection criteria for PPP projects were clustered, and the hierarchical structure was constructed as presented in Figure 1. After that, pairwise comparisons need to be performed for the same level elements with respect to control criteria to construct the comparison matrices. These comparisons were performed by using the fundamental scale proposed by Saaty (2000). At this stage, a workshop was conducted with 10 experts to understand decision makers' priorities, and as a result, fill up the comparison matrices. The consistency ratio of each matrix can be used whether the pairwise comparisons are consistent or not.

Comparison matrices and subordinate weights for selection criteria are presented in Table 2. In these matrices; C denotes "Country Related Criteria", P denotes "Project Related Criteria", CM denotes "Company Related Criteria", C1 denotes "Credit rating of the country", C2 denotes "Laws and regulations", C3 denotes "Political Stability", C4 denotes "Political Support", P1 denotes "Complexity of the project", P2 denotes "Economical Feasibility of the project", P3 denotes "Scope of the project", CM1 denotes "Experience in different types of PPP project in this country", CM2 denotes "Experience in similar type of PPP projects in other countries", CM3 denotes "Experience in similar type of PPP projects in this country".

A weighting process is used to obtain overall weight for each alternative. Figure 1 provides the overall priority of each selection criteria for PPP projects. The proposed approach finds the attractiveness of each PPP project by identifying the total rating of the project. To find the total rating of the project, a decision maker should multiply the overall weight of the criteria with its rating for each selection criteria, and add them up. It is worth noting that rating of each selection criteria should be determined by an expert team from an investment company.
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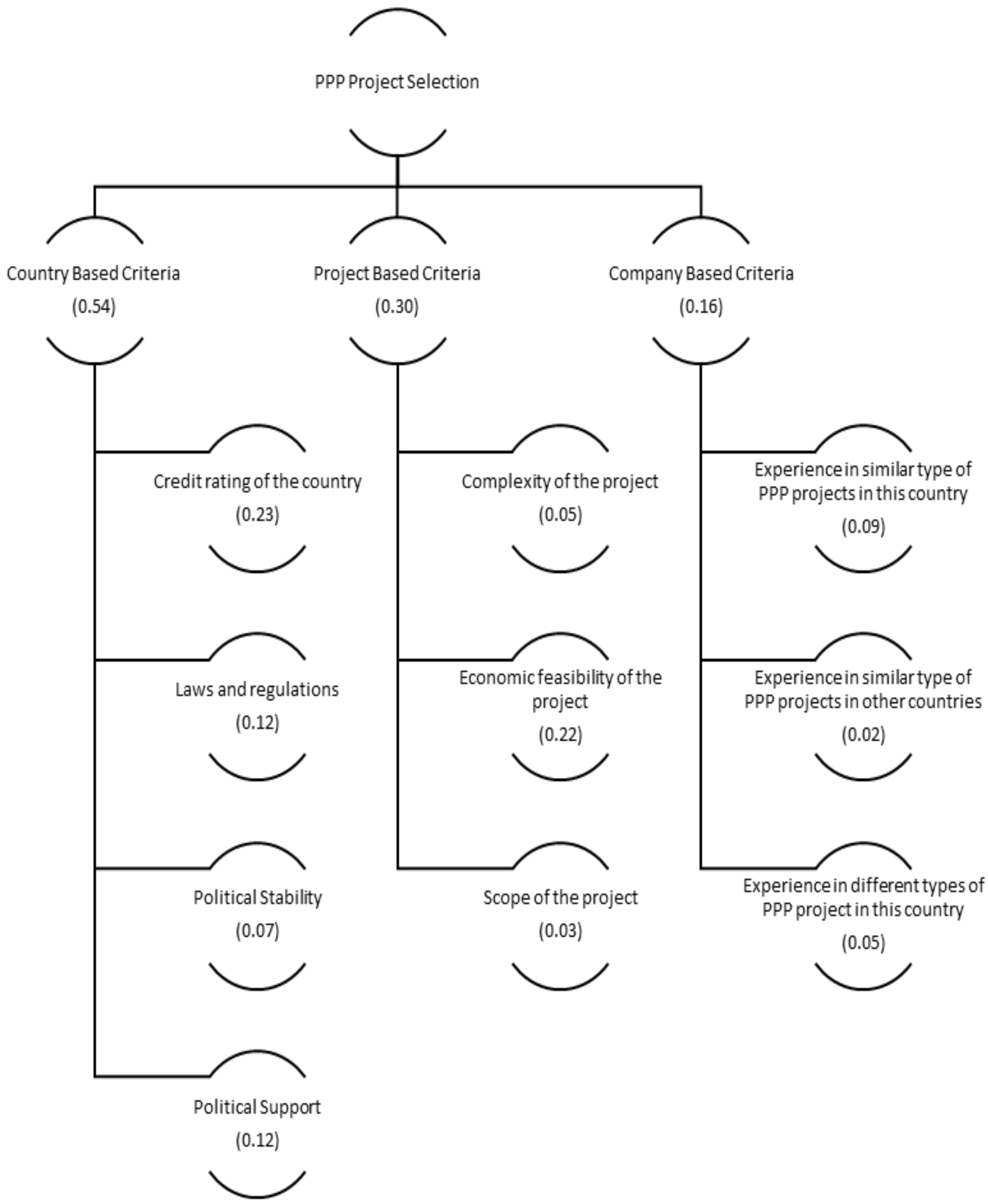

Figure 1: Network Structure of the Model

Comparison matrices and subordinate weights for selection criteria are presented in Table 2. In these matrices; C denotes “Country Related Criteria”, P denotes “Project Related Criteria”, CM denotes “Company Related Criteria”, C1 denotes “Credit rating of the country”, C2 denotes “Laws and regulations”, C3 denotes “Political Stability”, C4 denotes “Political Support”, P1 denotes “Complexity of the project”, P2 denotes “Economical Feasibility of the project”, P3 denotes “Scope of the project”, CM1 denotes “Experience in different types of PPP project in this country”, CM2 denotes “Experience in similar type of PPP projects in other countries”, CM3 denotes “Experience in similar type of PPP projects in this country”.

Table 2: Pairwise comparison matrices

PPP Project Selection	C	P	CM	Weights
C	1	2	3	***0.54***
P	1/2	1	2	***0.30***
CM	1/3	1/2	1	***0.16***

Inconsistency Ratio = 0.0089

C	C1	C2	C3	C4	Weights
C1	1	4	6	4	***0.42***
C2	1/4	1	2	1	***0.23***
C3	1/6	1/2	1	1/2	***0.12***
C4	1/4	1	2	1	***0.23***

Inconsistency Ratio = 0.0039

P	P1	P2	P3	Weights
P1	1	1/5	2	***0.18***
P2	5	1	6	***0.72***
P3	1/2	1/6	1	***0.10***

Inconsistency Ratio = 0.028

CM	CM1	CM2	CM3	Weights
CM1	1	2	1/2	***0.29***
CM2	1/2	1	1/4	***0.14***
CM3	2	4	1	***0.57***

Inconsistency Ratio = 0

A weighting process is used to obtain overall weight for each alternative. Figure 1 provides the overall priority of each selection criteria for PPP projects. The proposed approach finds the attractiveness of each PPP project by identifying the total rating of the project. To find the total rating of the project, a decision maker should multiply the overall weight of the criteria with its rating for each selection criteria, and add them up. It is worth noting that rating of each selection criteria should be determined by an expert team from an investment company.

Testing the Approach Through a Case Study

In order to test the proposed approach, three real PPP project alternatives were chosen from different countries. First project is healthcare project located in one of the European Union country, second one is transport project located in one of the Middle Eastern country, and last one is energy project located in one of the African country. All projects will be undertaken by using PPP.

An expert team from an investment company rated each selection criteria for different PPP project alternatives by using their experiences. Total ratings of projects were calculated, and is depicted in Table 3. According to the results, the most attractive project was chosen as transport project located in one of the Middle Eastern country. The expert team mentioned that the results are reasonable.

Table 3. Total Ratings for Case Study

Criteria		Project 1		Project 2		Project 3	
Country Related Criteria	Overall Weight	Ratings	Total Ratings	Ratings	Total Ratings	Ratings	Total Ratings
Credit rating of the country	0.23	8	1.84	9	2.07	5	1.15
Laws and regulations	0.12	9	1.08	7	0.84	2	0.24
Political Stability	0.07	8	0.56	7	0.49	4	0.28
Political Support	0.12	4	0.48	8	0.96	6	0.72
Project Related Criteria							0.0
Complexity of the project	0.05	8	0.4	6	0.3	4	0.2
Economic Feasibility of the project	0.22	6	1.32	7	1.54	8	1.76
Scope of the project	0.03	7	0.21	7	0.21	8	0.24
Company Related Criteria							0.0
Experience with different types of PPP project in this country	0.05	8	0.4	5	0.25	5	0.25
Experience with similar type of PPP projects in other countries	0.02	1	0.02	5	0.1	8	0.16
Experience with similar type of PPP projects in this country	0.09	1	0.09	1	0.09	1	0.09
Sum			6.4		6.85		5.09

Conclusion

In this paper, an approach was constructed to assist decision makers while selecting most suitable PPP project. For this purpose, the selection criteria for PPP projects were determined by means an extensive literature review and a questionnaire survey. AHP was applied to identify the priority of each selection factor. According to this weighting process, the most important selection factor was found as credit rating of the country. The proposed approach was tested for three different PPP projects. The results were found as reasonable. The major shortcoming of the framework is subjective judgment, as the rating of each selection factor is determined by an expert team. Future studies can be focus on decreasing the subjectivity of the proposed approach.

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A Comparative Life Cycle Assessment of Asphalt and Rigid Pavements

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Abstract

It is an indisputable fact that the environmental impacts of road construction are very important, given the hundreds of kilometers of roads paved with asphalt or portland cement concrete (PCC). However, the environmental burdens of asphalt and PCC pavements have not been determined precisely. Nowadays, significant scientific surveys are being conducted, which recognizes the importance of the environmental impacts of road pavements. In this context, the aim of this study is to evaluate the environmental impacts of asphalt and PCC pavements in terms of global warming, ozone depletion, acidification, photochemical oxide creation, and eutrophication. Within the framework of this aim, a hypothetical case study using the life cycle assessment methodology was conducted in this study. The life cycles of asphalt and PCC pavements were comparatively assessed limited with the material production phase, and it was determined which alternative has fewer environmental impacts during this phase. It was found that the asphalt pavement has considerably fewer environmental impacts than PCC pavements.

Keywords: *asphalt, life cycle assessment methodology, material production phase, portland cement concrete (pcc), road pavement.*

Introduction

According to Turkish Directorate of Highways, Turkey's highways are composed 37.72% of asphalt concrete (AC) pavements, in other words, flexible pavements (FPs), 56.89% of chip seal and 5.38% of other surface types (Karayolları Genel Müdürlüğü, 2020). FPs are widely used in Turkey. On the other hand, there are not rigid pavements (RPs), namely, portland cement concrete (PCC) pavements, apart from a few kilometers test sections. Since Turkey is a developing county, authorities attach importance to construct many new roads and to improve current roads (Karayolları Genel Müdürlüğü, 2019). Construction and maintenance of these roads are one of the main reasons of environmental pollutants including greenhouse gas (GHG) in the construction industry. That is why it is crucial to find out the environmental impacts of various pavement types and consider such impacts while planning a new pavement construction or improvement.

In most recent studies, life cycle assessment (LCA) of pavements have been carried out in three different ways: (1) economic input-output LCA (EIO-LCA); (2) process-based LCA; and (3) hybrid LCA which is a method containing both option (1) and (2) (Inyim et al., 2016).

Horvath and Hendrickson (1998) performed EIO-LCA to compare the 1-km section of FP and continuously reinforced concrete pavement (CRCP), and according to their findings, FPs were looking more environment-friendly than CRCP. Kucukvar and Tatari (2012) have compared CRCP and hot-mix asphalt (HMA) pavements with hybrid LCA, and they suggest that HMA pavements are more sustainable in terms of energy usage. In contrast to these studies, Yu and Lu (2012) suggest that PCC pavement could lead to less environmental burdens than asphalt pavement according to performed LCA as a case study. In addition, Embacher and Snyder (2001) suggest that RPs are more cost-effective than FPs according to their case study implemented with life cycle cost assessment (LCCA).

Much of the current literature on LCA of pavements pays particular attention to reduce environmental burdens, and much of these burdens are related to material production. For example, a previous study demonstrated that cement and reinforcement steel production constitute 94% of energy consumption for the CRCP in the material production phase (Zapata & Gambatese, 2005). In the same study, it was demonstrated that asphalt mixing, drying aggregates, and production of bitumen constitute 88% of energy consumption in the asphalt pavement. That is why, in order to reduce environmental burdens, many approaches have studied based on materials type and mixing methods such as; reclaimed asphalt pavement (RAP), warm mix asphalt (WMA), fly ash (FA) and recycled concrete aggregate (RCA).

Aurangzeb et al. (2014) have performed a hybrid life cycle assessment on asphalt pavement modified with RAP, and they have found that using 40% RAP in HMA can decrease energy consumption and GHG up to 28%. Giani et al. (2015) have suggested a combined pavement design that consists of using RAP and WMA, and this option decreased the environmental impacts up to 12% compared to the conventional design with virgin asphalt. In another study about WMA, by performing LCA, Mazumder et al. (2016) have found WMA can reduce global warming potential (GWP) in the ratio of 26% and acidification (AP) in the ratio of 29% compared to HMA. Another study by Ma et al. (2019) also suggests that WMA is more environment-friendly than HMA. Zapata and Gambatese (2005) state that replacement of cement to FA could provide a significant decrease in energy consumption. Shi et al. (2019) suggest that according to their EIO-LCA study, using RCA in the RP is a more environment-friendly option compared to conventional RP.

A previous report by Harvey et al. (2016) suggests that the pavement life cycle consists of six phases: material production, pavement design, construction, use phase, maintenance, and end-of-life (EOL). Material production contains both raw material acquisition and manufacturing HMA and ready-mix concrete. Pavement design is a decision-making phase, such as; determining the structural and functional needs of the pavement and deciding the composition of the pavement structure. Many studies dealing with these phases have been done. For example, Xu et al. (2019) argue that according to their LCA study, the use phase can contribute up to 78% to environmental impacts of the life cycle of the pavement. Zapata and Gambatese (2005) neglecting the use phase, maintenance phase, and EOL phase have argued that the construction phase has a minor share of total energy consumption. To be more precise, the material production phase is very important, together with the use phase and maintenance phase.

In this study, the aim is to compare RP and FP in terms of environmental impacts for the material production phase. To achieve this, one road section for each RP and FP were designed in the same conditions (e.g., soil, climate, traffic, etc.). Then, the life cycle inventory was generated for these pavements. For the FP, usage of RAP and for the RP, usage of FA was also taken into account. In order to determine the environmental burdens of the products used in pavements (e.g., HMA, ready-mix PCC, aggregate for base layers, dowels, and tie bars), the published environmental product declarations (EPDs) were utilized. Life cycle impacts (LCI) were determined based on a certain impact assessment method. Within the limits of this study, only the material production phase (i.e., raw material acquisition and manufacturing the construction products) were studied.

Methodology

Functional Unit

The functional unit was selected as the construction of 1 km pavement. The width of the road was 7.2 m (traffic lanes 2×3.6 m). The analysis period was 20 years, and it is assumed that no maintenance was carried out during the service life.

Description of the Road Section

A hypothetical road section was determined, and its characteristics were listed in Table 1. Two types of pavement were studied: FPs and RPs. These pavements were designed for the same road section; in other words, they are equal in terms of soil support and traffic loads.

Table 1. Design characteristics of the hypothetical road section.

Parameter	**Value**	**Parameter**	**Value**
ESALs (80-kN equivalent single-axle loads) for 1 year	750,000	Load Transfer Coefficient	2.8
Traffic Grow Rate	3%	Composite modulus of subgrade reaction, k	190 pci
Total ESALs	20 million	Roadbed modulus, M_R	10,000 psi
Analysis period	20 years	Subbase modulus, E_{SB}	15,000 psi
Initial serviceability index	4.7	Base elastic modulus E_{BS}	30,000 psi
Terminal serviceability index	2.5	Concrete modulus of rupture	650 psi
Drainage coefficient of rigid and FP	1	Concrete elastic modulus	4,200,000 psi
Overall standard deviation	0.39	Concrete compressive strength	5,430 psi
Reliability	%90	Road type	Typical two-lane
Standard normal deviate	-1.282	Pavement width	7.2 m

The design of the pavements was made according to the AASHTO-1993 design manual. For the FP, it is assumed the highway section was comprised of subbase, base, and asphalt concrete layers. For the RP, on the other hand, the concrete slab was located on a subbase layer. The layer thicknesses were shown in Fig. 1.

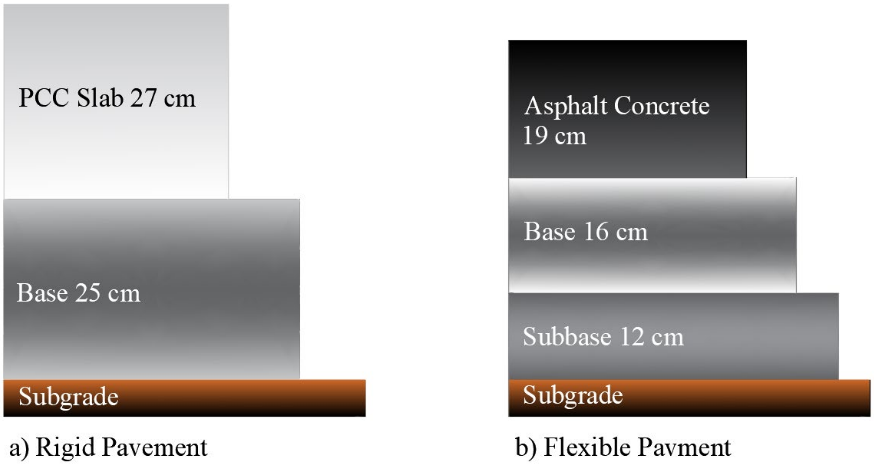

Figure 1: Designed pavement sections.

In this study, it was employed process based LCA, and the system boundaries have shown in Fig. 2. In the study, only road materials were considered. Construction, usage, maintenance, and EOL phases were not taken into account.

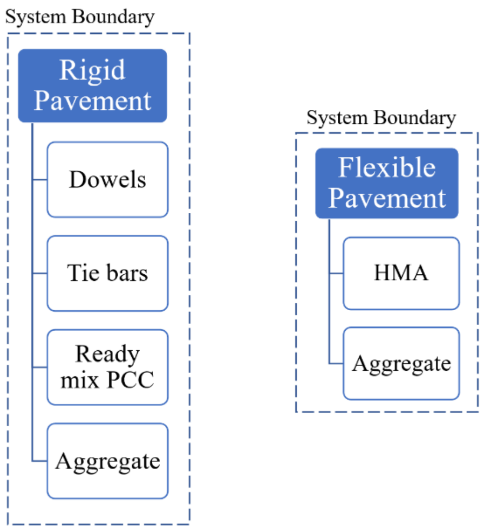

Figure 2: Life cycle system boundary.

Inventory Analysis

Quantities of the materials were calculated according to designed pavements. In order to generate inventory data, the EPD values of some companies were used. These EPDs were prepared by the environmental corporations using the cradle-to-gate approach. The list of the used EPDs are provided in Table 2. The system boundaries of these EPDs are shown in Fig. 3.

Table 2. List of the EPDs used in the life cycle inventory.

Product	**Declaration Owner**	**Declaration Number**	**Declared Product**
Ready-mix PCC	National Ready-Mix Concrete Association	EPD10294	5001-6000-00-FA/SL
Ready-mix PCC containing FA			5001-6000-40-FA
HMA	George Reed, Inc. Greg Reader	19.55.52 v10	2018-TM-004D-VSS-64-10-R0
HMA containing RAP		19.55.53 v4	2018-TM-004D-VSS-64-10-R25
Aggregate for base courses	Holcim Romania	S-P-00528	Aggregates
Dowels	Outokumpu Oyj	EPD-OTO-20190107-IBD1-EN	Structural steels
Tie bars	ArcelorMittal Europe-Long Products	EPD-ARM-20160051-IBD3-EN	Reinforcing Steel

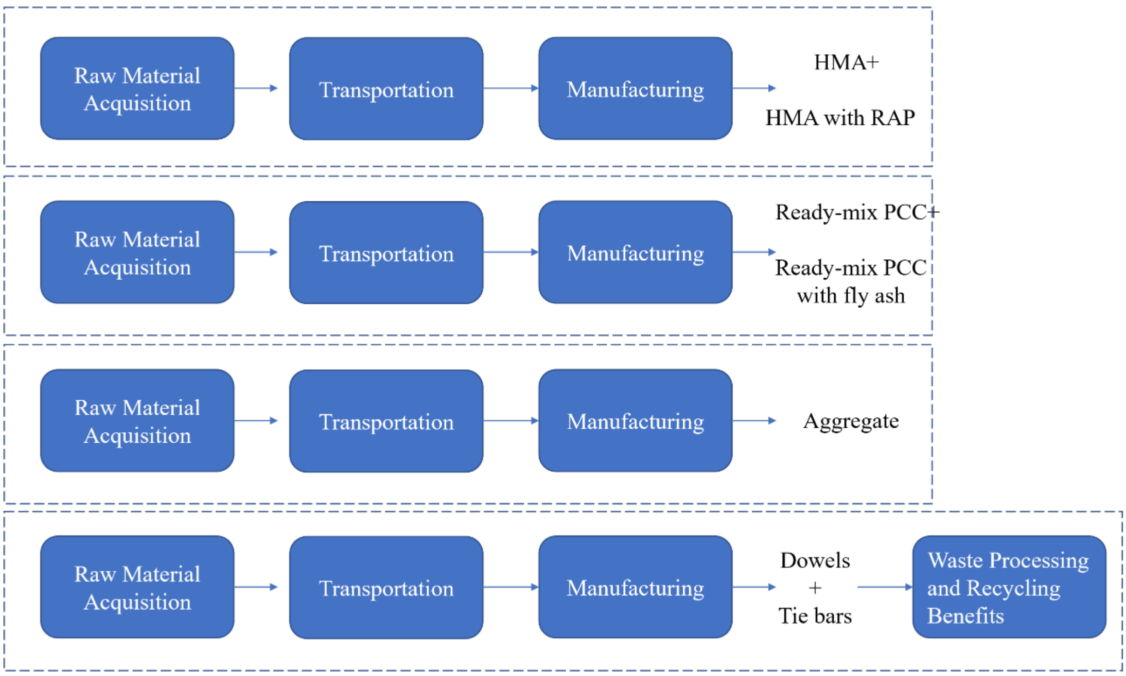

Figure 3: System boundaries of used EPDs.

Rigid Pavement (RP)

The RP comprises of concrete slab, subbase layer, dowels, and tie bars. Quantities of these components are shown in Table 3, Table 4, and Table 5. The placement plan of the dowels and the tie bars are shown in Fig. 4. Two type of PCC were studied: ready-mix PCC and ready-mix PCC containing FA at a ratio of 30% to 40%. EPDs of these mixtures are utilized to create inventory data of the concrete slab. Since the subbase layer is constructed with aggregate, an

EPD of aggregate production was used for the subbase layer. Finally, EPDs were used in order to generate inventory data of dowels and tie bars. The created life cycle system of the RP is shown in Fig. 2.

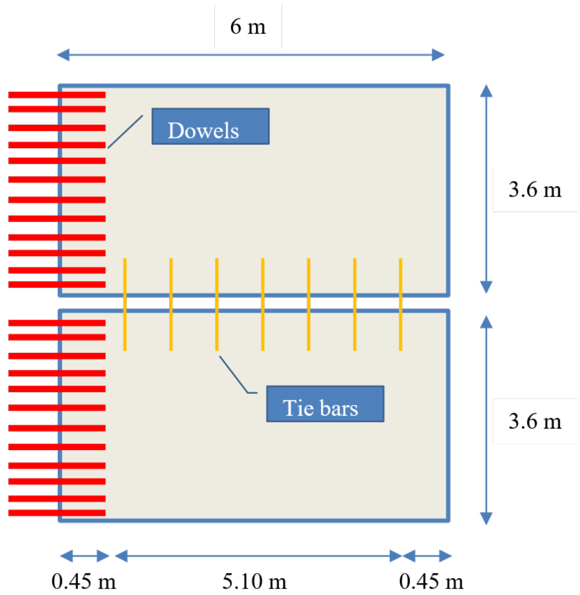

Figure 4: The RP's section plan.

Flexible Pavement (FP)

FP comprises of AC, base, and subbase layer. Quantities of these components were shown in Table 6. Two types of asphalt mix were studied for the asphalt concrete layer: HMA and HMA containing RAP at the ratio of 25%. EPDs of these mixtures were used in order to generate inventory data. For the base and subbase layer, on the other hand, EPD values of aggregate production were used. The created life cycle system of the FP was shown in Fig. 2.

Table 3. Life cycle inventory of the layers of RP.

Layer name	**Thickness (m)**	**Volume (m^3)**	**Specific Gravity (t/m^3)**	**Weight (t)**
Concrete Slab	0.27	1,944	2.4	4,665.60
Subbase	0.25	1,800	2.3	4,140.00

Table 4. Life cycle inventory of the dowels.

Design Variables of Dowels	**Value**
Unit weight of the dowel, kg/m^3	7,900
Dowel diameter, in	1.5
Dowel length, in	18
Number of dowels for two slabs (Figure 4)	24
Number of dowels for 1 km	4,000.08
Weight of a dowel, kg	4.12
Weight of dowels, kg	16,471.80

Table 5. Life cycle inventory of the tie bars.

Design Variables of Tie Bars	**Value**
Tie bar size no.	No.4
Diameter, in (cm)	0.5 (1.27)
Bar Spacing, in (cm)	33.7 (85)
Bar length, in (cm)	36 (91.44)
Unit weight of tie bars kg/m^3	7,850
Number of tie bars for two slabs	7
Number of tie bar for 1 km	1,166.69
Weight of a tie bar, kg	0.93
Weight of tie bars for1 km, kg	1,080.58

Table 6. Life cycle inventory of the FP.

Layer Name	**Layer Coefficient**	**Thickness (m)**	**Volume (m^3)**	**Specific Gravity (t/m^3)**	**Weight (t)**
Asphalt Concrete	0.42	0.19	1368	2.4	3,283.20
Base	0.14	0.16	1152	2.3	2,649.60
Subbase	0.11	0.12	864	2.3	1,987.20

Assessing Life Cycle Impacts

Inventory data entry was made in OpenLCA software version 2.1.2. While evaluating environmental impacts, widely accepted CML Baseline impact assessment method was used. The following environmental impacts were evaluated in the study: Acidification (AP), global warming (GWP), eutrophication (EP), ozone depletion (ODP), and photochemical oxide creation (POCP).

Results and Discussion

In all environmental impact categories, the RP has truly higher impacts than the FP. In addition, RAP can moderately reduce all environmental impacts of the FP, while FA can significantly reduce all environmental impacts of the RP. The total environmental impacts of the 1-km FP and RP are shown in Table 7 and Table 8, respectively. Besides, Fig. 5 illustrates these impacts as bar charts.

Table 7. Environmental impacts of 1-km FPs: FP without RAP (FP-R0) and FP with 25% RAP (FP-R25).

Indicator, unit	**Pavement Type**	**Base and subbase**	**HMA**	**Sum**
AP, kg SO_2 eq	FP-R0	2.01E+02	4.54E+02	6.55E+02
EP, kg PO_4 eq		1.70E+01	5.65E+01	7.35E+01
GWP, kg CO_2 eq		1.44E+04	1.03E+05	1.17E+05
ODP, kg CFC-11 eq		2.34E-06	1.30E-05	1.53E-05
POCP, kg C_2H_4 eq		3.08E+01	7.09E+01	1.02E+02
AP, kg SO_2 eq	FP-R25	2.01E+02	3.89E+02	5.90E+02
EP, kg PO_4 eq		1.70E+01	5.33E+01	7.03E+01
GWP, kg CO_2 eq		1.44E+04	9.07E+04	1.05E+05
ODP, kg CFC-11 eq		2.34E-06	1.02E-05	1.26E-05
POCP, kg C_2H_4 eq		3.08E+01	5.97E+01	9.05E+01

Table 8. Environmental impacts of 1-km RPs: RP without fly ash (RP-FA0) and RP with 40% fly ash (RP-FA40).

Pavement Type	**Indicator, unit**	**Ready Mix PCC**	**Dowel**	**Tie bar**	**Base and subbase**	**Sum**
RP-FA0	AP, kg SO_2 eq	3.25E+03	2.45E+02	9.06E+00	1.79E+02	3.68E+03
	EP, kg PO_4 eq	5.72E+02	1.25E+01	4.48E-01	1.52E+01	6.00E+02
	GWP, kg CO_2 eq	1.07E+06	3.20E+04	1.32E+03	1.28E+04	1.12E+06
	ODP, kg CFC-11 eq	2.74E-02	6.87E-08	2.30E-08	2.09E-06	2.74E-02
	POCP, kg C_2H_4 eq	7.69E+03	9.75E+00	6.11E-01	2.75E+01	7.72E+03
RP-FA40	AP, kg SO_2 eq	2.39E+03	2.45E+02	9.06E+00	1.79E+02	2.82E+03
	EP, kg PO_4 eq	4.00E+02	1.25E+01	4.48E-01	1.52E+01	4.28E+02
	GWP, kg CO_2 eq	7.41E+05	3.20E+04	1.32E+03	1.28E+04	7.87E+05
	ODP, kg CFC-11 eq	1.91E-02	6.87E-08	2.30E-08	2.09E-06	1.91E-02
	POCP, kg C_2H_4 eq	5.71E+03	9.75E+00	6.11E-01	2.75E+01	5.74E+03

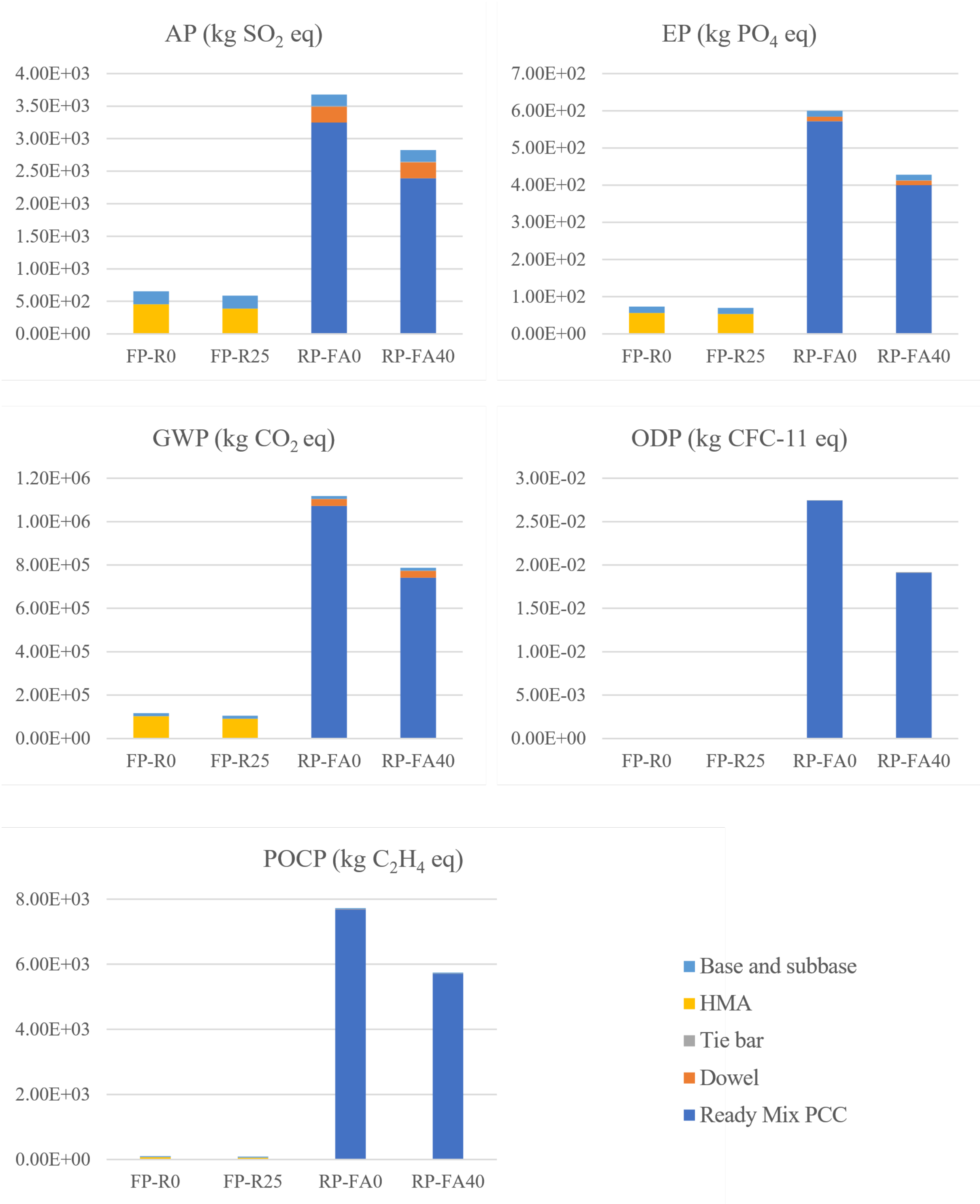

Figure 5: Environmental impacts of the pavements.

Acidification

AP of FP-R0 is 76.81% less than RP-FA0's. It is demonstrated that FA can reduce AP of RP 23.24%, and RAP can reduce the AP of FP by 9.98%.

In the RP, the production of ready-mix PCC dominates the AP. The production of dowels and base materials contributes slightly to AP. On the other hand, the production of tie bars accounts for a negligible proportion of AP. When it comes to the FP, the production of HMA constitutes virtually one-third of the total AP.

Eutrophication

EP of FP-R0 is 82.83% less than RP-FA0's. It is demonstrated that FA can reduce EP of the RP by 28.59%, and RAP can reduce EP of FP by 4.33%.

In the RP, the production of ready-mix PCC dominates EP. The production of dowels and base materials contributes gently to AP. On the other hand, the production of tie bars has minuscule effect on EP. In the FP, the production of HMA makes up roughly one-fourth of the total AP.

Global Warming

GWP of FP-R0 is 85.09% less than RP-FA0. Besides, it is demonstrated that FA can reduce GWP of the RP at 29.61%, and RAP can reduce GWP of FP at 10.42%.

In the RP, the production of ready-mix PCC dominates GWP. In contrary, the production of dowels and base materials constitutes a little fraction of GWP. The production of tie bars makes up a minor percentage of GWP. In the FP, the production of HMA accounts for approximately one-seventh of the total GWP.

Production of materials of 1-km FP leads to 117 tons CO_2 eq of GHG emissions. If RAP is used in HMA, it can be reduced by 12 tons CO_2 eq for 1-km FP. According to the calculator tool of the Environmental Protection Agency (EPA), a reduction of 12 tons CO_2 eq GHG equals to 180 tree seedlings grown for ten years (EPA, 2020). Considering thousands of kilometers of road construction, using RAP could make lots of contributions to reduce GHG emission of FPs.

Production of materials of 1-km RP leads to 1,120 tons CO_2 eq of GHG emissions. If FA is used in the PCC, it can be reduced by 333 tons CO_2 eq for 1-km RP. According to the calculator tool of the Environmental Protection Agency (EPA), a reduction of 333 tons CO_2 eq GHG equals to 4995 tree seedlings grown for ten years (EPA, 2020). This reduction is significantly higher than the reduction that RAP provides to FP. On the other hand, using HMA with no RAP instead of PCC with FA can reduce 670 tons CO_2 eq of GHG. This amount of GHG equals 10,050 tree seedlings grown for ten years (EPA, 2020). Considering thousands of kilometers of road construction, using FA in PCC or preferring HMA instead of PCC could make lots of contributions to reduce GHG emission of FPs.

Ozone Layer Depletion

ODP of FP-R0 is 99.92% less than RP-FA0. It is demonstrated that FA can reduce ODP of the RP by 30.28%, and RAP can reduce ODP of FP by 17.99%.

In the RP, the production of ready-mix PCC dominates 99.99% of ODP. On the other hand, the production of dowels, base materials, and tie bars contributes barely to ODP. In the FP, the production of HMA makes up nearly one-sixth of the total ODP.

Photochemical Oxide Creation

POCP of FP-R0 is 98.23% less than RP-FA0. It is demonstrated that FA can reduce POCP of by RP 25.62%, and RAP can reduce POCP of FP by 10.99%.

In the RPs, the production of ready-mix PCC dominates more than 99% of POCP. On the other hand, the production of dowels, base materials, and tie bars accounts for a minuscule percentage of POCP. In the FP, the production of HMA constitutes almost one-third of the total POCP.

Conclusions

The study evaluates the environmental impacts of FPs and RPs. These hypothetical pavements were designed in the same conditions. Then, in the limitation of the material production phase, a life cycle analysis was performed. Obtained results were interpreted, and possible conclusions have been drawn.

The most obvious finding to emerge from this study is that RPs significantly higher environmental impacts than FPs in all impact categories. The second major finding is that using FA can provide a severe amount of GHG reduction for the RP. On the other hand, RAP can reduce GHG moderately.

One of the other significant findings to emerge from this study is that the production of ready-mix PCC dominates all environmental impacts of the RP. Meaning, production of dowels, tie bars, and aggregate produces a minuscule fraction of environmental impacts compared to PCC.

The major limitation of this study is to take into account only the material production phase (e.g., HMA, ready-mix PCC). The study does not evaluate the construction, maintenance, use, and EOL phases. That is why further research is required to determine how much the other phases can create environmental impacts.

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Computerized Maintenance Management System Data Utilization in Facility Management

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Abstract

Computerized Maintenance Management System (CMMS) is a maintenance planning and management tool that has been widely accepted and utilized in manufacturing, industrial production, and utility management. The use of CMMS assists with the condition monitoring, fault detection and diagnostics, reliability, and performance improvement in these industries. However, the use of CMMS in building maintenance and facility management (FM) is limited to the development of a maintenance log, tracking of work orders, and preventive maintenance scheduling. The purpose of this study is to investigate the possible utilization of CMMS data to identify possible relationships between the building characteristics and work orders as indicators of maintenance issues and equipment failures. For this purpose, the CMMS data was collected from three higher education institutions (HEIs) in the state of Colorado, USA between 2013 and 2017 and have been analyzed using descriptive, inferential and relational statistical methods. The results provide a better understanding of the correlations between facility age, facility type, and work orders, showing that CMMS data can be useful in identifying correlations, which can be useful to facility managers. Furthermore, areas that need improvement in CMMS use in HEIs FM were revealed from the recent research efforts such as condition assessment, strategic planning, and the integration of CMMS with other technological advancements such as building information modeling (BIM), building automation systems (BAS), and integrated workplace management system (IWMS).

Keywords: *building maintenance, CMMS, higher education facility management, facility management.*

Introduction and Purpose

Building maintenance practices enhance building systems, components, and equipment to perform efficiently. Advancements in information and computer technologies have led to the increasing use of software systems in building maintenance management. Computerized Maintenance Management System (CMMS) is a software platform that assists in planning and monitoring maintenance activities with real-time data processing (Fernandez et al., 2003).

O'Donoghue and Prendergast (2004) emphasized the extensive use of CMMS in manufacturing plants. In addition to the maintenance planning and monitoring, the CMMS is utilized for condition monitoring, fault detection and diagnostics, and performance improvement in manufacturing, industrial production, and utility management. The reliability of the equipment and facilities has critical importance in these industries, which increases the worldwide recognition and the use of CMMS. Comparatively, equipment failures are less critical in buildings except for some essential facilities such as healthcare, data, and communication centers. Given that, the common use of CMMS in building maintenance and facility management (FM) has been limited to processing work orders, scheduling required maintenance activities, and tracking the performance of the completed work in terms of completion time, labor hours, and spare parts (WBDG, 2016). In other words, the use of CMMS in building maintenance and FM has a significant focus on day-to-day activities.

The purpose of this study is to investigate the possible utilization of CMMS data to identify possible relationships between building characteristics and work orders as the indicators for maintenance issues and equipment failures. To do so, a data set was collected and analyzed from three higher education institutions (HEIs) in the state of Colorado, representing a large portfolio of buildings with different facility types. The findings of these efforts were promising in terms of utilizing CMMS data in condition assessment and FM planning. In addition, the researchers identified areas that need more attention in the integration of CMMS with other technological advancements such as building information modeling (BIM), building automation systems (BAS), and integrated workplace management system (IWMS).

Background

Korka et al. (1997) performed a comprehensive study on the use of CMMSs in three naval bases with approximately 1200 facilities, including several facility types. Their study revealed that in addition to the maintenance reporting, planning, scheduling, material, and work order control, a CMMS is a platform that assists in analyzing maintenance information, which then leads to an effective decision-making process. The importance of CMMS as a platform for decision analysis rather than a data monitoring tool was emphasized in several studies (Vanier, 2001; Labib, 2004; O'Donoghue et al., 2004). However, the same studies identified the following reasons why CMMS is not effectively utilized in strategic planning and decision-making in FM: lack of full understanding of the capability of CMMS modules, lack of adequate training for the maintenance staff, and unavailability of useful and efficient data (Vanier, 2001; Labib, 2004; O'Donoghue et al., 2004).

Kans (2008) stated the importance of the use of CMMS in condition monitoring and the integration of CMMS with other IT platforms in organizations, such as enterprise resource planning, commonly known as ERP. Moreover, her study had an emphasis on utilizing CMMS for decision support, mainly for failure prediction and performance improvement. A comprehensive study analyzing CMMS data with the purpose of determining maintenance performance revealed irregularities in the work orders, such as the need for proper recording of the completion time of work orders to better analyze the response, repair, and downtime of equipment (Lai, 2015). Another study demonstrated the use of CMMS data in reliability and failure analysis with a rule-based system for heavy equipment in the mining industry. The CMMS data was reorganized with a semantics-based process by focusing on keywords, which is a promising effort in terms of utilizing data for strategic planning in FM (Hodkiewicz & Ho, 2016).

The recent research efforts on CMMS in building maintenance and FM have an increasing trend in integrating CMMS and building information modeling (BIM) (Wang & Piao, 2019; Lavy et al., 2019). The visualization and interoperability capabilities of BIM with the implementation of industry foundation classes were integrated with CMMS, building energy management systems (BEMS) and building automation systems (BAS) (Shalabi & Turkan, 2017). FM-enabled BIM implementation with a real-world project identified the information required for the integration of systems, the process of gathering and exchanging data, and the challenges faced during the handover process (Pishdad-Bozorgi et al., 2018).

These studies indicate that CMMS has valuable data for condition assessment, failure detection, and performance evaluation in building maintenance and FM. However, detailed studies in analyzing CMMS data to examine its effective use in FM planning still remain limited. Increasing attention to information technologies (IT) integration and data exchange in building maintenance and FM is promising for achieving the best results in utilizing CMMS data.

Data Collection and Methodology

The CMMS data in this study were collected from three HEIs in the state of Colorado between 2013 and 2017. The time interval of the data sets was consistent among institutions. Microsoft Excel was used for extracting data sets from the CMMS software of each institution. The corrective work orders in CMMS data sets constitute the main focus of this study, reflecting maintenance issues and equipment failures. Given that previous studies revealed the higher frequencies of the electrical, heating, ventilation, and air conditioning (HVAC) and plumbing work orders in work order data sets (Besiktepe et al., 2019; Lai, 2015), the CMMS data sets in this study were limited to the corrective work orders in three maintenance activities: electrical, HVAC, and plumbing.

A total of 84,524 work orders of three HEIs were analyzed in the study. The gross square footage (GSF) of these HEIs in 497 buildings is 19,180,096 square feet. The characteristics of the data sets representing the total number of work orders with the number of buildings, total GSF, and average facility age per each HEI are presented in Table 1.

The methodology comprises descriptive, inferential, and relational statistical analyses for investigating any possible relations between the number of work orders and facility age and facility type. The statistical analyses were performed in IBM SPSS Statistics 26 software. The descriptive statistical analyses comprise the determination of the mean and standard deviation of the work orders in three maintenance activity groups among HEIs. The data sets were analyzed for the statistical normality and based on the Shapiro-Wilk test results ($p < .05$), it was determined that the data sets are not normally distributed in any of the three HEIs. After the determination of non-normality, Spearmen's correlation coefficient was used to indicate the relationship between the facility age and the number of work orders with the strength and direction of the relationship. Spearman's correlation coefficient can be used as an alternative to Pearson's correlation coefficient if the data are not normally distributed (Aldrich, 2018). The relation distribution of the work orders across the facility types was determined with the Kruskal-Wallis test, which is the nonparametric alternative for one-way ANOVA.

Table 1. The characteristics of the data sets.

HEIs	# of work orders	# of buildings	Total GSF	Average facility age
#1	26,137	283	10,809,377	43.7
#2	38,032	167	5,237,595	60.4
#3	20,355	47	3,133,124	70.2

Results

The results of the descriptive statistical analysis for the number of work orders of three maintenance activities are presented in Table 2. Sampling numbers (n) refer to the number of buildings in each HEI. It is apparent that the number of work orders is not dependent on the number of buildings, and HEI #2, with 167 buildings, has the highest total number of work orders in three maintenance activities.

Table 2. The total numbers, the mean, and standard deviation of work orders per HEIs.

	HEI #1 (n=283)			**HEI #2** (n=167)			**HEI #3** (n=47)		
	# of WOs	mean	sd	# of WOs	mean	sd	# of WOs	mean	sd
Electrical	6,243	22.06	43.282	13,172	78.87	115.826	8,071	171.12	279.652
HVAC	11,633	41.11	115.639	13,998	83.82	119.199	6,800	144.68	233.653
Plumbing	8,261	29.19	277.719	10,862	65.04	91.205	5,484	116.68	185.467
Total	26,137			38,032			20,355		

Spearmen's correlation coefficient was used for investigating the relationships between the facility age and the number of work orders in three maintenance activity groups. The results are presented in Table 3, Table 4, and Table 5 for HEI #1, HEI #2, and HEI #3, respectively. A weak positive correlation was observed with the facility age and the number of electrical, HVAC, and plumbing work orders in HEI #1. However, a weak negative correlation was observed with the facility age and the number of HVAC work orders in HEI #2. There was no significant correlation observed in HEI #3. In addition, correlation analyses identified strong positive correlation between electrical, HVAC, and plumbing work orders at all three of the HEIs.

Table 3. HEI #1 Spearman's correlation coefficients.

	Facility Age	Electrical WOs	HVAC WOs	Plumbing WOs
Facility Age	1	.250**	.221**	.267**
Electrical WOs		1	.764**	.807**
HVAC WOs			1	.802**

Plumbing WOs				1

Table 4. HEI #2 Spearman's correlation coefficients.

	Facility Age	Electrical WOs	HVAC WOs	Plumbing WOs
Facility Age	1	-.068	-.186 *	-.084
Electrical WOs		1	.913**	.935**
HVAC WOs			1	.914**
Plumbing WOs				1

Table 5. HEI #3 Spearman's correlation coefficients.

	Facility Age	Electrical WOs	HVAC WOs	Plumbing WOs
Facility Age	1	-.133	-.254	-.118
Electrical WOs		1	.844**	.881**
HVAC WOs			1	.858**
Plumbing WOs				1

* *Correlation is significant at the 0.05 level*
** *Correlation is significant at the 0.01 level*

Based on the available data, it was only possible to classify the facility types in HEI #1. The facility types in the other two HEIs were assigned through different percentages for each building, such as 25% classroom, 25% office, and 50% research. Hence, a single facility type for each building in HEI #2 and HEI #3 could not be identified.

The distribution of the electrical, HVAC, and plumbing work orders was investigated among the facility types in HEI #1. The null hypothesis for the investigation of this distribution is:

$H_o =$ The distribution of work orders is the same across the categories of the facility type.

Since the data sets fail to meet the assumptions of one-way ANOVA, such as the normal distribution, the Kruskal-Wallis test is used as the nonparametric alternative for the one-way ANOVA (Aldrich, 2018). The Kruskal-Wallis test results provide the decision to reject the null hypothesis among the facility types. Thus, the Kruskal-Wallis test indicates that the number of work orders is significantly different across facility types for each maintenance activity type. The distribution of the means of electrical, HVAC, and plumbing work orders per facility type are presented in Fig. 1, Fig. 2, and Fig. 3. Research, office, library, classroom, and athletic facility types received higher numbers of work orders in the three maintenance activity groups.

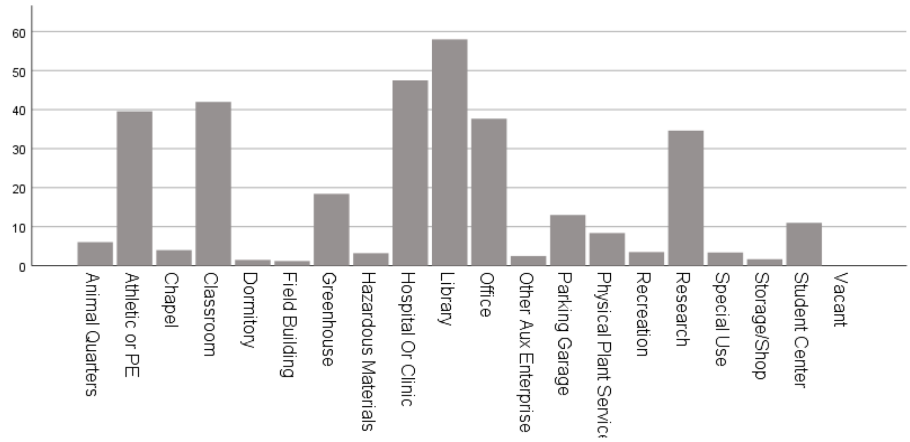

Figure 1: Means of electrical work orders per facility type in HEI #1.

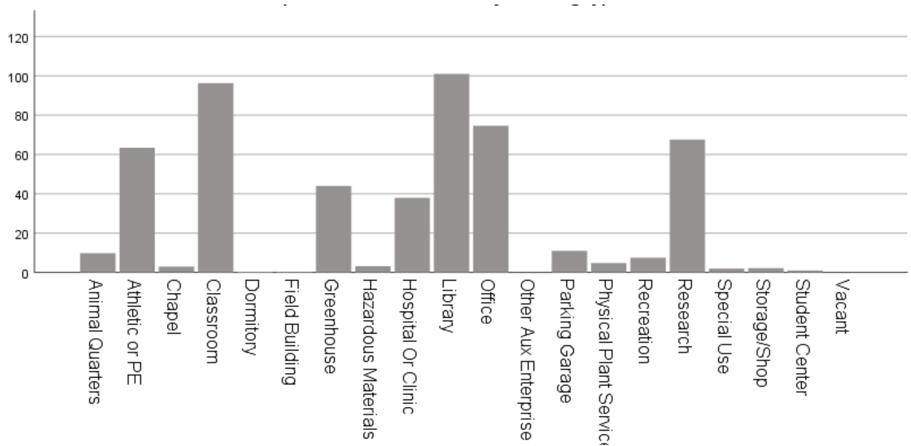

Figure 2: Means of HVAC work orders per facility type in HEI #1.

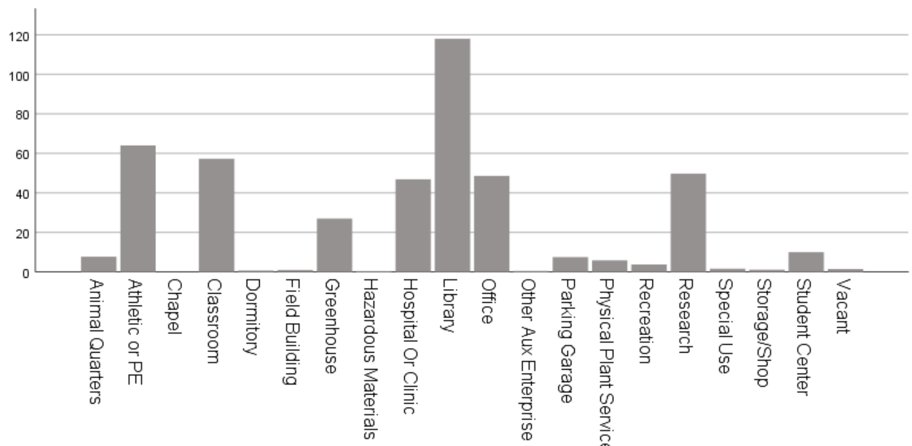

Figure 3: Means of Plumbing work orders per facility type in HEI #1.

Discussion and Conclusion

The purpose of this study was to investigate the possible utilization of CMMS data to identify possible relationships between building characteristics and work orders as the indicators of maintenance issues and equipment failures. The collected data sets from three higher education institutions (HEIs) in the state of Colorado were analyzed with descriptive, inferential, and relational statistical methods. The results of this study show that CMMS data can be useful in building maintenance and FM, and can be promising in identifying correlations between facility age, facility type, and work orders. In other words, CMMS data has the potential to aid FM professionals in better overall building maintenance planning, beyond what it is currently used for with respect to processing, tracking, and scheduling day-to-day maintenance activities.

The weak positive correlation observed with the facility age and the number of electrical, HVAC, and plumbing work orders in HEI#1 is promising in terms of assisting maintenance planning, such as revealing the need for increased attention to aging buildings. However, the correlations in HEI#2 and HEI#3 are inconsistent with this result; and thus analyses with a larger sample population are strongly recommended to better establish the relationships between the facility age and CMMS work order data. In addition, the strong positive correlations observed between electrical, HVAC, and plumbing work orders in all HEIs are remarkable, since these three systems often work together for the proper functioning of the building systems. The failures in any of these systems result in performance loss in the building systems, which eventually affect the overall building performance. Given that, the strong positive correlations observed between electrical, HVAC, and plumbing work orders would assist facility managers in identifying the risks and effects of the possible failures in these three systems.

The identification of facility type in the CMMS used by the three HEIs was not consistent. The FM department of HEI #1 provided the facility types in the data sets, which then enabled the analysis of the distribution of work orders across the facility types. Certain types of facilities such as research, office, library, classroom, and athletic received higher numbers of work orders in the three maintenance activities considered. Further analysis investigating the correlation between the total GSF or the average maintenance cost per SF in these facility types has the potential to increase the understanding of the relationship between facility type and maintenance activities.

The data collection and statistical analyses performed in this study provided a better understanding of CMMS data structure with the areas that need improvement. None of the data sets analyzed in this study include equipment IDs or a barcode system that would improve the use of data specifically in the condition assessment process of building maintenance. Although the start date of the work orders appeared in the data sets, the completion date of work orders was not complete, which provides essential information to determine the time between failures of equipment. In addition, recent research studies in architecture, engineering, construction, and FM have a significant focus on integrating technological advancements and their interoperability. In addition to the CMMS, building information modeling (BIM), building automation systems (BAS), and integrated workplace management systems (IWMS) are other information technologies that could improve the efficiency of FM strategies. These technologies continue to evolve; however, the following challenges need to be addressed to enable the effective use of them: the lack of understanding in the capability of the technological advancements, the shortfall of trained FM trades for the proper data recording, and poorly defined information exchange or interface requirements.

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Corporate university 2.0: Challenges and implications for construction firms

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Abstract

Corporate university (CU) is an umbrella term for educational entities that are 'strategic tools to assist organizations in achieving their mission by various learning activities that support individual and organizational learning, knowledge and wisdom.' CUs help organizations to turn organizational learning into action, manage change through targeted investment in education and training, manage talents, and remain competitive in the long run. Accelerated digitalization of businesses in recent years offers a plethora of possibilities for firms to benefit from CU and their digital forms as critical tools to achieve business goals. While strategic management, organizational learning and digitalization in project-based organizations have long received the attention of researchers in the construction industry, potentialities of CUs are yet unexplored from the perspective of construction organizations and their supply chains. Literature on CUs shows that firms from different industries need to find the appropriate mix of digital and in-person learning solutions that best fit with their business realm. Following a literature review, paper clarifies the knowledge gap on CUs in the construction business and identifies key areas of concern and challenges for developing CUs, which might be conducive to enhancing the long-term competitiveness of construction firms in a knowledge-driven economy.

Keywords: *Construction firms, corporate university, digitalization, organizational learning, strategic management.*

Introduction

Management of the knowledge assets of organizations and development of sustainable learning environments have become vital than ever to cope with change, survive, compete and prosper in a knowledge economy (Chan et al., 2005; Zhai et al., 2014), which makes 'learning' the collective responsibility of everyone in organizations (Chan et al., 2005). Accordingly, organizational learning (OL) as a multi-level process that refers to the systematic promotion of a learning culture in organizations and their supply chains at all levels through various systematic approaches and tools emerges a critical capability for many firms (Eken et al., 2020; Almaian & Qammaz, 2019; Katkalo et al., 2019). Corporate universities (CUs) can be effective entities to integrate OL into the business processes and value chains of firms to achieve corporate strategies (Allen, 2002), and make learning a critical part of daily activities to transform firms into learning organizations (LO) (Rhéaume & Gardoni, 2015; Singh et al., 2019). Katkalo et al (2019) argue that CUs can be the key drivers of digital business transformation for firms.

The globalization of capital (Singh et al., 2019); the diminishing shelf-life of knowledge in many fields (Singh et al., 2019); the employability gaps in the labour market; the need to meet the expectations of new-generation and high-skilled employees (Kolo et al., 2013; Chen et al., 2019); the pace of technological change which frequently requires the re-skilling or up-skilling of employees (Singh et al., 2019), and other factors such as bringing a common culture, loyalty and sense of belonging in organizations (Scarso, 2017) are amongst the factors that enforce firms to establish CUs to address the challenges of a knowledge-driven economy. Katkalo et al (2019) argue that CUs are increasingly becoming the strategic marketing tools of firms.

The CU concept looks highly relevant to the construction management body of knowledge where researchers have long sought alternative strategies for the success of OL in the construction industry. Recent reviews of the OL literature in the construction field, however, show that OL is yet an abstract, vague, incoherent and an underdeveloped concept, several aspects of which are to be further studied (Almaian & Qammaz, 2019). Researchers such as Chinowsky et al (2007) long ago highlighted the need to focus on a long-term outlook for learning in the construction industry, which requires comprehensive and holistic approaches for learning. We argue that CU can be a valuable concept to facilitate OL in construction supply chains as long as the peculiar characteristics of the construction business are adequately understood and addressed. As part of a portfolio of ongoing research projects on OL (see also Okullu & Acar, 2020), the paper highlights key areas of concern for developing a CU model for the construction firms, following a review of the main findings of the relevant literature on OL and knowledge management (KM).

Corporate university and the digitalization of OL

The term CU refers to the "*whole set of continuums, from physical to virtual, that comprises a few employees to all employees, which produces measurable advantages for well-being, which is a division coming from the training department extended into a knowledge management system, which is autonomous and relies also on alliances*" (Rhéaume & Gardoni, 2015). The evolution of the CU concept in the past few decades in several industries parallels the increased complexity of contextual factors that surround CUs. While the first generation of CUs were more in the form of training departments with a tactical and operational focus that relied mainly on classroom-based activities, they increasingly gained a strategic nature over time to function as platforms for strategy development and execution according to fulfil the missions of organizations (Allen, 2010; Kolo et al., 2013). Development of strategic capabilities and skills that are pertinent to business performance via facilitating, integrating, and disseminating knowledge within and across organizations represented the shifting focus of CUs (Rhéaume & Gardoni, 2015; Kolo et al., 2013; Prince & Stewart, 2002). Partnerships with other companies, educational institutions and the wider community were amongst the characteristics of the second-generation CUs (Homan & MacPherson, 2005). Table 1 clarifies the important differences between the traditional training departments and the corporate universities and shows the shifting focus of the CU from a narrower to a more holistic, proactive and cohesive one that is targeted at enhancing the overall business performance with a more global perspective. Recent research evidence shows that CU of the present day is in the middle of another paradigmatic shift that bring the concept into the forefront as the "learning labs" of firms (Singh et al., 2019), in parallel with the shift in the educational environment from being curriculum-centred to work role-centred (Singh et al., 2019). Taking on more dynamic, flexible and heterogeneous forms, CUs today allow firms building intellectual capital in interdisciplinary environments (Singh et al., 2019), exchanging knowledge, experience and innovation both within and between organizations (Scarso, 2017), and linking individual-level learning to overall corporate strategies, especially by leveraging learning management systems and new technologies (Singh et al., 2019; Homan & MacPherson, 2005).

Table 1. Training department vs corporate university.

	Traditional training department	Corporate university
Objectives	▪ To improve individual performance	▪ To improve individual and corporate performance
Focus	▪ On individuals; isolated efforts to react to specific problems in performance ▪ Reactive	▪ On the organization; systematic and proactive approach which aims to help business strategies ▪ Proactive
Structure	▪ Fragmented and decentralized; the activities are split according to the skill categories	▪ Cohesive and centralized; the activities are integrated within a global learning strategy
Objectives of training processes	▪ Job-specific	▪ To support corporate transformation and expansion
Registration	▪ Open	▪ Just-in-time learning
Trainers	▪ Internal and external experts	▪ Internal managers and independent experts; partnerships with public or private research centres and universities
Diffusion	▪ Based on the instructor	▪ Experience from many technologies
Audience	▪ Employees	▪ Employees, managers, suppliers, partners, customers
Results	▪ Improve working skills	▪ Improve business performance

Sources: Adapted from Guerci et al., (2010) and Rhéaume & Gardoni (2015)

After a comprehensive review of the literature, Singh et al., (2019) concluded that researchers interpreted the CU concept with alternative orientations including the *business*, *learning*, and *knowledge management*. From a *business* perspective, CU refers to the organization-owned learning entities that provide business-related education. From a *learning* perspective, CUs refer to flexible frameworks within organizations for shaping and implementing learning strategies that reflect their learning culture, which as a result lead to a learning organization (LO). From a *knowledge management* perspective, CUs are not peculiar educational or training arrangements, but tools for managing organizational knowledge. Whatever perspective is adopted, many scholars agree that CU concept branched out from existing concepts like OL and knowledge management (KM) (Prince & Stewart, 2002; Chan et al., 2005; Almaian & Qammaz, 2019). KM, mainly used in the strategic management field, identifies the ways that an organization collects, stores, optimises and delivers its knowledge assets to create value for the organization (Zhai et al., 2014). Strategic management of knowledge in an organization is about perceiving knowledge needs, understanding, integrating, and institutionalizing the knowledge flows at different levels (Almaian &

Qammaz, 2019). Following Chan et al (2005) and Zhai et al (2014), we adopt the scholarly perspective that KM is a subset of the larger OL concept. According to this perspective, organizational knowledge can be considered as a key component of OL, which concerns the changes in the knowledge assets of an organization. While OL aims to create organizational knowledge, KM focuses on its optimization and delivery of its economic value for appropriation and use (Zhai et al., 2014). Thus, OL and KM can be highlighted as the two critical areas to be understood for appropriating the CU concept for construction businesses, according to their peculiar characteristics and needs.

Existing body of knowledge on CU (e.g., the corporate wheel model of Prince and Stewart, 2002) shows that four key processes should be centrally coordinated, nurtured and integrated in any organization for the success of CU initiatives: (i) knowledge system and processes, (ii) learning process, (iii) network and partnerships and the (iv) people processes (Prince & Stewart, 2002). The configuration of these subsystems and the ways that resources are distributed, balanced or blended across formal, informal and social learning activities (see Table 2) in organizations determine the character of the corporate learning model (Katkalo et al., 2019).

Table 2. Types of learning in corporate learning models.

Formal learning (Structured learning within specific educational programs, courses, and other educational events, for which goals and learning outcomes are formally defined and put in writing)	Informal learning (Learning with non-defined goals, mostly in the form of “side effects” of other activities such as work and communication, and often associated with daily professional activities and on-the-job training)	Social learning (Learning through interaction with other learners. Often part of informal learning and collaborative learning, as a natural outcome of the professional activity and life of the learner)
▪ e-learning	▪ mentoring	▪ wiki
▪ conferences	▪ web conferences	▪ user-generated content
▪ road show	▪ articles	▪ comments
▪ rotations	▪ shadowing	▪ ratings
▪ physical classroom	▪ books	▪ blogs
▪ performance reviews	▪ web sites	▪ friending
▪ game-based learning	▪ webinars	▪ video
▪ virtual classroom	▪ case studies	▪ web jams
▪ forums	▪ podcasts	▪ tagging
▪ …	▪ webcasts	▪ microblogging
	▪ coaching	▪ discussions
	▪ …	▪ …

Sources: Tabulated from Katkalo et al (2019)

Indeed, many of the digital learning tools have long been used in the business world; what is new, however, is the rapid movement of the learning content to cloud-based platforms, increased ease of accessibility across multiple devices and the rapidly growing user-created content (Benson-Armer et al., 2016). CU 2.0 represents the digitization of CU in accordance with the digitization of businesses especially in the last decade, which is yet an “ongoing project" according to Singh et al (2019). While the content development, standardization of learning, and the focus on knowledge transfer by combining in-class and distance learning were prioritized in the earlier examples of CUs, CU 2.0 today focuses on the moderation and customization of the online content to meet learner demands, blending of formal and informal learning, personalization of learning, and the formation and certification of skills (Katkalo et al., 2019). Table 3 summarizes the drivers for the digitization of CU.

Table 3. Drivers for and outcomes from digitization of CU.

Drivers	Outcomes
▪ Changing nature of businesses and consumption	▪ Reduced time and cost of training
▪ The rapid pace of technological change	▪ More engaging and dynamic content delivery methods (virtual reality, gamification, social media, online simulations and others)
▪ The diminishing half-life of technical knowledge	▪ Velocity into getting curriculums out to the masses
▪ Shorter product life cycles	▪ Reduced need for physical learning spaces
▪ Geographical dispersion of learners and the difficulties regarding the training logistics	▪ More sophisticated measurement of learning outcomes
▪ Need to reduce training and the associated travel costs	▪ Flattened knowledge hierarchies
▪ Fast and effective deployment of mission-critical knowledge	▪ Flexibility in content delivery, independent of time and space (e.g., for geographically dispersed employees, in non-standard hours, or home workers)
▪ Need for knowledge on demand	▪ Flexibility in the pace of learning (e.g., one's learning at any time according to his/her capabilities and life circumstances)
▪ Need for well-trained and up-to-date workforce	▪ Active learning – learners that take the responsibility of learning and the increased expectancy of learning in non-working time

Sources: Tabulated from Homan & MacPherson (2005); Ryan et al (2015); Clarke & Hermens (2001); Katkalo et al (2019); Singh et al (2019) and Benson-Armer et al (2016)

While the rapid developments in e-learning technologies provide a significant advantage for the CU 2.0, researchers argue that success of CUs can be limited by the contextual factors (Homan & MacPherson, 2005), as evidenced by the recent reports of management consultancy firms around the world (see for example Benson-Armer et al., 2016). This is not only because many trainers struggle with the challenges of a new field (e.g., the pedagogy of e-learning) (Homan & MacPherson, 2005), but also because of the lack of a universal solution that fits to all organizations. Accordingly, firms from different industries need to find the appropriate mix between digital and in-person training that best fits with to realm of their business (Benson-Armer et al., 2016), and develop learning management systems to organize and streamline their learning activities (Ilyas, 2017).

A review of challenges for construction firms

Having clarified in the previous sections that OL and KM -when the latter is taken as a subset of the former- constitute the main theoretical blocks of CU, we highlight below some major findings of the construction management literature on OL to clarify challenges relating the future initiatives that may be targeted at developing CU models for the construction firms. A quick search of the publication databases for construction firms reveals that there is a significant knowledge gap regarding the CU concept in the construction industry (see Figure 1), although construction management researchers have long been recognizant of the significance of OL for construction firms.

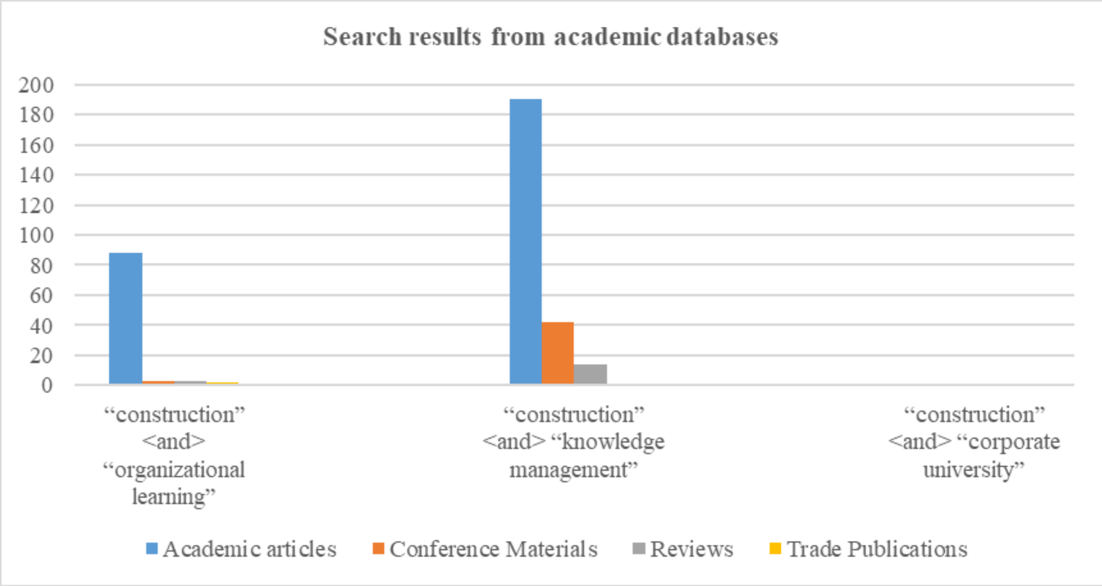

Figure 1: Search results from academic databases.
Source: Scopus, Science Citation Index (WOS), Social Sciences Citation Index (WOS) (as of September 2020)

The need to transform construction firms into learning organizations to improve performance and remain competitive in a knowledge-driven economy by creating sustainable learning agendas has been emphasized by scholars since the early 2000s (Love et al., 2004; Chinowsky et al., 2007; Tennant & Fernie, 2013). As a result, a number of OL models have been developed for construction firms, in-depth analysis of which is out of the scope of this paper due to page limitations. However, a thorough understanding of the major conclusions drawn from the OL literature of the field appears critical to highlight the technical, organizational and environmental challenges for establishing CUs in the construction industry. Research evidence shows that many of the challenges identified so far stem from the *technical* and *organizational complexity* of the project-based (one-off / unique) nature production, as result of which, different types of projects develop specific learning approaches that recognize local conditions and idiosyncratic challenges (Hopkin et al., 2019; Castillo et al., 2018). In addition to being situation-specific, the tacit nature of knowledge in construction projects makes it difficult to codify and apply to future projects (Winch, 1998; Hopkin et al., 2019).

Organizational complexity of construction projects is highly correlated with their technical complexity, which necessitates the temporary coalition of a large number of specialized groups that need to work together over the life cycle of projects. Business performance is dependent upon loosely coupled and short supply networks (Tennant & Fernie, 2013), which has numerous consequences for OL at both organization- and inter-organizational levels. Discontinues in information flows (Styhre et al., 2004), inability to develop mutual understanding and trust in temporary coalitions (Knauseder et al., 2007; Styhre et al., 2004), and the changing team membership over the life cycle of projects that lead to the failure of the social networks which support knowledge sharing (Almaian & Qammaz, 2019), are to mention a few, especially at organization level.

On the other side, due to the strong influence of inter-organizational dynamics in construction projects, the tendency to view OL in construction as ‘learning networks’ is growing in the construction management research community (e.g., Chan et al., 2005; Styhre et al., 2004; Tennant & Fernie, 2013), in parallel with the paradigm shift in the KM field where networks are investigated as important mechanisms of knowledge creation and sharing (Styhre et al., 2004; Sun et al., 2019). Consequently, OL capabilities, which can be defined as the "the total of the organizational mechanisms aimed at enabling for a continuous learning among organizational members," are not always located in individual firms, but distributed within a network of firms, where knowledge sharing among the members of a community of practice or community of learning can be as critical as the formal OL mechanisms (Chan et al., 2005; Styhre et al., 2004). Research evidence shows however that inter-organizational transfer of knowledge can be more complicated than intra-organizational knowledge transfer due to several boundaries such as culture, context or the practice involved (Sun et al., 2019). Table 4 includes a list of frequently cited challenges for OL in the construction industry.

Table 4. Challenges for OL in construction firms.

Challenges	References
▪ Project-based (unique) nature of business and fragmented environment including large number of boundaries between permanent organizations, different project organizations, and between project- and parent organizations and discontinues in supply chains and information flows	▪ Barlow & Jashapara (1998); Styhre et al (2004); Knauseder et al (2007); Hopkin et al (2019); Almaian & Qammaz (2019); Sun et al (2019)
▪ Distribution of organizational learning capabilities between different organizations and actors	▪ Styhre et al (2004)
▪ Changing team membership over the life cycle of projects, leading to the failure of the social networks which support knowledge sharing	▪ Almaian & Qammaz (2019)
▪ Simultaneous execution of multiple projects	▪ Almaian & Qammaz (2019)
▪ Urgency of projects – Time pressure that negatively affect inter-organizational knowledge transfer	▪ Sun et al (2019)
▪ Inability to learn from previous projects	▪ Almaian & Qammaz (2019)
▪ Inability to develop mutual trust and understanding in a temporary coalition of organizations	▪ Knauseder et al (2007); Styhre et al (2004)
▪ Lack of feedback mechanisms / lack of existence of knowledge sharing mechanisms - unstructured and informal managements systems that inhibit information flows	▪ Styhre et al (2004); Knauseder et al (2007); Chinowsky et al (2007); Almaian & Qammaz (2019); Eken et al (2020)
▪ Individualization of experiences and project co-workers leaving the project organization or the permanent organization	▪ Knauseder et al (2007)
▪ Tacit and situation specific of knowledge that is difficult to codify and apply to future projects	▪ Winch (1998); Hopkin et al (2019);
▪ Variety of construction projects that develop specific learning approaches according to local conditions and idiosyncratic challenges	▪ Hopkin et al (2019);
▪ Numerical dominance of small firms in construction business	▪ Barlow & Jashapara (1998); Alashwal et al (2019)
▪ The lack of an organization's culture that does not facilitate and encourage knowledge sharing	▪ Almaian & Qammaz (2019); Eken et al (2020)
▪ The lack of leadership for OL	▪ Chan et al (2005)
▪ The lack of support from senior executives	▪ Chinowsky et al (2007)
▪ The lack of support from employees	▪ Chinowsky et al (2007)
▪ The lack of value measurement systems – measuring value from investing in learning	▪ Chinowsky et al (2007)

Conclusion

CUs can be efficient platforms for managing change in a knowledge-driven economy by enhancing OL capabilities and functioning as the 'learning labs' of construction firms and their business partners. The ongoing paradigm shift in the CU field shows that creation, moderation and personalization of learning content by learners over digital learning managements systems characterise the CU 2.0. Literature on CUs reveals that there is not a magic solution that fits to all types of firms, since contextual factors may significantly constrain the success of CU initiatives in different industries and for different types of firms. Construction firms need to develop the 'most appropriate' corporate learning model for themselves by blending various learning activities (see Table 2) that best fit to their business needs and the peculiar challenges they face (see Table 4).

Overview of the literature on CU suggest that scholars approach the concept with KM, learning and the business perspectives. While there is a considerable body knowledge on the KM and OL in the construction management field, our review shows that there is a significant knowledge gap regarding the business perspective (see Figure 1). For, the CU concept by definition refers to centralized, holistic and coherent solutions that are targeted at achieving learning in the whole supply chain of firms, including also the clients. In this sense, CUs can be valuable platforms to address the discontinuities of learning in the supply chains of construction firms, OL capabilities of which are shaped within loosely coupled networks of numerous organizations, groups, and individuals. Especially the CU 2.0 can provide significant benefits for coping with the challenges of cultural, contextual and practice-related boundaries for inter-organizational learning by leveraging the emerging e-learning technologies. Small and medium enterprises, which constitute the majority of firms in the construction industry, deserve special attention in this context due to their resource constraints. CU 2.0 can be efficiently used to develop co-learning environments and sustainable learning networks for SMEs, business performance of which have significant impact on the overall performance of the construction industry.

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Dispute Avoidance Mechanisms: A Better Construction Delivery

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Abstract

This paper aims to elaborate on the issue of claims and how to avoid disputes using claim management mechanisms with specific emphasis to dispute boards. Dispute avoidance tools are recognized as one of the most efficient methods for a successful delivery of construction projects, therefore becoming a construction management tool themselves.

Keywords: *dispute board, dispute avoidance, construction management.*

Dispute Avoidance Techniques

In order to avoid it efficiently, we must firstly establish the definition of the dispute. Usually, the specific contract addresses this in its definitions section.

The dispute is defined in the FIDIC Gold Book of 2008 as "*any situation where (a) one Party makes a claim against another Party; (b) the other Party rejects the claim in whole or in part; and (c) the first Party does not acquiesce, provided however that a failure by the other Party to oppose or respond to the claim, in whole or in part, may constitute a rejection if, in the circumstances, the DAB or the arbitrator(s), as the case may be, deem it reasonable to do so.*" Alternatively, ICC Rules of Dispute Boards also provides a definition as follows: "*"Dispute" means any Disagreement that is formally referred to a Dispute Board for a Conclusion under the terms of the Contract and pursuant to Article 18 of the Rules*".

What we easily assess though, is the fact that the dispute occurs when site issues or disagreements have been elevated to a level that the parties cannot solve it on their own and need a resolution method. Therefore, the basic aim is, to eliminate the elevation of the problem. Disputes can be related to the interpretation of contract provisions, quality of the work, progress achieved (or not achieved) in the project, delays and payment. Disputes often arise due to poorly drafted contractual documents, misinterpretation of such documents, and insufficient communication between the parties. The parties at stake may be employer and the contractor; contractor and the subcontractors and/or suppliers and employer and consultants.

One way to avoid disputes before they arise is the collaboration of the parties to the contract in the utmost widest way possible. In the following of this paper, the contract management methods focusing on two prominent internationally recognized standard contracts was dealt.

Another way of dispute avoidance is the involvement of a third party to supervise the management of the contract and efficient performance of the works. The engineer, supervisor or the contract manager positions had initially been created for this purpose. However, due to the interrelation between the employers and such third parties, the intervention of these entities are not sufficient to avoid the disputes as they are considered partial.

On the basis of such circumstances, the concept of Dispute Boards finds its way into practice. A Dispute Board ("DB") is "*an intermediate dispute resolution mechanism established at the outset of the project and remaining in place until the end thereof whereby board members, with the expertise of the relevant construction sector, upon request provide prompt recommendations or decisions whenever a dispute arise*." (Taggart, 2015)

Dispute Board concept developed in the 90s in United States and gradually in common law countries. Australia has been one of the far most improved countries with regards to contribution to the alternative dispute resolution concepts. Although reluctant to adopt dispute board mechanism in early stages, usage of Dispute Boards in Australia has steadily been increased by years as they achieved a remarkable success in resolving disputes without referring to arbitration or litigation. Alongside being referred to in numerous major projects, their popularity amongst rather smaller projects has significantly raised in this period. (Jones, 2012)

Developing countries are still making their baby steps; however are already introduced to the dispute board mechanism through the internationally funded construction projects which make the boards obligatory for the purposes of funding the specific projects.

Dispute Boards: What Makes Them Preferable?

Dispute Board concept include numerous sub-concepts varying in accordance to the empowerment granted to the board. For fullest efficiency for the specific project the board and its duties may be tailored.

Types of Dispute Boards

In order to understand what type of board is ideal for the avoidance of disputes in projects, we need to know the classification of dispute board types which may be set out in many different ways. However two of these classifications particularly have importance. The first of these classifications is based on the competence of the dispute boards. Accordingly, boards mainly divided into three:

- Dispute Review Boards
- Dispute Adjudication Boards
- Combined Dispute Boards

Dispute Review Boards are only competent to give recommendations that are not binding. Dispute Adjudication Boards are competent to give decisions or recommendations. This is important due to binding character of the decisions and execution of these. The binding character of decisions is very significant in regard of abiding by the decisions in various cultures, therefore, this presentation is focused on the role of Dispute Adjudication Boards on avoidance of delays in projects and not on Dispute Review Boards'.

As the third subtype Combined Dispute Boards can be mentioned, which were brought into the practice by the International Chamber of Commerce ("**ICC**") that are competent to give both recommendations and decisions. However, because the Combined Dispute Boards carries with itself the discussions on the subject of its competency (Çetinel & Taggart, 2016), there is not yet an established acknowledgement on its practice.

Another classification is the one based on the term of the dispute boards. Accordingly, dispute boards divides into two:

- *Ad-hoc* Dispute Boards and
- Standing Dispute Boards

Ad-hoc dispute boards are only formed and became competent when a dispute has arisen. Standing Dispute Boards became competent at the beginning and are competent during the term of the project, they stay informed of various incidents and subjects by being situated in construction projects on a regular basis and be a witness to course of the work in their visits to the sites. In order to benefit the preventive quality of dispute boards, Standing Dispute Boards may be preferable over *Ad-hoc* Dispute Boards which only become competent when a dispute has arisen.

How to Support Construction Management by Preventing Disputes with the use of Dispute Boards

Early Appointment

One of the most encountered problems in the practice is the failure of appointment of the board during the work and/or within the period that was stipulated in the contract; despite the existence of a Standing Dispute Board in the contract. Therefore, our first suggestion is to overcome this problem and to form the board within the period that was stipulated under the contract. However it may varies in different contracts, the period most commonly used and also recommended by International Federation of Consulting Engineers (FIDIC) is 28 days from the commencement of the contract.

There are several developments to prevent the extension of the appointment period and consequently rendering the mechanism ineffective. In some of the recent decisions in United Kingdom and Switzerland, it has been emphasized that dispute board is mechanism which should be applied before arbitration and that if the contract in question is a FIDIC contract, there is a valid contract between the parties in regard of the dispute board, since the clauses on appointment and working of disputes boards are stipulated under these contracts. To put it another way, in case one of the parties refuses to sign the contract between them and the dispute board, the contract can be regarded as it was signed and the decisions given by the dispute board shall be enforceable against the party that refused to become signatory. (*Peterborough City Council v Enterprise*, 2014; *A v B*, 2014)

Regular Meetings and Site Visits

The meetings held with the site team of the contractor and the employer are the most significant activities of Standing Dispute Boards (Chern, 2015). Such activity can become the most useful tool for the avoidance of delays if it is executed for the determination of possible delays by the board, communication with the parties and to raise awareness the parties have. The effective performance of this activity may be possible in case the meetings are held and site visits are paid frequently.

However the contracts in the practice usually contains provisions that the site visits should be made in every 3 or 4 months, the frequency of site visit are even further reduced in order to decrease costs. Such approach can only decrease costs in the short term and may cause inevitable delays and disputes; therefore it should be avoided. The frequency of site visits should be determined with regards to the project type and program.

The meetings should be a tool for increasing the communication between the parties and strengthen the respect and trust for the dispute board. Thus, first of all, the parties are prevented from expressing problematic points of work performance due to various reasons and they can more clearly discuss the solution of the problematic points or the proposal for the prevention of possible problems, being aware of the fact that the job is being pursued by competent people in the matter. In the practice, there are some parties who accelerate the settlement process even for the purposes of declaring to the dispute board that the problem that constitutes one of the agenda items is solved when the board comes to the site meeting.

Another advantage of the meetings is that, if senior management of the parties in addition to the site team is also provided in the meetings, more active measures can be taken and decisions can be reached resulting to avoidance of possible problems and delays.

It is very important at these meetings to request and review of the work program and the revised work program by the dispute board, especially for the avoidance of delay. Parties thus have the opportunity to engage in speech and assessment on program, delays and possible delays, and take constructive steps on delays with various solution proposals in the face of questions raised by the dispute boards.

Payment Delays

Lastly, delays related to payments that must be made on the employer side are also one of the problematic issues that should not be underestimated and dispute boards may also play an active role in these disputes.

Employer’s Financial Strength

In cases where the employer's delay in payment has not actually occurred but its financial strength is doubtful, the contractual rights of the contractor can be considered as the first steps in preventing the delay in payment. The best example that can be given from the practice is the right of the contractor to ask for the financial condition of the employer, regulated under the Article 2.4 of the 1999 FIDIC Contracts. Indeed, even if there is no delay in the payment of these items, if the contractor has justifiable doubts about the employer's financial situation, this provision provides the right to ask the employer to provide "reasonable" level of evidence showing its financial adequacy. This issue is especially important in projects where serious level of work increases are taking place. In practice, these requests are rejected or the documents provided are far from being "reasonable". At this stage, the parties may apply to the dispute board and request a decision on whether the contractor is entitled to ask the employer to provide this document and what it should be. The decision of a dispute board can prevent economic problems may arise that could not be avoided in a later stage and may be effective in protecting the cash flow of the project.

Late Payments

Another role of the dispute boards is to determine the payment right of the contractor (and other rights in the contract relating to payments if any) if the employer is delayed for payment due to any reason. One of the most comment practices is application to the dispute board with the default of the employer, to determine the reasons for the failure in the payment or the scope of other rights relating to late payments. If the employer complies with the decision of the dispute board that was given as a result of this request, the cash flow problem of the contractor would be solved without having to wait for the end of the project and the possible associated problems that may grow much further in the future are also would be avoided (Seppälä,, 2015).[1]

Functioning of the Dispute Boards in Practice: The Example of Independent Dispute Avoidance Panels

Dispute avoidance panels have recently introduced as tailor made dispute avoidance tools specific to large infrastructure projects. Olympic Games dispute avoidance panels, both in London 2012 and Rio 2016 are good examples of such initiatives since these organisations include a great number of construction projects that have very tight timetables, organization committees felt the need of Dispute Boards panels, for the consistency of operation across every Dispute Board.

For Rio 2016, DRBF was approached by the organisation for its assistance in preparation of rules providing appropriate dispute avoidance and rapid dispute resolution procedure and accordingly special dispute board rules were drafted. Such rules took place in every contract between Rio 2016 organisation and 35 contractors (Patterson, 2016).

London 2012 on the other hand has been an example of using NEC3 and the dispute avoidance panel, established by the Olympic Delivery Authority, consisting of 11 construction industry experts to identify and resolve potential claims before they became contractual disputes (Fullalove, 2008).

The recent expansion project for CERN hadron collider in Switzerland also adopted a standing independent panel of individuals to serve on standing basis to help avoiding disputes and project effectiveness.

Conclusion

To conclude, there are various ways to avoid disputes and one of the aims of the Dispute Board concept is to develop an institutional method for this necessity. Focusing on the improvement

[1] The series of decisions that set international case-law in this regard, are undoubtedly Persero cases. There was seven years between the last judgment of the court of appeal (2015) that provided the execution of the related decision and the first decision of the dispute board in the Persero case and even the interest payments related to the decision have reached extremely high figures. However, this precedent ruling that the dispute board decisions should be executed immediately, since the dispute board decisions are binding on the arbitration or the court until otherwise agreed, has been a guide for the practice. Please see for more information about the Persero cases: Seppälä, 2015.

of the dispute boards in terms of competence and enforceability as well as increasing their activity at site and at other matters between the parties, such as the matter of avoiding the delay in payment, shall increase the effectiveness of Dispute Boards and problems caused by the dispute process shall be minimized since avoiding the disputes is a more sustainable method than dispute resolution. Therefore, conferences and panels held to discuss this matter and finding ways to develop the dispute avoidance mechanisms have vital significance for the construction industry.

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Demystifying the Role of an Information Manager in BIM Based Projects: The Skills and Competencies Required

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Abstract

An Information Manager (IM) is designated to manage information in Building Information Modelling (BIM) based projects. The competencies of an IM have so far not been adequately defined despite of the uniqueness of this role. This results in failing to meet the industry needs as the other existing professionals in the construction industry try to define IM's role according to their own liking. Thus, the aim of this study was to define the competencies expected of an IM. Firstly, the key tasks expected of an IM was derived through a desk study using standard BIM protocols. Secondly, an informal public opinion study was conducted, accompanied by a code-based analysis using NVIVO software. This defines the competencies required of an IM for each task. The results were validated using an expert survey interviews. The findings revealed that an IM must be a construction professional well-versed in construction technology, contract administration and with competencies to use BIM workflows/software. The study contributes to knowledge by identifying the gap that currently exists between the industry needs and the performance of professionals working as IMs, which could be invaluable when designing a curriculum for a course on information management within a BIM environment.

Keywords: *Information Manager, Building Information Modelling, Skills, Competencies.*

Introduction

Building Information Modelling (BIM) is the digital representation of the physical and functional information of construction projects, with a shared database that can facilitate the whole process of managing a building life cycle (National BIM Library, 2012). The efficiency provided by BIM (Holmström, Singh, & Främling, 2015) comes with many risks, which hinder its implementation (Ku & Taiebat, 2011). A BIM manager who has both new and old skills and an open mind (Merschbrock & Erik, 2015) is needed as a key performer (Rahman, Alsafouri, Tang, & Ayer, 2016) to directly associated with the top management throughout the BIM project. The BIM protocol commissioned by the Construction Industry Council (CIC) of the United Kingdom (UK) in February 2013 is meant to address this requirement. The primary objective of this protocol is to enable the production of building information models at defined stages of a project (CIC, 2013, 2018). The protocol recommends the appointment of an Information Manager (IM) with defined key responsibilities who has a significant role to play among BIM team members. The competencies required of an IM are yet to be defined clearly due to the novelty of the role. Currently, the other disciplines and BIM specialists are quick to define the role of the IM to suit their own requirements. This results in failing to meet the industry needs. It is, therefore, vital to define the competencies required from an IM working within a BIM collaborative environment.

BIM Project Team

The common platform generates by BIM ideally lessen the risks associated with a project and provide for stronger communication among project stakeholders. Then again, the most critical challenge faced by project stakeholders is to learn to work collaboratively when using the BIM model (Eastman, Liston, Sacks, & Liston, 2008). These challenges are especially critical when one BIM model exchanges among different parties, that requires an alliance of all stakeholders. Therefore, it is still questionable whether BIM with its unresolved limitations and conflicts can truly serve the industry. These limitations can cause mistakes during the project sequence and it would be impossible to identify the parties responsible for. This is unlikely to be expected if stakeholders follow correct protocol (Guo, Yu, & Fang, 2019; National BIM Library, 2012; Takim, Harris, & Nawawi, 2013). The traditional BIM project team requires rearrangement of contractual relationships and collaborative processes, and most importantly employment of key professionals with amended skills (Allen Consulting Group Pty Ltd ACN, 2010). These skills have to be clearly initialised (Aranda-mena & Froese, 2009; Olatunji, 2011) according to standardised conventions and protocols (National BIM Library, 2012).

Role of the Information Manager and Importance of Identifying the Competencies

Lack of defined roles in BIM, mainly concerning to its “Information Ownership” is one of issues that have arisen when converting traditional projects into BIM based projects (Aranda-mena & Froese, 2009). CIC BIM protocol identified the necessity of a designated role to manage the BIM process and subsequently introduced the key position named IM to overcome this issue. The IM is to be initially appointed by the client whose responsibility to ensure that there is an IM appointed throughout the project life cycle (CIC, 2013, 2018). This can be done as a stand-alone appointment or one that changes as the project proceeds. However, Jackson (2016) highlighted that there will be an ambiguity about that person who has to perform the role of the IM with appointment of the main contractor as project might be previously led by the design team. The lead designer or lead consultant can be designated as the IM at the inception and various design stages of the project, while the contractor can take up the role during construction and in the final stages of the project (Faulkner, 2015). The principle role of the IM is to manage the information exchange process and initiate & implement the project and asset information plans and BIM protocols (CIC, 2013, 2018). However, as stated by Al-shammari (2014), role of the IM is not only to act as an information exchanger, but also to understand and incorporate the whole BIM procedure to derive the expected BIM model. CIC

(2013, 2018) highlighted that IM is an independent role without design related responsibilities other than dealing with design related information. The BIM coordinator will have to get involved with clash detection and model coordination along with design lead, thereby freeing the IM from design related responsibilities. The role of the IM is exclusive and not designated "to do BIM" for other members of the project team (Mills, 2015). Alternatively, the tasks of the IM could be shared within members of the project team.

Traditional professional routes are generally facilitated with formal university education and workplace training attached to their degree curriculum. Their profession being still young, IMs neither receive such formal education nor a training. The absence of the courses that specifically focus on the key competencies of IMs made it difficult to define the competencies required of an IM and the difference between an IM and any other professionals. This illustrates the need for a competency-level benchmarking of the role of IM. Also, this has created an ambiguity regarding the role of IM, which causes conflicts with the other positions in a BIM project (Sinclair, 2012). Misinterpretation regarding the role of IM has caused negative impacts on BIM projects, such as negligence; poor quality and safety standards; poor documentation; etc. (Guo et al., 2019). Some individuals consider the handling of the information related to the BIM model as the sole responsibility of the IM (Jackson, 2016) owing to the lack of a clear definition. Neither a document controller nor a project manager can simply fit into the role. Hence, there is a knowledge gap about defining the competencies of IM as none of the existing protocols and guidelines have clearly defined them.

Research Methodology

The study used a mixed research approach which included a desk review, an informal opinion study and finally an expert interview survey.

Step 1: Desk Review

The desk review analysed the information published on BIM standard guidelines to identify the main and the sub tasks of an IM. These guidelines included the BIM standards published by Construction Industry Council, British Standards Institution, BIM Task Group. The tasks set out by these guidelines were combined to have a common list of tasks through a thematic analysis using a tabulation process.

Step 2: Informal Public Opinion Study

The data collection using traditional qualitative approaches (i.e. case studies, interviews) was restricted due to the novelty of the profession, the geographical and time limitations. Hence, competencies of IMs were identified through an informal public opinion study using online sources. Public opinion research provides information about what the public, which in this case is the focus group, thinks in general. The definition of public opinion considered in the study was "the complex collection of opinions of many different people in the focus group and the sum of all their views" (Barna, 2019). The data sources were weighted from 1-5 according to the ascending order of reliability (Table 1). These sources included a focus group represents the people who are knowledgeable about the nature and the expectations of the IM includes but not limited to BIM experts, BIM specialist recruiters, stakeholders of the BIM project. It was not possible to know in advance the whole population of the study as the data sources used covered a vast area. Hence, 175 data sources were randomly selected considering the time constraints and 330 opinions could be obtained from them.

Table 1: Data sources used in informal public opinion study.

Description of the data source and basis on which it was weighted for reliability	Weight given	# of sources	# of statements
Research publications: The facts given here are scientifically proven. Hence this source was ranked as the highest.	5	30	60
BIM guidelines: Most of the guidelines provide the details, and interpretations relating to BIM specialists and their roles and responsibilities. Hence, the data obtained from these guidelines are highly reliable and accurate, due to their practical application. Thus, this data source was also given the highest weight.	5	10	18
Online job advertisements: The eligibility requirements indicated are considerably trustworthy as their sole purpose is to attract the best possible candidates and the companies concerned spend considerable time and cost for publishing these advertisements. Yet, the details are not scientifically proved or standardised. Hence this data source was ranked as the second highest.	4	75	135
Online forums: Brainstorming sessions are held to exchange different views and knowledge on a particular subject. The focus group of usually include the experts in the area concerned. Hence, these forums have a considerable degree of reliability, which, however, is lower than the reliability of each of the first three sources.	3	8	15
Online discussions of professional networks: These are similar to online forums. Yet their aim is to maintain business relationships, the information provided in them will be considerably reliable as in the case of online forums.	3	10	18
Personal and company blogs: These blogs provide the name of the person or the company expressing the opinion. Technically, the opinion expressed has considerable reliability and accuracy. The opinion givers can be expected to express the same opinions if they are interviewed personally in the absence of geographical and/or time constraints. Yet, the reliability of these sources is comparatively lower than those of online forums and online discussions.	2	8	15
Websites: The degree of reliability is similar to blogs. Websites that could be edited by any user were not considered in the study.	2	22	45
Online newspapers and magazines: The data publishes in these documents are reliable and accurate in order to	1	12	24

ensure the goodwill of the readers. However, compared to other data sources, newspapers and magazines are the least reliable source.			

Next, the study used NVIVO to first assign the classified sub tasks of an IM to the NVIVO nodes and the resulting NVIVO node structure, was then used to extract the data from the data sources, categorize the data into relevant subtasks given in Table 1 and incorporate them into the NVIVO code structure. The coding process involved the tracking of relevant words and phrases mentioned in the data sources, combining the words to identify the connections among them, and categorising the words and phrases into one node to direct them to the relevant subtask. NVIVO charts for each main task were then generated and indicates the number of statements that mention wordings related to the competencies for each subtask of that main task. A reference value was calculated based on the number of statements and the weight given for the type of data source used. The threshold for the reference value in a competency was 30 and all the competencies with threshold values less than 30 were ignored. Finally, competencies were tabulated (except repetitive tasks) required for each subtask.

Step 3: Expert Validation

The resulting competencies at the second stage were further validated with expert interviews. Interviewees were selected with the use of purposive sampling and consists of 10 experts involved at senior level for more than 10 years with working experiences in BIM projects.

Research Analysis and Findings

The identified main tasks included, General Management and BIM (A), Construction Technology and BIM (B), Communication and Information Exchange (C), Common Data Environment: CDE (D) and IT Services (E). The results of the desk review categorised all the subtasks under the main tasks as presented in table 2. The list of competencies was identified and tabulated by analysing the resulting NVIVO charts obtained for each of the main tasks, following the coding process explained in research methodology section. These charts are not included in this paper due to the limited space. Next, the tabulated competencies had to be amended slightly based on the changes proposed by the experts who were interviewed. These changes included merging “people coordination” and “leadership skills” into one competency. Also, “working under pressure”, “meeting deadlines” and “handling multiple demands”, were merged as one competency. Further, the experts suggested that the “knowledge of BIM protocols” should include other standard BIM guidelines such as BSI documents and RIBA work stage plan. In addition, it was suggested “working knowledge of multidisciplinary working practices and their interdependencies” is not necessary, only the mere knowledge about the scope responsibilities of each stakeholder is sufficient for an IM. The experts moreover suggested that “extensive knowledge of and experience in information management support systems” should be deleted from the competencies as it has already been covered by the other competencies. “Hands-on field experience in construction and building construction sequencing” and “familiarity with building design, construction, and operations” were merged into one competency. Also, “high level of professionalism displayed in dealing with owners and design professionals”, “influencing skills across the whole company irrespective of seniority, organizational or contractual boundaries”, “excellent presentation skills, preferably in publishing papers or presenting BIM matters at conferences” were deleted and “excellent interpersonal, written and spoken communication skills" was amended as "excellent people, written, spoken and communication skills" to cover the aspects of deleted competencies. Moreover, "competencies required for maintaining ICT systems" has been deleted as the experts suggested that this competency is already covered by "knowledge of IT and network infrastructure principles". Finally, it was proposed that all the competencies related to IT hardware and software knowledge must be listed under IT services and should not be repeated in other main task categories. Figure 1 illustrates the final list of competencies after the expert validation.

Table 2: Main and sub tasks of the information manager

Subtasks	Main Tasks	R
References (R): 1 = (CIC/INF MAN/S, 2013), 2 = (Faulkner, 2015), 3 = (British Standards Institution (BSI), 2013)		
1. Project team management	A	1
2. Risk management and risk allocation across the project team	A	1
3. Value management	A	1
4. Performance management	A	1
5. Change management	A	1
6. Attending project and design team meetings	A, B	1
7. Supporting the implementation of project BIM protocol	A	1
8. Maintaining BIM standards during the project	B	2
9. Deciding the extent of information required for project outputs	B	1,2
10. Providing information during each stage	B	1,2
11. Agreeing on the formats and assembling information required for project outputs	B, C, D	1,2
12. Agreeing, implementing and establishing an information structure across the roles	B, C, D	1
13. Establishing, agreeing and implementing maintenance standards of the information model	B, E	1,2,3
14. Receiving, compliance validating and providing advice on any non-compliance of information with the information model	B, C, D, E	1,2,3
15. Incorporating as built test information into the model	B, C	1,2,3
16. Establishing and managing information exchange procedures	C	1
17. Enabling the integration of information within the project team	C	1
18. Agreeing with and implementing record keeping and archiving, and maintaining an audit trail for the information model	C	1,2,3
19. Communication and corporation within the team	C	1
20. Establishing, managing, compliance validating of the CDE and providing advice on any non-compliance of the CDE	D	1,2
21. Arrangements to host the CDE	D, E	1

Discussion

The current study reveals that IM has to be trained and well educated about BIM workflows, functions of BIM software and all-inclusive operations in the field of IT. The IM's knowledge in the field of construction has to be a combination of construction technology and contract administration of BIM based projects. Hence, IM has to be a profession that emerges from the construction industry. While the IM is expected to demonstrate a wide range of competencies for each subtask; he/she is not required to have in-depth knowledge of in the fields such as construction or IT. The findings of this study considerably elevate IM within the BIM team compared to existing professionals in the construction industry. Further, this study established that the extent of the IT knowledge required is not very high unlike in the case of IT specialists. IM would require expertise only in BIM software although the person appointed for the position has to be conversant with several different software packages. In addition, the management and communication skills are also desired. Hence, the IM can be accredited as an

General Management and BIM (A)

- Information management expertise
- People coordination and leadership skills
- Knowledge of BIM processes
- Knowledge of project management and its software. Ex: Primavera
- Adhering to every aspect of changes compulsory for the process and managing the team
- Knowledge of and experience in risk management: Specialty – Financial risks
- Expertise in upfront planning
- Knowledge of strategic planning techniques
- Awareness of financial management
- Working under pressure
- Prioritization of work according to their importance
- Identifying changes in BIM workflows
- Research and development competencies: change management
- A working knowledge of engineering contracts
- Contractual knowledge about BIM based projects
- Knowledge of BIM protocols. Ex: PAS 1192-2:2013, CIC Outline Scope of Services for the Role of Information Manager, BSI documents, RIBA work stage plan

Construction Technology and BIM (B)

- Specialist knowledge about BIM processes and techniques
- Experience in developing and delivering BIM standards
- Contemporary knowledge about industry standards. Ex: BS1192/ PAS 1192
- In-depth knowledge of BIM delivery processes
- Experience in the development and delivery of projects. Ex: Integrated Project Delivery
- Knowledge of and career background in construction processes
- Awareness of project workflows
- Academic and/or industry qualifications related to Information and Communication Technologies
- Experience in organizing and managing information systems
- Experience in extracting data from CDEs
- Design knowledge and ability to navigate through models and verify key data
- Hands-on field experience in construction and building construction sequencing
- Adaptation of the curricula of BIM-enabled coordination practices
- Understanding databases and data structures; ability to use databases

Communication and Information Exchange (C)

- A working knowledge of data/information exchange protocols
- Conflict resolving related to Requests for Information (RFIs)
- Excellent people, written, spoken and communication skills
- Experience with project extranets and virtual collaboration technologies

Common Data Environment: CDE (D)

- A working knowledge of CDE
- Theoretical and practical knowledge of BIM guidelines. Specialty: PAS 1192-2:2013, CIC Outline Scope of Services for the Role of Information Manager

IT Services (E)

- Ability and experience in using BIM software tools to generate accurate and error-free models. Specialty: Revit, Revit Structure tool, 3D simulation and animations, Newforma, Solibri Model Checker, 3D design authoring software, Navisworks, Navisworks Manage, Synchro PRO, Revit plug-in MWF, CodeBook, AutoCAD Civil 3D, Prolog, ArcGIS, Tekla BIMsight, COBie, Infraworks 360
- Excellent knowledge of and demonstrated proficiency in IT and network infrastructure principles

Figure 1: Results of the expert validation: The list of competencies required for an IM

Conclusions

IM is a professional required in BIM based projects, brought in to meet the need for an expert within the project team who will have the authority for the information management processes. The expected set of duties of an IM does not include design related work and IM has to focus only on information management. The competencies expected from an IM are not well defined unlike in the case of other traditional professions in the construction industry. A need has arisen to fill this free-for-all position due to the absence of an educational and training programmes for IMs. It was not clear whether the competencies essential for IM are aligned with the competencies expected of IT experts, that is whether to consider an IM as a specialist in the field of IT. Hence, the purpose of the research was to identify and outline the competencies expected from an IM working in BIM based projects. A mixed research approach was used to collect and validate data. The findings reveal that the IMs should come from the field of construction. However, an IM must demonstrate outstanding performance when dealing with BIM related software, CDE, and IT which cannot be expected from the professionals currently working in the construction industry. Further research directions were identified considering the limitations of the study. The outcome of the study provides a basis for new educational and training programmes which could be designed and structured based on the competencies required from an IM. The study findings also reveal the hypothesis that the extent of knowledge required by an IM in the field of construction is compatible with the extent of knowledge expected of a QS, which has to be verified through further research and by developing a framework that will enable construction professionals, especially QSs, to become IMs. It is recommended, therefore, to introduce an educational programme for QSs to fill the gap between an IM and QS. The programme could be either a set of additional modules included in the programmes meant for QSs or it can be a diploma/MSc. programme specifically intended for QSs and containing modules related to BIM workflows, BIM software and IT related operations.

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Evaluating the Impact of Selected Design Parameters on Interactive Daylighting Analysis

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Abstract

Construction industry shares a considerable portion in consuming energy in the U.S. and around the world, where lighting represents the single largest portion in electricity consumption even during daylight hours. Improper design and simulation of daylighting characteristics result in an increased use of energy. A daylighting analysis of potential design scenarios needs to be analyzed via software to improve daylighting performance of sample buildings. Although there are many daylighting guides for healthier and higher quality interior environments for occupants, the relationship between building design parameters and daylighting analysis is still at its infancy in literature. This study aims to find out how changes in interiors, such as furniture, and in exteriors, such as tree shading, would affect the amount of daylight observed by the building occupants in a campus building. The methodology will include changing design parameters and simultaneously performing a daylighting analysis in the Building Information Modelling (BIM) version of the same building. Findings will include similar and different values of daylighting metrics as obtained by the software analysis as an alternative way to evaluate design in the later stages of the project. Graphical analysis will be used to assess the daylighting performance and the correlations among building design parameters.

Keywords: *building information modeling (BIM), daylighting analysis, daylighting performance, design parameters.*

Introduction

Daylighting has an inevitable impact on the energy efficiency and user comfort in buildings, mainly based on architectural design and building characteristics. Although some building characteristics, like location and orientation are decided very early in the design stages, other design preferences to impact the interior and exterior elements of the building are left to the final stages. Previous studies have emphasized the impact of daylighting in human health and wellbeing (Beute & de Kort, 2018), while addressing the perceptual aspects of daylighting in terms of occupants' point of view (Amundadottir et al., 2017). There is enough evidence that daylighting can be identified as one of the driving factors in architectural design, yet the impact of potential daylighting design scenarios has not been fully analyzed and compared via software applications based on interior and exterior building properties. This study aims to find out how changes in interiors, such as furniture, and in exteriors, such as tree shading, would affect the amount of daylight observed by the building occupants in a campus building. The results of the study will be used to improve daylighting performance of sample buildings and show correlations among building design parameters.

Background

According to Environmental Protection Agency (EPA), the average American spends approximately 90% of their time indoors (EPA, 1989). With using indoor office and classrooms at a minimum of forty (40) hours weekly, many design parameters including daylighting design becomes of outmost importance to sustain productivity and prevent issues related to Sick Building Syndrome (SBS). People in working spaces that have direct exposure to daylight have been reported to have better mental health, well-being, and productivity (Boubekri et al., 2014). As it can be observed from the previous studies, daylighting has been a prominent component of healthier and higher quality interior environments for occupants. In addition to health and well-being benefits, the proper use of daylighting strategies have been found to save energy usage in commercial and campus building for up to one third of the overall energy consumption (Ander, 2016).

Daylighting design is a major part of energy-efficient building design. Previous studies have already highlighted how interior elements, such as furniture, can impact the energy performance of buildings. A recent example focused on the impacts of mostly-used-furniture-layouts on indoor daylighting performance in residential working rooms (Mousavi et al., 2018). They found that the biggest changes occur in daylight distribution uniformity, however the change in furniture orientation could not improve tropical daylight performance in buildings. Another study focused on daylight conditions within educational buildings and performed experimental measurements and simulations (Costanzo et al., 2017). The results showed that daylight optimization in classrooms is a very complex task and the evaluation of daylighting in a classroom should be based on the calculation of several climate-based metrics.

Other daylighting studies focused on changing the parameters outside the building rather than inside. Outside parameters mainly includes obstacles that can affect daylighting, such as vegetation around the building and the shading of neighboring buildings. A study in Hong Kong focused on the effect of shading in energy and daylighting performance of an office building (Li & Wong, 2007). Results showed notable impact on the annual electricity consumption due to the impact of surrounding obstacles. Specifically, it was found that electricity savings had an exponential relation with the angle between the façade of the office building with the highest obstruction point of surrounding parameters. There was a logarithmic correlation between the obstruction angle and the electricity savings, which emphasized the importance and potential impact of exterior elements in daylighting design and analysis. This study utilized EnergyPlus as the software application to analyze the energy performance of a generic commercial building with daylighting controls obstructed by neighboring buildings of various heights.

A 3D building model is required to perform daylighting analysis. Previous studies mentioned the use of Building Information Modelling (BIM) tools to perform energy and environmental analysis (Chong et al., 2017). BIM is used to create 3D building models and has been recognized as a collaborative information exchange tool, which provides a reliable basis for decision-making during buildings' design, construction, and operation (Santos et al., 2017). Various software applications are available in the market for energy modelling and analysis that works in connection to BIM. Autodesk Revit is used as a BIM tool to create the building model. Autodesk Insight, which is a daylighting analysis plugin for Revit, can perform energy analysis in Revit by using BIM 360 cloud-based platform (Autodesk-Insight, 2020). Similarly, IES from Radiance is a powerful daylight analysis tool, which simulates daylighting conditions under different conditions to help improve the well-being and productivity of building occupants (IESVE, 2020).

Considering the effectiveness and accessibility of energy-modelling tools, this study utilizes Autodesk Revit to create the 3D model of the campus building and IES and Insight to perform daylight analysis on this building. Interior and exterior parameters are changed in the building design, assuming these decisions are made at the final stages of the design that the team does not have any availability to implement further passive design strategies. The furniture orientation as well as vegetation outside the building will be the only two parameters in control of the team to come up with alternative ways to evaluate design in the later stages of the project.

Methodology

Daylighting Analysis with Software Applications

This study adopts a step-by-step approach to perform dynamic daylighting analysis with the help of two software applications: IES and Insight (Fig. 1). First step includes the creation of a 3D model of the SEED building, in Thomas Jefferson University's East Falls Campus located in Philadelphia, PA, with Autodesk Revit. SEED building is composed of a first floor and a mezzanine floor spread over 14,000SF. The building is used for faculty offices and classrooms. Passive design features are extremely important in daylighting analysis. The building has aluminum window systems and sunshades over regular sized (4'-wide) windows, which hare placed on all sides of the building. West side has the entrance with double doors. There are curtain walls all around the building. This study was primarily performed at the South side of the building (Fig. 2).

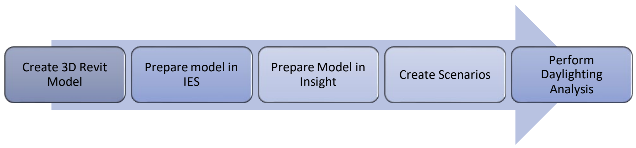

Figure 1: Research setting.

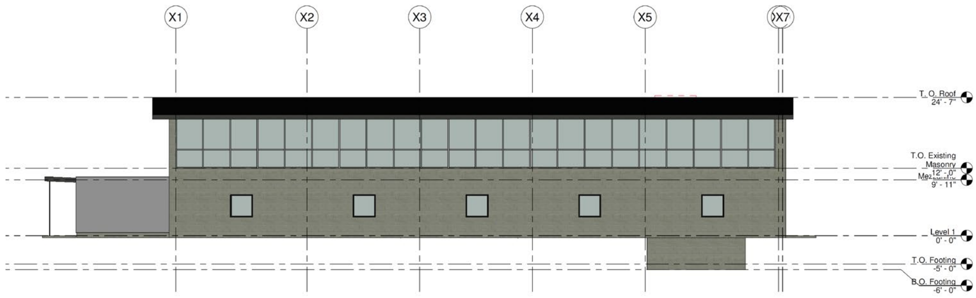

Figure 2: South elevation.

Next step includes preparing models for the daylighting analysis. Based on the details of the BIM model, similar geometry of the building was created in IES, as IES cannot directly get Revit model as an input for simulation. For Insight, a detailed BIM model for the building has been used to perform daylighting simulation due to the software's ability to work with Revit files directly. SEED building's 3D model, as well as passive design strategies were reflected in the models used in IES and Insight. In both software applications, daylighting analysis included setting up daylighting parameters and input. Below parameters were set in the same range in both IES and Insight:

- *Date and Time:* Both software tools generate two metrics and graphical output based on the point-in-time data set.
- *Location:* Location was set as the address of the SEED building in Philadelphia, PA.
- *Weather Conditions:* These are defined based on the location data.
- *Sky Type and Conditions:* Sky conditions such as overcast or clear is defined to have a climate-based sky specific for daylighting simulation based on location and date/time. Commission Internationale de l'Éclairage (CIE) Standard sky conditions were used in both tools. This physically accurate sky model is recognized as an industry standard and controlled by two illuminance values to be chosen as overcast or clear (Darula & Kittler, 2002).
- *Working Plane and Analysis Grid Size:* This is defined to set the work plane of interest and provide a base for the accuracy of simulation. Selection of the analysis grid and specific nodes within the grid/work plane allows hourly illuminance values to be calculated over a year in case an annual daylighting simulation is performed. Specific nodes can work as daylight sensors. Especially, in Insight, due to its link to the Revit file, it is possible to draw an analysis grid to perform daylighting analysis in a specific area, as it was done in this study.
- Trees and Other Biophilic Elements: Vegetation outside the building can be changed in the 3D model upon performing the daylighting analysis.
- Interior elements: Interior elements, such as location of semi-permanent or movable objects, like shelves, furniture, etc.

Five simulation scenarios were created in each software applications:
1. 3D model without trees
2. 3D model with trees outside the building
3. 3D model with extra use of curtains on windows located on the South side
4. 3D model with furniture
5. 3D model without furniture.

In the final step, daylighting analysis was performed by configuring several additional inputs depending on the scenario selected. As it can be observed from the above scenarios, the first two scenarios include changes in exterior elements, while keeping interior properties the same. Scenario 1 includes the analysis of the building in its 3D model without trees. Scenario 2 uses the same model and adds trees to the outside locations as shown in Fig. 3 for Insight and Fig. 4 for IES. Scenario 3 adds extra interior shading to the South windows. For Scenario 4, the 3D model with furniture was used to capture the impact of changes in interiors (Fig. 5).

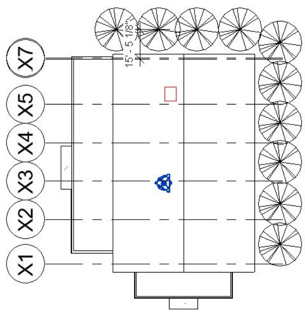

Figure 3: 3D model with trees in Insight (note North to the left side).

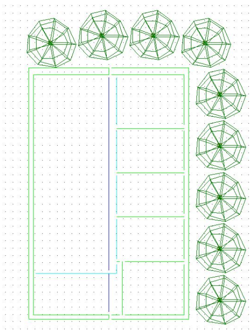

Figure 4: 3D model with trees in IES (note North to the left side).

Figure 5: SEED building with furniture.

Results

The analysis was performed over the semi-open areas of the building, as West and South sides. West side has the entrance, whereas South side has curtain walls and additional windows. When IES was analyzed with clear sky and without trees, the illuminance values lied in the range of 1800 lx at the South-West intersection and around 600-1200 lx at South (Fig. 6). Similarly, Insight resulted in a more than 1500 lx close to windows and at the South-West, however the range was broader to be 600-1200 lx at the South (Fig. 7).

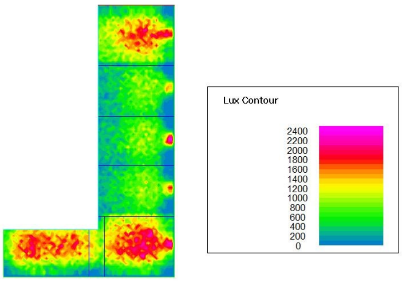

Figure 6: IES graphical result without trees.

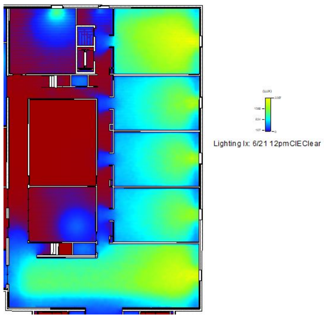

Figure 7: Insight graphical result without trees.

The analysis with trees needed more configuration for precise analysis. While both programs use CIE Standard sky conditions, each software interpreted trees and curtains differently. Transparency of trees and curtains as components in Revit determine the amount of light that pass through these objects. The value of transparency was set to 90% for both trees and curtain in Revit. IES calculated the impact of the trees using reflectance and roughness of the trees. A default 3D cherry tree provided by IES was used with values of (0.2) red reflectance, (0.9) green reflectance, (0.1) blue reflectance, and (0.3) roughness. Dimensions of the trees were selected to be the same in both software applications. As it can be observed in Fig. 8 and Fig. 9, the inclusion of trees as diminished lux values 1200 lx from 1800 ls in IES and to 200-1000 lx range in Insight.

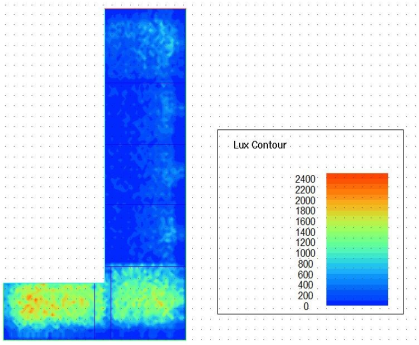

Figure 8: IES graphical result with trees.

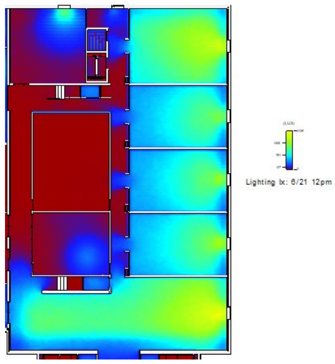

Figure 9: Insight graphical result with trees.

While the curtain was modelled using an in-place mass tool, IES provided default curtain for window. The impact of the curtain in IES was determined by a parameter called Shading Coefficient. Since white linen was assumed in both programs, the shading coefficient in IES was set to 0.54. The results in Fig. 10 show that curtain shading had a similar affect to the inclusion of trees, however decreased the lux values slightly less compared to the addition of vegetation. With curtain shading, the illuminance values were down to 600-800 lx at the South side. Fig. 11 shows that Insight has similar results with the curtain addition and have lux values between 107 and 719 at the South side.

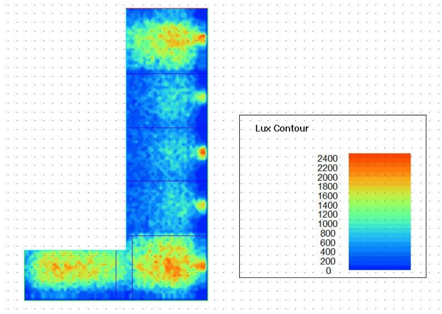

Figure 10: IES graphical result with curtains.

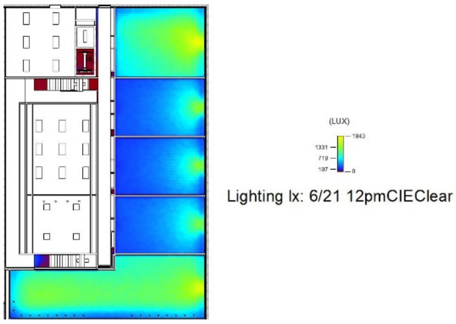

Figure 11: Insight graphical result with curtains.

When scenarios with and without furniture were evaluated, it was seen that they have minnow fluctuations to the lux values in both software applications, and the main impact was caused by vegetation at the exterior side and shading devices at the interior side of the building.

Conclusions and Discussions

This study investigated how changes in interiors, such as shading and furniture, and in exteriors, such as vegetation and trees, would affect the amount of daylight observed by the building occupants in a campus building by using two software applications as IES from Radiance and Insight from Autodesk. Design parameters were changed to simulate five different scenarios in performing a daylighting analysis in conjunction to the 3D Revit model of a campus building. Results showed that, IES and Insight give similar metrics in a scenario without trees and vegetation around the building. However, when trees are included, excessive shading and a considerable decrease in IES is observed compared to Insight. When the software tools were analyzed with and without furniture, graphical and numeric representations resulted in similar metrics in terms of lux values. This suggested that the inclusion of additional furniture as interior elements did not considerably affect the daylighting values. On the other hand, when another interior object such as a curtain was added to the model as a shading device, it created similar results in both software applications with a decrease in lux values, even if regular windows were in place without shading.

It should be acknowledged that the same 3D Revit models were used in both software applications, however additional parameters needed to set in the software applications as per their simulation engines and input requirements. With similar parameters set, they ended up validating one-another's results, except the case of result with trees. Metric results showed significant correlation between the lux values of IES and Insight daylighting values. Both IES and Insight were found successful in daylighting analysis under changing design parameters.

Findings indicated the impact of the changes of interior and exterior elements. As these elements are mainly created in Revit, the advancement and properties of the Revit model should be considered in daylighting analysis. Revit gives various options in the information as well as the appearance of certain elements like vegetation that can drastically impact the results of the daylighting analysis. As an example, Revit allows transparency to be changed in trees. Users need to decide how much transparency should be used for vegetation in the Revit model to mimic the actual case as much as possible and to produce reliable daylighting simulations.

For future studies, daylighting parameters can be configured in Revit based on the details and properties known and required at different phases of a project such as design development or construction documentation. As built daylighting analysis will only allow to change minor features in a building that may not improve daylighting as needed.

Acknowledgements

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Value Generation of Companies and Customers by means of Innovation: a Case Study of a Metro Rail Concession

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Abstract

Innovation is seen as a determining factor for economic growth, productivity and competitiveness. The application of new ideas to products, processes or other aspects of the activities of the organization leads to an increase in "value". The investment in innovation of the metro rail system increases the benefits to its operation. As an example, a single line deployed is capable of transporting about 60 thousand passengers per hour / direction, with the car and the bus having a capacity of only 1.8 thousand and 5.4 thousand passengers, respectively. The objective of this study is to analyze how a utility in the subway rail segment generates value for the company and customers by means of the implementation of innovations. In order to achieve the proposed objective, a specific project of the studied concessionaire will be approached. It generated a considerable increase in the revenue and quality of services provided, since it increased safety and reduced the time per trip. The results explored are the organizational structure of the concessionaire, the main stakeholders, strategies for value generation, and the challenges for implementing innovation as well as the perceived value for the company and for the customers.

Keywords: *award, innovation, outcome, value generation.*

Introduction

The economic, social and urban infrastructure and the process of developing a region or country have a high degree of correlation. According to the Institute of Economic Applied Research (IPEA, 2010), the availability of infrastructure in a territory is an indicator of its development conditions. In this sense, providing a region or country with a proper infrastructure, by means of planed investments, is vital for increasing the social and economic indicators. In social terms, the benefits of implementing systems on rails propitiate a high availability of transportation. A single line implemented is able to transport near 60 thousand passengers by each hour/direction. On the other hand, car and bus have a capacity of only 1.8 thousand and 5.4 thousand passengers, respectively. Besides, systems of rails propitiate the increase of mobility in urban centers, incrementing the quality, security and regularity of the public transportation for the population.

The late development of the country, the lack of resources and the industrial and population concentration made several cities of Brazil to fight the challenge of serving the demand of collective transportation in an efficient and effective way. Ramis and Santos (2012) emphasize that governments must improve the accessibility to urban centers so that the collective transportation fulfills the needs of mobility. However, the lack of investments needed by the systems is making the population of the Brazilian urban cities to suffer with the terrible conditions of the public transportation, involving: overcrowding, lack of trust regarding time sheets, slowness of deployment, old vehicles, expensive tickets and others.

In this context, Campos (2009) says that a quality product is the one that perfectly fulfills, in a trustable and safe way and at the right time, the needs of the customer. Thus, the objective of this work is to analyze how a concessionary of the metro-railway segment generates value for the company and customers by implementing innovations. In order to reach the proposed goal, a specific project of the studied concessionary that generated a considerable increase in revenues and quality of the services provided will be approached.

Literature Review

Public-Private Partnership Agreement (PPPs)

The end of the 20th century was marked by a series of movements for privatizing state companies and the concession of services of public utility. Brazil was influenced in a significant way by such movements, which had, in the middles of the decade of 1990, the apex of both privatizations and transfer of concessions to private operators. According to Correa et al (2002) the Brazilian program of privatizations was one of the greatest in the world, involving the sale of assets that totalized, approximately, US$ 80 billion.

However, the fact of a State privatizing and granting to the private initiative the management, maintenance and operation of services and public utilities, does not guarantee, alone, higher levels of quality for the society. Thus, the emergence of those new relations between State and private sectors did not have the creation of mechanisms to fulfill the requirements of the society, preserving the competitiveness of sectors of the economy and fair prices to final users (Salvatori & Ventura, 2012; Bastos & Macedo-Soares, 2015). Thus, the factors leading to create a PPP are related with: 1) the possibility of transferring for activities of the public sector the “stimulating characteristics of innovation and managerial skills” maintained by the private partner that will incorporate efficiency in public services (Medeiros, 2004); and 2) the use of private resources in order to make investments in public services, which will allow public resources to be directed to other areas of public interest and better efficacy in the use of resources focused in providing goods related with infrastructure (Hodge & Greve, 2007).

PPPs have also been adopted to control delays and high costs in public works, increasing the efficacy in projects management and reducing maintenance costs and the operation of public enterprises. The most common benefits associated with partnerships are: introduction of innovations in services provision; allocation of risks for parties more able to manage them; efficient management of building and operating risks; increase of operational performance and others (Grilo, 2008).

For the specific case of the metro-rail system, the intervention was needed for modernizing the system, having a planning to expand the rail network with implementation of new stops, acquisition of new trains, replacement of signaling networks, new lines to serve cities that still do not have transportation on rails, serving a demand of the society that needs mobility and the whole accessibility infrastructure (Silva & Estender, 2015).

Strategic Planning for Business Innovation

In order for the company to become competitive, it is necessary that it knows its needs, limitations, capacities and skills. Tavares (2000) says that it is in the "Strategic Planning (SP) that the company discovers those internal demands, which may be satisfied in the future, on its business scope". In this sense, the scenario analysis is extremely important for the life of an organization. The SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis is a technique used for the management and strategic planning of the companies (Fig. 1).

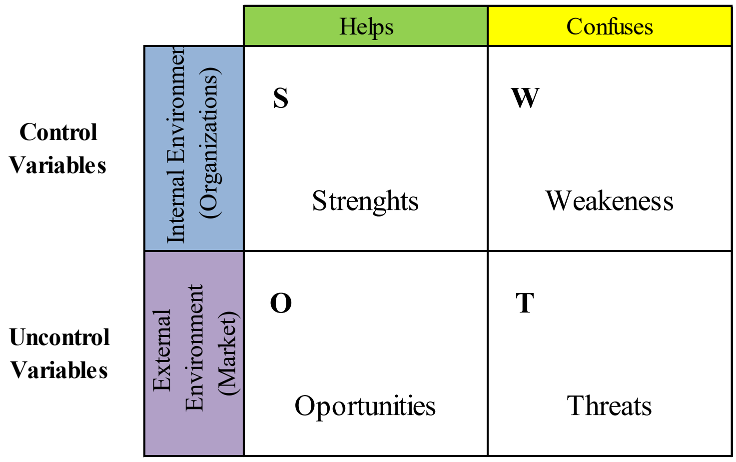

Figure 1: SWOT analyses (Ferrel et al., 2000).

The Strategic Planning of Innovation (SPI), is inserted according to the SP of the company. It stars with the collection of information from the internal and external environments, opportunities, threats and with the analysis of this information made by the Board of the company. This information helps to implement the strategic planning in the company, improving its performance. Thus, those activities will subsidy the decision taking in order to define which strategy the company will implement, aligning it with its environment because the company is inserted in a unique environment, but where there are constant modifications (Coral et al., 2009).

Value Chain

The value of an asset is related with what the customer is willing to pay by this asset. The value chain creates, sequentially, the delivery of this value to the customers. The organization has a competitive advantage by executing the primary and secondary activities in a "cheaper" or better way than the concurrency (Porter, 1990). For the case of a concession, this becomes interesting in terms of business sustainability and possible contract renewal, since the business becomes viable for everyone involved.

According to the model developed by Porter (1990), all companies consist in a resume of activities executed to project, produce, sell and deliver a product. All those activities may be exposed by means of a value chain, exhibited in Figure 2. The value chain of an organization and the condition how it executes its individual activities, is a consequence of its history, of its strategy, of its actuation executing its strategy, and of the basic economy of the activities themselves (Porter, 1989).

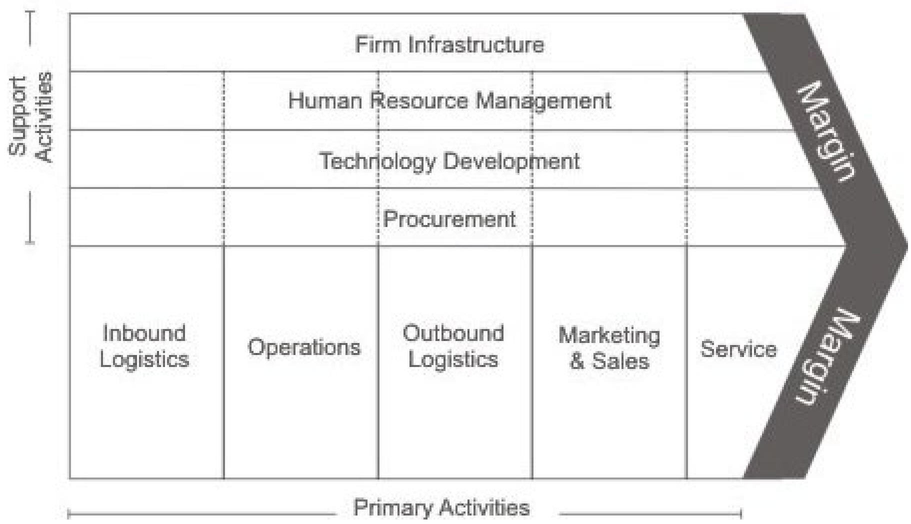

Figure 2: Value chain (Porter, 1989).

Regarding value for the customer, Mello and Leão (2008), describe three analyzes for understanding. The first one regards the value of the product for the client, in other words, the evaluation made by the client about the relation between benefits and perceived costs. The second one is about the value of the client for the company, concerning the value that a customer has for a company during the relationship and consumption period. The third one is the customer value, in other words, how people express their personal values by means of specific activities, among them the consumption.

Regarding companies operating the metro-rail system, one value such as a competitive differential is the quality of the services provided. Thus, companies well succeeded in their business acknowledge being essential to have a high quality of service (Parasuraman et al., 1988) allowing a greater profitability, greater loyalty of customers (Lewis, 1994) and decrease of production costs. Gronroos (1982) presented two aspects of the quality of service; the technical quality regarding results that the customer could receive after the service and the functional quality, regarding processes allowing to deliver the service to the client. In this sense, Allen and DiCesare (1976) consider that quality is divided into two categories: for the user, including aspects such as speed, reliability, comfort, convenience, security, special services and innovations; for the non-user, including aspects such as the efficiency of the system, pollution and search.

Research Methods

The methodology is divided in two stages. The first stage consists in a literature review about relevant concepts for the study of the proposed theme. The second stage of the research consists in a qualitative approach and the chosen method was the single case study (Yin, 2005), due to the specificity of the theme. For data collection, semi-structured interviews were used, besides the analysis of documents, such as projects, contracts and procedures. The research followed a script of semi-structured questions focused on obtaining data on: the project's objectives for the company and society (value generation); the technical executive challenges and the process challenges (design, communication, time, cost); and the opportunities generated for the company and professionals involved. Data collection followed four steps: 1) application of the questionnaire; 2) observation of the techniques adopted and the applied processes, through visits to the workplace of the interviewed professionals and other professionals involved; 3) analysis of the documents used; and 4) conversations with members of the project teams, in order to identify factors that impacted the implementation. Four professionals with more than eight years of experience in project management and control were interviewed. In this specific case, those professionals participated in the implementation stage of the studied system.

The criteria for selecting the case were: access by the researchers to the key-stakeholders and project documentation. Based on the criteria presented, a company from the segment of large size concessions was selected. For the choice of the case the characteristics of the project contributed because, by being unique, however of large size, it had the complexity of acting in two distinct processes: building and operation and maintenance of the system. The company is a public-private concession (PPP) providing services of urban transportation by means of the commercial operation and maintenance of the urban passenger rail network of an important Brazilian state. The time of concession is 25 years. This deadline comprehends the implementation of several improvements in the subway network; one of them is the object of this study.

Project Description

The Signaling Project, as a part of this study, is an incremental innovation and consists in implementing the metro-rail signaling system automatic train protection (ATP). This is a system of automatic protection that happens by means of the oversight of train speeds, making impossible for the train driver to exceed the speed limit previously established for each track of the track way and overtaking during red lights. Another function of the system is to oversight the speed that guides the train driver by means of a display called Man Machine Interface (MMI) installed in the cabin of the train, informing the speed profile to be followed (based on the maximum speed allowed in each track, considering the positions of the loading and unloading platforms, curves and other restrictions such as, for instance, track maintenance for a greater gain of performance during march. Implementation of the project has as main objectives: 1) To reduce travel time, by using the system automation; 2) To improve the security of users, considering the mechanisms of stopping in case of speed over the allowed one; 3) To reduce the periods of system maintenance, considering the automatic operation of the system; 4) To generate value for the concessionary, both financial by means of the Return of Investment, as well as for the image of the company, regarding client, users and others.

Results

Strategies for Business Innovation

A characteristic of contracts type PPP is the investment in improvements of the system and in the innovation of services aiming, as a consequence, to improve the customers' service and the increase of revenues to the company. The business strategy is the starting point for the direction that the company wants to follow. Aiming to know the strategy of the company, means are sought in order to address the data and the information in an efficient way. Table 1 shows the potential of value generation for the concessionary, from the SWOT analysis.

The main strategy for generating value for the concessionary is the investment in innovation of the existing structure, in order to potentiate customer service, by implementing more modern equipment and by the accessibility and enlargement of the metro-rail system, besides reducing the travel time of the railway composition, which would double the amount of travels.

Table 1. Potential of value generation of the business.

Internal Environment (Organizations)	**Strenghts**	Increase of security of passengers transportation
		Investments in innovation
		Quality of Service (speed, accessibility and others)
		Client Satisfaction
		Market Strength
	Weakeness	Very Old Rotating Material
		Stops to maintenance of the road
External Environment (Market)	**Oportunities**	Enlargement of the metro-rail mash
		Increase of Revenue (number of travels/day)
		Improvements of metro-rail control systems
	Threats	No payment category
		Competition with other modalities of transportation
		Interface with border communities
		Single Transportation System

The creation of a value chain by the company is the differential between the cost of opportunity of all production for the service and the willingness in offering satisfactory prices for its customers, because the goods and services offered to the market are economically adjusted with a maximizing of economic profits, and this propitiates a return of the investment made and the offer of prices that leads the company to have a spotlight regarding its direct competitors. Fig. 3 shows the chain value used by the concessionary being studied.

The main activities of the concessionary are important for maintaining the innovation processes. The analysis of innovation demands prioritize the implementation of the projects, the analysis of performance evaluates if the quality is inside the standards established, quality of service regards the perception of customers and the management of processes ensures the operation of this cycle. In support activities, client service is related with the benefits reached implementing the innovation, the support of the Board and Managers is important for the good progress of the projects, definition of priorities stipulates the order of internal investments and hiring new technologies is related with the implementation of projects.

Margin is the generation of productivity gains, personal satisfaction, motivation, reaching the goals of the strategic planning, organization image and contribution for society. In face of what was exposed, the conception of value chain of the concessionary propitiates an analysis and a connection of resources in order to recognize how its processes are operationalized and what are the results in the route for reaching the strategic goals, thus allowing the value generation to internal and external clients of the services delivered.

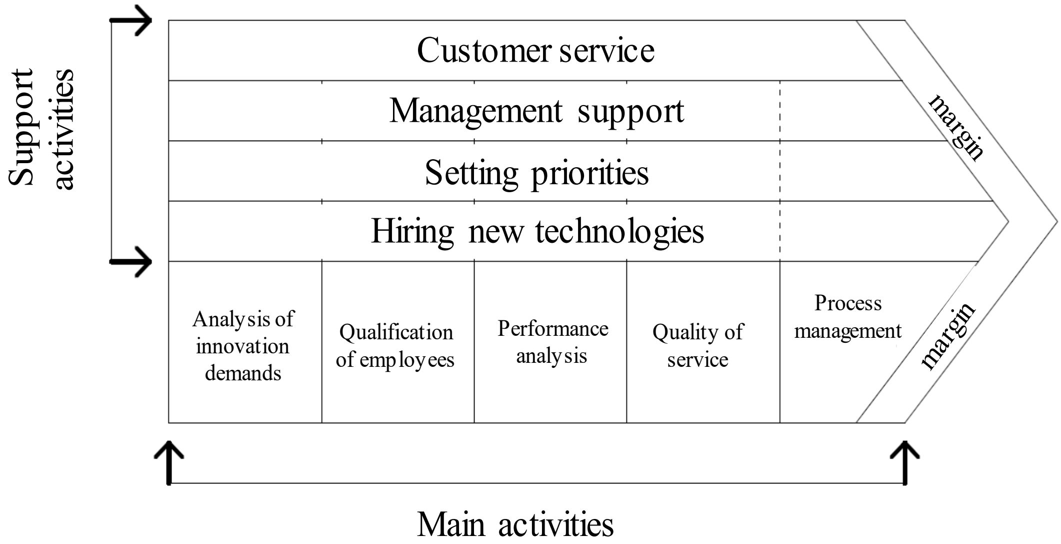

Figure 3: Value chain of the concessionary.

Challenges for Implementing Innovations

The challenges previewed for implementing the signalization project, both on the technical part as well as on the organizational one, despite being studied and considered in the risk matrix of the project during implementation, prove to be more significant and with greater impacts than the forecast ones. Regarding the technical part, it is worth to highlight: 1) Precarious condition of existing equipment; 2) Lack of functionality projects of equipment; 3) Large extension and diversity of regions surrounding the roads; 4) Joint implementation with the operation. In the organizational part highlights for: 1) Defining the priorities and responsibilities of the project; 2) Training the teams for operating and maintaining the system; 3) Strategic alignment of the project with the customer needs; 4) Communicating with customers, specially government and users, about delays implementing the project.

The implementation of the process was made by overlapping the current signaling system, in a track built during the imperial period, whose maintenance process remained stagnant without follow-up of technologic advancements during several years and with a still active train fleet, manufactured in 1963. Even knowing this history, the hired company had great difficulties for developing equipment allowing the compatibilization with old equipment. In many cases, engineering costs significantly exceeded the planned estimation, which could compromise the value analysis for the concessionary.

Due to the advanced age of the train network, several equipment did not have operations manuals and projects of functionalities, demanding studies and the development of those projects by the hiring company in a much greater amount than the one estimated. Because of that reason, the deadlines for concluding the first stretch of the rail-way project were postponed more than once, because every week emerged a new need of adequacy to the existing structure. The good communication with the customers was an essential factor for managing the expectancies regarding the system operation.

Activities of project implementation were happening in parallel to the operation and all infra-structure activities along the tracks they passed by large restrictions of access and times, since the programs were disputed with the system maintenance. Thus, the proper training of the team involved both in operations as well as in maintenances of the system was very important for the progress of the project. The integration model for project management, focused mainly on the constant changes of the scope of the innovation projects, greatly helping the implementation of the new technology. Fig. 4 shows the model of Project Management.

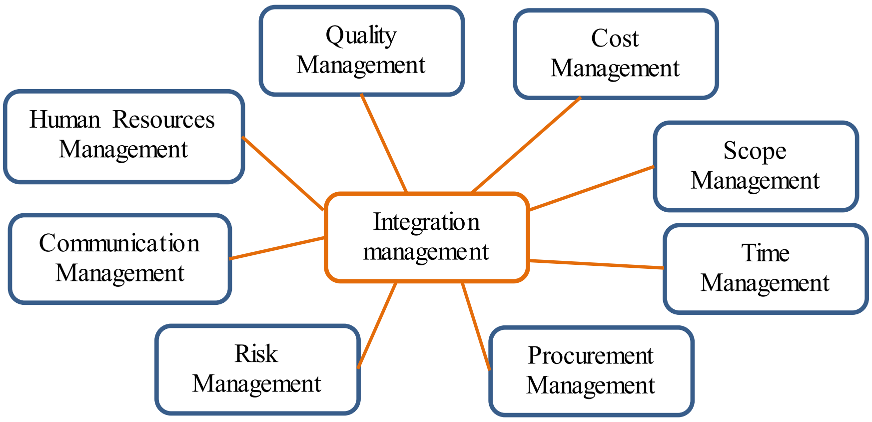

Figure 4: Integration model for the project management.

Value Perceived for the Company and for Customers

As detailed in the work methodology, the implementation of the signalization project had well defined goals for understanding the interests of the concessionary and of the customers. Item 1) Reduction of the travel time, serves the customers with regards to travel optimization and serves the company with regards to the increase of passengers using the metro-rail system. Item 2) Increasing the safety of users, due to the speed control, reduced the number of accidents of the trains, preserving the physical integrity of the passengers and system operators, as well as reducing passives for concessionaries and the number of stops of the compositions and of the railway for maintenance of problems caused by accidents, corroborating with item 3) Reducing maintenance periods of the system, in this point, under the perception of the client, the compositions continue to circulate fully, keeping the number of planned trips. Item 4) Generating value for the concessionary, benefits the concessionary because a good operation of the system, fulfills the expectancy of trips bringing return for the investment, leading to new investments in the systems that, in consequence, keep a good image of the concessionary in face of the customers, specially, for the contractor. For the customers – users of the system – this item drives the constant improvement of the system used.

For implementing the signalization project, approximately 250 million Reais were invested, during a period of 3 years, expecting to reduce by half the travel time for each railway branch. According to data from the year report issued by the concessionary, in 2016 more than R$ 100 million Reais were invested in the metro-rail system. Investments in maintenance and renewal of the fleet made the average mileage rounded between failures (Mean Kilometer between Failure – MKBF) to surpass in 133% the year of 2015. Gross Operating Revenue of 2016 reached $ 638.5 million, a growth of 10% regarding the previous year and this growth is a reflex, mainly, of the increase in the number of transported passengers.

Conclusions

The objective of this work was to identify how investments in innovation generate value for a concessionary of metro-rail transportation. This study took place from the analysis of an important project of the concessionary and how the innovation sector relates with the others, because this relationship explains, largely, the good performance for implementing the projects. In the case studied there was a large interface with the team of system maintenance, besides the need of training the operators of the new system implemented, for the regular service of the users.

The second point regards the strategic planning of the company. This tool allows to establish a panorama about how is the company and the strong points with potential for growth and the weak points for improvement. Besides, it is possible to draw the strategies for having advantage in each new project, more specifically, what generates value both to the company as well as to the customer, identifying the stakeholders involved for a better comprehension of this process. Finally, it is worth to highlight that, in the case study, the investment in innovation brings benefits for everybody involved. On the one side, the company improves the results of the business and continues to invest in new technologies; on the other hand, customers are serviced with more quality and agility.

As a contribution for literature is the relation that investments in innovation generate value for those involved from the following proportions: 1) Companies start to perceive the importance of the customer under the optic of the business and to turn its attentions for it and not only for the product itself; 2) The technologic evolution allows to improve the services from the needs of business and customers.

The study of a single case has a limitation inherent to the methodology adopted, however the option by it was due to the specificity of the sector of metro-railroad concessions and due to the fact that few studies exist exploring the proposed theme.

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Correlations between the Factors of Verbal and Non-Verbal Communication

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Abstract

Effective communication plays an important role in the success of construction projects. In recent years, studies showed that non-verbal communication is as effective as verbal communication for trust building, collaboration, conflict resolution, and motivation. The purpose of this study is to explore the dependencies between verbal (communication system) and non-verbal (emotions and moods) communication. Correlations can define cause and effect relationships. Two different questionnaires were administered that used two different models for verbal and non-verbal communication. Positive and Negative Affect Schedule (PANAS) method is used to assess non-verbal communication and Organizational Communication Capability Model to assess verbal communication. The correlations are analyzed based on the answers of these questionnaires. Forty-five valid questionnaires were received. A negative high correlation was found between the maturity of organizational communication and negative moods. A high correlation was found between the maturity of communication capability and emotional management behavior. A low correlation was found between the maturity of communication capability and positive moods.

Keywords: *construction management, communication, correlation, non-verbal communication.*

Introduction

Researchers stated that for project success or failure communication has an important role (Maier et al., 2006, Emmitt & Gorse, 2007), for this reason communication must be understood and organized affectively. Especially in complex processes as construction, communication plays an important role because, for a single individual, it is not possible to run all the construction process, different professionals from related fields participate. Construction is a goal and project-oriented process which every person work for different tasks and need different kind of information but around the same goal. Emmitt and Gorse (2007) stated that effective communication is very important in construction between teams and individuals to be successful of the construction process. Effect of communication in construction has become an important topic since 1960's and informal communication is analyzed in the study of Higgin and Jessop (1965).

In a traditional way, the success of a construction process can be assessed by the variables as time, cost and quality (Zuo et al., 2018; Ejohwomu et al., 2017). However, researches showed that, one of the main factors of the failure of a construction process is the failure in soft skills. There are many soft skills that can be defined, and effective communication is one of these skills (Zuo et al., 2018). According to Mulcahy (2009), communication is the most frequent problem in every project and project managers spend 90 percent of their time communicating. It is important to find the gaps in the communication process. Besides that, in construction project management, communication is the most important factor for success because leadership and decision-making process depends mostly on the effectiveness of the communication. And effective communication can decrease the level of effectiveness and performance of a company, while poor communication can cause misunderstandings (Greenbaum, 1974).

In the organizational communication system, the factors defined mostly listed as verbal communication factors. But in recent years, it has been found out that emotions and moods are important for constructing an effective communication system. Also, most of the soft skills of project management professionals are affected by non-verbal communication factors (Zuo, 2018). The assessment of the overall organizational capability maturity of an organization can be possible with the organizational communication system, moods, emotions, and interdependencies between them. However, factors that affect organizational communication system are mostly defined without the emotions and moods that can be called as non-verbal communication, emotions and moods cannot be separated from the work environment. Non-verbal communication variables including emotions and moods are defined and analyzed with the method PANAS (Positive and Negative Affect Schedule).

The aim of this paper is to examine the correlations between the factors of organizational communication and emotions and moods. It is important to find out the maturity level of communication in a construction company but it is also very useful to point out the correlations between the factors and emotions and moods because interdependencies can be used for finding out the deep causes of the problematic points of the factors. This assessment is required for taking the organization to the next level in the effectiveness of organizational communication.

Organizational Communication System

Organizational communication system defines organizational communication in a systematic way that consists of aim, units, and interdependencies. The subject of defining an organizational communication system is limited in the literature. General system definition is based on aim, separated units and interrelation of these units. System theory helps to put together the separated units of communication together and linking the communication activities and elements. So, by this approach it is important to visualize the factors as an integrated whole. In this research organizational communication system is analyzed based on goals, units or factors that operate together and the interdependencies of the factors (Blazenaite, 2011). To analyze the organizational communication system, it is important to find out the units of this system which are called the factors that affect communication.

There are many researches that define the factors of organizational communication. Ference (1970) stated that many factors affect the process and the information processing in the communication system. He analyzed the decision process of the individuals and at the communication system definition focused on the information sending and receiving process of the individuals. Greenbaum (1974) defined organizational communication in terms of message sending and receiving activities as Ference (1970) but defined the communication system in terms of purpose, operational procedures, and structure. He stated that these parts of the systems are interdependent and affects each other. There are many variables that he defined as, policy statements, procedures, rules, problem solving, adaptation to change, implementation of new ideas, promotion, information, and instruction that enables the work done. Shelby (1993) analyzed the boundaries of communication in terms of organizational, management and business communication and stated that the system is essential for communication. Constructing a conceptual model based on the structure and system of organizational communication starts with the finding out the variables of the system and interactions between them. Communication system is several related units that operate together to reach a common goal (Blazenaite, 2011). Emmit and Gorse (2007) claimed that some of the main factors that affect communication are team building, sharing values, solution of minor differences and conflicts, asking questions and creation of trust between team members in construction companies. Te'eni (2011) suggested a cognitive-affective model to make the organizational communication more effective by changing the medium and attributes of the message itself. The aim of the study of Te'eni is to design a technology to make communication more effective. This model is developed based on the three main factors of the organizational communication that are impact, process, and inputs.

Maier et al. (2007) defined 27 factors that affect communication in their study which are representation, notation, terminology, needed information, availability of information about competitors, availability of information about company, availability of information about procedures, availability of information about product specifications, hierarchies, usage of procedures, roles and responsibilities, activity at interface with the other party, handling of technical conflicts, transparency of decision making, application of corporate vision and values, common goals and objectives, mutual trust, best practices, collaboration, team identity, project reviews, lessons learned, overview of sequence of tasks in the design process, autonomy of task execution, generation of innovative ideas, education and best use of capabilities. In the study of Maier et al. (2011), they defined more than hundred recommendations to improve communication in design. 63 engineers are selected to recommend factors and asked to define their position and the projects. Besides that, some recommendations are taken from the literature. Results of the interviews are as follows,

- Four major sets of factors effects communication which are information, individual, team and organization,
- 24 out of more than hundred are selected as most frequently mentioned factor

In this study, questions based on four major sets of factors are used in the questionnaire to analyze the organizational communication system.

Emotions and Moods

Factors that affect organizational communication system are mostly defined without the emotions and moods that can be called as non-verbal communication. Non-verbal communication variables including emotions and moods are defined and analyzed with the methods PANAS (positive and Negative Affect Schedule) and Emotional Behavior Management Method. Emotions play an important role in non-verbal communication. Researches show that more than 50 percent of communication is affected by non- verbal communication. In recent years, emotions became an important topic in the organizational context. You cannot separate the emotions from the work environment especially organizations which the human factor is important for communication. Crawford (2007) stated that emotions consist of three different components as,

- Feelings are what we experience
- Emotions are feeling that we express.
- Moods are feelings that became stable.

It is hard to measure non-verbal organizational communication. It is important that how the participant feel about the non-verbal communication. PANAS will be useful for measuring those feelings. The Positive and Negative Affect Schedule is one of the most widely used affect schedule model which measures self-report mood. According to Watson et al. (1988), high PA means energy, pleasure engagement and concentration and low Pa means sadness and lethargy. Similarly, high NA means distress and unpleasurable engagement and low NA means serenity and calmness. There are many scales about PANAS but although strong models find out a high correlation between negative and positive moods, there are also anomalous findings that positive and negative moods have insignificant correlation. Watson et al. (1988) state that short PA-NA scales are not reliable and very long scales have reliability problem. Besides that, the sensitivity and reliability of the correlations of the PANAs model depends on the time frame.

Table 1. 10-item PANAS model of Watson et al. (1988).

PA	NA
Interested	Distressed
Excited	Upset
Strong	Guilty
Enthusiastic	Scared
Proud	Hostile
Alert	Irritable
Inspired	Ashamed
Determined	Nervous
Attentive	Jittery
Active	Afraid

In this study, a 10-item PANAS model of Watson et al. (1988) is used which consists of 10 positive moods and 10 negative moods by using the 5-point Likert scale where 1 means never and 5 means always.

Methodology

The maturity level of organizational communication system can be assessed by using a maturity model. Maturity model can be defined as a staged approach to improve a system or process. The development of a process on a desired path stage-by-stage can be seen by maturity models (Arif & Al Zubi, 2017). Maturity Grid method is taken as a base for the C-CMM (Communication Capability Maturity Model) which has different maturity level definitions in each maturity level of factors. Capability Maturity Model is redefined to define C-CMM. For assessing the level of emotions and moods in the communication process, PANAS questions are applied to participants.

A questionnaire is designed for assessing communication maturity level of construction companies. Maturity grid approach of Maier et al. (2006) is taken as a base for its maturity grid approach but the levels of maturity are changed according to Capability Maturity Model that the levels are defined again for Communication Capability Maturity Levels. Questions are from the literature, which defines the factors, and key factors that affect the communication process of the organization. Besides these questions, a Delphi study is conducted both for if extra questions are needed and to assess the weighted values of each question which means the weighted effects of each factor to the organizational communication. It is hard to measure non-verbal organizational communication. It is important that how the participant feel about the non-verbal communication. PANAS will be useful for measuring those feelings. The Positive and Negative Affect Schedule is one of the most widely used affect schedule model which measures self-report mood. Communication Maturity Level Questionnaire is sent to nearly 100 people but only 45 of them responded which 5 of them are not completed. The ages of the participants are between 24 and 63 mostly centered at the ages 30 and 35. 63 percent of the participants named under 'Architects 'that are architects and interior designers and 37 percent of the participants named under 'Engineers 'that are civil engineers, electrical engineers and mechanical engineers.

Results

When the correlations between the key factors of the verbal communication are analyzed, the interpretation of correlation coefficient is done according to literature as follows.

- High correlation if correlation coefficient is between 0.8 and 0.6
- Moderate high correlation if correlation coefficient is between 0.6 and 0.5
- Moderate low correlation if correlation coefficient is between 0.5 and 0.4

It is important to analyze the interdependency of communication system and emotions and moods. As seen from the Table 4.4 there are many correlations are defined between communication capability maturity level, positive moods, negative moods.

Table 2. Correlations of C-CMM and emotions/moods.

	Communication Capability Maturity Level	Positive Moods	Negative Moods
Communication Capability Maturity Level		0,35	-0,55
Positive Moods	0,35		-0,44
Negative Moods	-0,55	-0,44	

The correlations are as follows,

- There is a negative moderate high correlation between communication capability maturity level and negative moods. It means that negative moods have a negative effect on the effectiveness of the organizational communication.
- There is a negative moderate low correlation between positive moods and negative moods with the correlation coefficient -0.44.
- There is a moderate low correlation between emotional management behavior level and positive moods with the correlation coefficient 0.43.

It is not surprising that there is a negative moderate high correlation between communication capability maturity level (CCML) and negative moods. It means negative moods of the employees of the organization impact the maturity level of organizational communication. But it is surprising that there is lower than the moderate low correlation between communication capability model and positive moods.

The assessment of the overall organizational capability maturity of an organization can be possible with the organizational communication system, moods, emotions, and interdependencies between them. Interdependencies can be used for finding out the deep causes of the problematic points of the factors. This assessment it required for taking the organization to the next level in the effectiveness of organizational communication and also for the other areas such as productivity and organizational effectiveness which are affected by the level of organizational communication.

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Potential of BIM for Decision-Making in Public Infrastructure organizations of Pakistan: Assessment through ICT practices

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Abstract

Infrastructure organizations go through extensive decision-making and face multiple challenges in different stages of a project life cycle, such as planning phase, monitoring and review phase and maintenance and repair phase. The decision makers are required to make best decisions by making critical analysis of the situation in order to produce best results. Literature and best practices around the world has established the fact that Building Information Modeling (BIM) can be useful for improving the quality and effectiveness of decision-making in infrastructure management organizations. However, since the BIM utilization for infrastructure management is still under evolution, it is necessary to assess adoption potential of such organizations for BIM. One of the hypothesis is that the current use of information and communication technology (ICT) can highlight the readiness of the organizations to adopt BIM as a tool for decision-making. This study presents a similar assessment for Pakistan. Nine public infrastructure organizations were studied in detail and interviews were also conducted to determine the potential of BIM for decision-making in public infrastructure organizations of Pakistan. These organizations included; public educational institutions' maintenance departments, highway organization, works department, water supply organization, infrastructure development organization, port infrastructure organization, and gas supply organization. First, conceptual information flow for decision-making in public infrastructure organizations was established through literature review. This conceptual flow was used to identify the different (1) phases (2) factors, and (3) decisions under the three major functions of infrastructure management organizations. These functions included; project planning, monitoring and review, maintenance, repair and operations. Thereafter, considering the conceptual information flow, the organizations were studied by the research team. This was done through in-person observations of various decision-making functions alongside interviews from the experienced personal involved in decision-making at these organizations. As such all the assessments were performed purely in qualitative manner. From a macro level perspective, the overall potential for BIM adoption was less encouraging. At functional level, it can be said that organizations were found "partially or moderately ready" for *project planning*, "not ready" for *monitoring and review* and "moderately ready" for *maintenance, repair and operations*.

Keywords: *Building Information Modeling (BIM), Information and Communication technology (ICT), Infrastructure, Public*

Introduction

Literature and best practices around the world have established the fact that Building Information Modeling (BIM) can be useful for improving the quality and effectiveness of decision-making in infrastructure management organizations. Logically BIM can be very helpful in Planning, Monitoring and Reviewing, and Maintenance and Repair phases of Infrastructure since it can provide information to the decision makers in a meaningful manner. However, utilization of BIM for infrastructure management is still under infancy and it is hard to prove its practicality for the practitioners. It is therefore important to assess adoption potential of such organizations for effective BIM utilization for all the above-mentioned phases. Thus, this study aims to assess the readiness of BIM adoption for decision-making in infrastructure management organizations. Concept of technology acceptance suggests that a technology is well adopted by an individual or a firm, if it is perceived to be useful and is easy to use. This paper seeks to identify the perception about adoption potential for decision-making in infrastructure management organization. It is achieved by interviewing the professionals of infrastructure management organizations. Finally, conclusions have been drawn based on their feedback.

BIM Adoption for Decision-Making in Infrastructure Management

The decisions related to technological changes are influenced by many factors. The need for innovation is the main cause behind driving such technology adoption decisions. Studies have revealed that the use of advanced technologies is minimal in the construction industry and more emphasis should be directed towards active adoption. The use of BIM in infrastructure has been even slower in its adoption and application as compared to building construction (Kim et. al., 2015). Besides innovation being a basic need, there are other influential factors on which the technology adoption decisions are based. Azhar et. al., (2015) grouped these factors into internal factors (technological, organizational factors) as well as external factors (i.e. Legal and regulatory, information exchange needs and contractual relationships between key stakeholders).

Best practices related to BIM adoption that have been highlighted during the process of BIM implementation internationally were reviewed order to understand the BIM readiness level of any organization. It was deemed vital to assess the current state-of-practice for each of their functional areas. This would help bring a clear picture of where the organizations need to initialize from for BIM implementation. Generally, it was revealed that the application of BIM during the design and construction phase is gaining ground fairly, however much is to be explored and accounted for actively. It was also discussed that governments have started to request that large public facility agencies adopt and implement building information modelling (BIM) in their business processes. In this regard, some have issued BIM guides, however, majority of them are mere technical specifications that are useful at the project level, but provide no support for the organization-level adoption effort (Gurevich et. al., 2017). The conventional protocol for corrective, predictive, preventive maintenance requires for availability of intricate data that usually takes a lengthy time to be gathered; however, BIM could facilitate Real-Time

Data Access (Gerber et. al., 2011) with on-hand availability of all the necessary information at all times.

On account of adoption potential, it was efforts could be directed in the work areas including; Technology, Organization and Process (Staub-French, 2011). These are the basis of any Infrastructure Organization and as part of the best practice, any efforts for BIM adoption should be ordered along these lines. It was also studied that there were usually two perspectives that governed the decision-making processes related to technology adoption. These were the rational perspective and the behavioral perspective; infrastructure organizations were influenced by either of the one in making the technology adoption decision. The literature review was also carried out to study about the decision-making process in infrastructure organizations. Also, it highlighted some of the factors that were crucial in the decision-making process.

Moreover, the advantages of BIM were studied and how it could help make the infrastructure processes better. In general, BIM is regarded as one of the most recent innovations in the construction industry, which resolves the problems of projects faster. BIM can be applied by project participants to achieve objectives such as reducing design errors, reducing time and cost, improving design and construction integration, and increasing coordination and cooperation among different sections (Samimpay and Saghatforoush, 2020). In this regard, several cases were studied for comparison between non-BIM and BIM implemented projects and the differences in their performances were studied. For example; a case of comparative study of two bridges was studied, where the construction of one of the bridges was undertaken through the conventional construction procedure (Fanning et. al., 2014). The second bridge was delivered with first-time implementation of BIM. Both the bridges had the same Project Contractors with exactly same delivery methods; the only difference was the use of technology to execute and monitor the construction. The results at the completion of construction revealed quite notable differences. Despite the heavy costs that were incurred (mainly due to first-time implementation of BIM), there were reduced need of Change Orders (CO's) and Request for Information (RFI's) in the BIM-implemented construction (Fanning et. al., 2014). Also, it was particularly remarked that there was no need for rework on BIM-implemented Bridge, whereas the non-BIM Bridge required for rework of two items. The comparative analysis of the feasibility of both projects proved that BIM could aid in cost-savings overall, however first-time implementation does carry a considerable cost in its own place. In spite of this, the benefits rendered by the technology outweigh the cost burden in long term. In another case study, Bensalah et. al., (2019) found that the integration of BIM into railway projects yielded several advantages such as collaboration, time saving, cost optimization, prevention of conflicts between networks, optimization of facility management, improvement of the quality of works, prefabrication.

Conceptual Information Flow for Decision-Making in Public Infrastructure Organizations

Conceptual information flow for decision-making in public infrastructure organizations was established through literature review. This conceptual flow was used to identify the different (1) phases (2) factors, and (3) decisions under the three major functions of infrastructure management organizations.

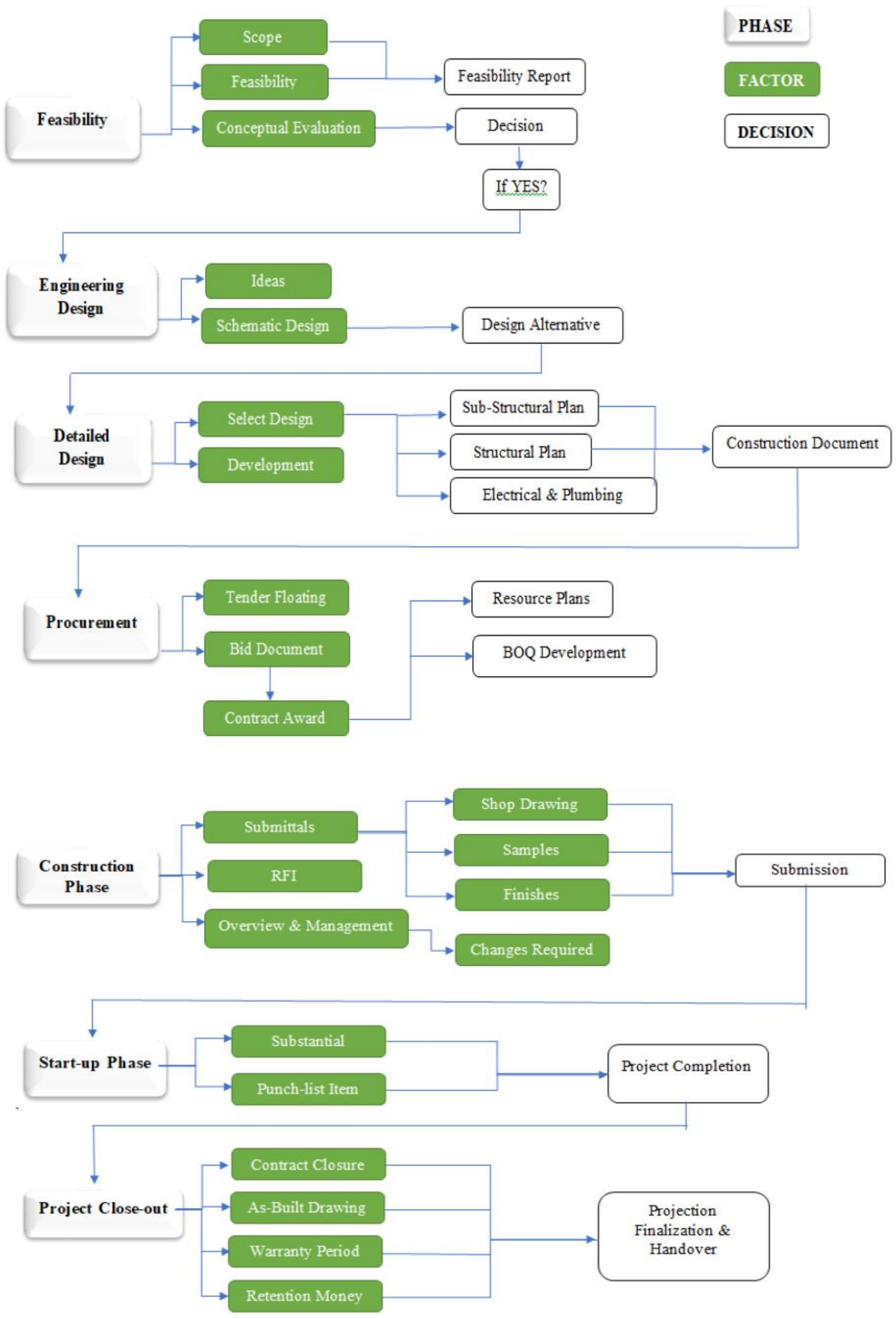

Figure 1. Conceptual Information Flow for Infrastructure Decision-Making

These functions included; project planning, monitoring and review, maintenance, repair and operations. Figure 1 provides schematic representation of the same.

Assessment of BIM Adoption Potential for Decision Making in Infrastructure Management Organization

Considering the conceptual information flow, the organizations were studied by the research team. One of the hypotheses is that the current use of information and communication technology (ICT) can highlight the potential of the organizations to adopt BIM decision-making tool. This study presents a similar assessment for Pakistan. Nine public infrastructure organizations were studied in detail and interviews were conducted. The basic demographical details are provided in Table 1. The assessment was conducted through in-person observations of various decision-making functions alongside interviews from the experienced personal involved in decision-making at these organizations. As such all the assessments were performed purely in qualitative manner.

Table 1. Studied Organization and Respondents' Basic Demographics.

Type of Organization	Infrastructure	Respondents' Designation	Qualification	Experience
Public University	Educational Facilities	Senior Civil Engineer	B.E. Civil	> 15years
Highway Authority	Roads & Highways, Office Buildings.	Deputy Director	B.E. Civil, MEM, ME Transportation	>10 years
Works and Services	Office Buildings, Roads & Highways	Deputy Secretary	B.E. Civil, M.Sc. Transportation and Construction Management	> 30 years
Water Supply	Utility Infrastructure	Project Manager	B.E. civil, ME Environmental Engineering	> 28 years
Gas Supply	Utility Infrastructure	Functional Head	B.E. Petroleum	> 3 years
Public University	Office Buildings, Utility Infrastructure, Educational Facilities	Director Services	B.E. Civil, M.E. (Civil)	> 30 years
Infrastructure Planning and Development	Mass Transportation System	Senior Civil Engineer	B.E. Civil, M.E. Structures	> 25 years
Port	Port infrastructure, office buildings and utilities.	Assistant Executive Engineer	B.E. Civil, M.E. Structures, Construction Management	> 15 years
Public Schools	School buildings	Executive Engineer	M.E.M	> 7 years

Use of ICT Project Planning

Following Table 2 provides extracted information from the structured interviews with regards to use of ICT for project planning phase by the infrastructure management organizations. Four major decision functions in this regard including; Communication modes, Estimates, Mapping support, Engineering and design works and Information Storage were discussed during the interviews. It was concluded that most of the organizations are dependent on using paper-based system for data collection and exchange. Communication was being conducted using the modern tools.

Table 2. Use of ICT for Project Planning Decision Functions.

Organizations	Project Planning Decision Functions				
	Communication Modes	Estimates	Mapping support	Engineering design works	Information Storage
Public University	Organizational portal, emails, mails and faxes, video conferencing.	Spreadsheet, CAD	Google Earth	Design Software	Spreadsheets, electronic copies, paper-based files.
Highway Authority	Portals, emails, SMS, fax, mail, messengers and video conferencing	Manual techniques, Spreadsheet, CAD	Google Earth	--	Paper filling, scans, electronic files
Works and Services	Emails, SMS/MMS, fax, mail, messengers and video conferencing	Paper drawings	Manual maps	--	Paper filing and spread sheets
Water Supply	Paper-based	Manual	GIS	No software	Paper based storage
Gas Supply	Portal, emails, SMS/MMS, faxes, video conferencing	Spreadsheet, CAD	Manual maps, Google Earth	No software	paper journals digital data base such as scanned files
Public University	Emails and mails and memos	Manual, Spreadsheet	Manual maps, Google Earth	Design Software	Portal, Manual files system.
Infrastructure Planning and Development	Portal, emails, SMS/MMS, fax, mail, messengers	Manual, Planning software	Google Earth, Paper drawings	No software	Paper based as well as electronic interface
Port	Internet	Manual, Spreadsheet	Google Earth and ArcMap/ Arc Viewer	No software	Paper based as well as electronic interface
Public Schools	Faxes, emails	Manual, Spreadsheet	Manual Maps	No software	Paper-based system, Scanned Files

However, the legal requirements made it necessary to use paper-based communication for most of the official works, in addition to the electronic methods. Most of the organizations prepare initial estimates using manual methods assisted through use of spreadsheets. With regards to utilization of mapping information for planning, both manual maps and utilization of google earth (mainly on individual basis) was evident. Use of software for engineering and design works was found to be very weak. For data storage mostly paper-based system is used but scanned files and electronic files are also utilized.

Use of ICT for Monitoring and Review

The following Table 3 provides extracted information from the structured interviews with regards to use of ICT for project monitoring and review by the infrastructure management organizations. Four major decision functions in this regard including; data evaluation, information exchange, cost analysis and sustainability assessment were discussed during the interviews. None of the organizations utilize data evaluation software, while information exchange (externally) was found to be paper-based. In some instances, the information exchange (internally) was being supported through electronic means.

Table 3. Use of ICT for Monitoring and Review Decision Functions.

Organizations	Monitoring and Review Decision Functions			
	Data Evaluation	Information exchange	Cost Analysis	Sustainability
Public University	No software	Paper-based (externally) Partially electronic (internally)	Through consultants	No system
Highway Authority	No software	Paper-based	Manually	No system
Works and Services	No software	Manual RFIs (Electronic)	Manually	No system
Water Supply	No software	Paper-based (both internally and externally)	Manually	No system
Gas Supply	No software	Paper-based (externally) Partially electronic (internally)	Manually	No system
Public University	No software	high on paper based	Manually	Partial Evidence of software usage (for academic purpose only)
Infrastructure Planning and Development	No software	paper based RFIs electronically	Through consultants	Through consultants
Port	No software	Paper based	Manually	Through consultants
Public Schools	No software	paper based	Manually	No system

In some cases, the RFIs by the external stakeholders during the monitoring and review phase were also assisted by electronic means. It was explained by the interviewee that this has been the professional protocol since as far as it can be remembered, and the project stakeholders require documents in hard form exclusively, as there are very high chances of forgery in electronic data. The data present online or in electronic form is not usually updated and reliable. Cost analysis was being conducted (for recurring bills etc.) manually or through consultants. There was no system evident with regards to sustainability checks during the monitoring and review.

Use of ICT for Maintenance, Repair & Operations

The following Table 4 provides extracted information from the structured interviews with regards to use of ICT for maintenance, repair & operations by the infrastructure management organizations. Four major decision functions in this regard including; facility management, inspections and its data extraction, maintenance decisions and budget allocation decisions for the same were discussed during the interviews.

Table 4: Use of ICT for Maintenance, Repair & Operations.

Organizations	Maintenance, Repair & Operational Decision Functions			
	Facility Management	Inspection and its Data Extraction	Maintenance Decisions	Budget Allocation Decisions
Public University	No pronounced method	Manual /Data stored in hard and soft forms	Manually	No technology-based method
Highway Authority	Facility Management System (FMS)	Using cameras as well as site & visual inspections	Based on paper fillings	HDM 4.0
Works and Services	Computerized Maintenance Management Systems	Manually	Manually	Manually
Water Supply	No systematic means	Manually	Manual	Manually
Gas Supply	Manual SWOT analysis	Manually	Based on paper filings	Manually
Public University	No facility management process	Manually	Based on paper filings	Manually
Infrastructure Planning and Development	No pronounced method	Manually	Based on paper filings	Manually
Port	No pronounced method	Manually	Manually	Manually
Public Schools	Manual SWOT analysis	Manual means (such as site inspection and visual inspection)	Manually	Using MS. Project

Except for two, remaining had no pronounced method of facility management incorporated in their organizations. The inspection and its data extraction were being conducted typically through manual methods. Maintenance decisions were mainly being taken through manual (paper-based) records. While except for coupe of organizations, budget allocation for maintenance decisions were being assisted manually without use of any technology. Thus, there were some moderate evidences of use of technology for facility management, to some extent for inspection and couple of examples for budget allocation decisions.

Conclusions

From a macro level perspective, the overall potential for BIM adoption was less encouraging. At functional level, it can be said that organizations were found "partially or moderately ready" for *project planning*, "not ready" for *monitoring and review* and "moderately ready" for *maintenance, repair and operations*. The results are explanatory enough to conclude the readiness level of each candidate Public Infrastructure Organization. As assessed, the Organizations had no awareness about BIM, or any of the benefits it could bring about with its adoption. There is no evidence of a single BIM implemented facility in any of the Organizations tested. However, this does not present the downside of picture, as each of the Organization was a fully functional institution with successfully established infrastructure. However, to make the process of decision making easier, efficient and more profit-oriented with the adoption of Building Information Modeling (BIM), decision support frameworks, systematic procedures and processes shall be adopted to bring the most out of infrastructure organizations.

Recommendations

In this regard, based on the behavioural aspect of the decision-making process, a BIM adoption plan for infrastructure management organizations shall be proposed in-line with the specific needs of the organizations. The plan can be based on the following steps.

1. Prepare a flow chart to determine each step of a candidate project.
2. Determine how BIM can increase efficiency.
3. Small Scale implementation of BIM.
4. Spread the benefits & results.

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Technical Evaluation for Optimal Energy Retrofitting Alternative Selection: A Case Study of An Institutional Building

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Abstract

Built environment is accountable for almost 40% of total global energy consumption. Among all subsectors within the built environment residential and non-residential buildings with 30% of total energy consumption in their operational phase proven to have great potential in acting as one of the pioneers in energy conservation. But regardless of all the efforts to restrain the incremental trend for energy consumption, just for final energy demand in buildings an upward mobility of 7% since 2010 is observed. Among all proposed energy conservation measures since Kyoto protocol energy retrofitting demonstrated promising impact on building energy demand due to accumulated number of outdated building stocks. Therefore in line with North Cyprus energy efficiency strategy for 2023, this study targeted investigation on proposed retrofitting measures in an attempt to improve energy efficiency in a sample case study of Civil Engineering faculty building of Eastern Mediterranean University in a partly semi-arid climate of North Cyprus. The selections of retrofitting measures in this study are performed according to the need for continuous activity of such institutional buildings without compromising its function. Therefore from variety of possible measures for energy retrofitting four different scenarios are as roof insulation, windows glazing along with reduced air infiltration, utilizing lux and lighting control sensors and finally the combination of all aforementioned scenarios are selected to be examined using dynamic thermal modeling software (Design Builders) on the case study. The outcome from thermal modeling validated using actual bills of utilized energy sources to verify accuracy of thermal modeling. In general, the result indicated the significant reduction in energy demand for most of the alternatives. Also from the existing retrofitting alternatives, the research proposed optimal alternative suggestion considering generated thermal comfort and mutual interaction of each measure on another which in final stage could be considered as baseline reference devised for local energy efficiency.

***Keywords**: energy efficiency, energy retrofitting, thermal modeling, stimulation tools.*

Introduction

It has been estimated that by 2050 up to 10 billion people on earth will need social services demand such as housing, clean water, food, transportation and other related infrastructure that subsequently will lead to rise in energy demand in different sectors in parallel with population growth (UN, 2015). The share of residential and nonresidential buildings from total global energy consumption is currently around 30%, where 80% to 90 % of that associated with building operating phase, and the rest 10% to 20% consumed as embodied energy. Eventually the fact that buildings in their operating phase divulge greater potential for application of energy conservation measures is proven (Ramesh et al., 2010). International energy agency in its annual report mentioned that, the amount of floor area covered within next 40 years estimated to be tripled in Africa and almost double for most of Asian region in parallel with population growth (International Energy Agency, 2017). Accordingly with exponential growth in building construction it seems indispensable to consider existing building stocks for energy efficient interventions as a key to considerably reduce the inauspicious impacts of buildings on the environment and economy as well as the pressure on fossil fuel reservoirs (Menassa, 2011).

Energy retrofitting as one of the efficient interventions within energy efficiency measures refers to overall optimization of building energy performance. It is considered as major approach toward sustainable built environment with considerably low cost and high return which additionally proposes remarkable reduction in global energy demand as well as greenhouse gas emission (Ma et al., 2012). The annual replacement rate of existing buildings by the new construction in Europe is only around 1% to 3% (IPEEC, 2017). Considering the slow replacement rate, up to 110 million buildings out of estimated 210 million existing buildings are desperately in need of renovation that implied to the huge potential of building's energy retrofitting existed in just EU (Artola et al., 2016). But regardless of this massive retrofitting potential approximately only 2% of the buildings undergo renovation each year which evidently full potential energy saving could not be achieved (Ma et al., 2012). recent educational and cultural awareness in energy consumption pattern, controlling over energy use regulation, reform in the pattern of energy consumption and application of energy conservation measures on the buildings led to proposing different encouragement method such as regulatory and voluntarily instrument, building energy codes, incentive and eco labeling based scheme to promote investment into energy efficiency measures (Silva & Sandanayake, 2012).

Developing economy in 1980s in Turkish Republic of Northern Cyprus (TRNC) initiated the urbanization process and dominant factors such as United Nation (UN) peace plan, along with other financial determinants like inflationary expectation, devaluation in Turkish Lira altogether generated rapid stimulated construction investment in North Cyprus (Yorucu & Keles, 2007). As a result of this exponential construction growth and due to lack of political agenda for controlling urban planning as well as absence of regulatory bodies to superintend the process of construction, poorly built buildings without initiative in the reduction of energy consumption became as critical features of the construction sector in North Cyprus (Ozarisoy & Altan, 2017). So, form one hand it has to be emphasized that building construction as whole due to aforementioned issues tend to demonstrate great potential for application of retrofitting measures in TRNC. On the other hand the magnitude of institutional buildings category as a case study selected for this study substantiated based on the fact that number of universities in North Cyprus significantly increasing and by taking to account the time spent by students and staff in university buildings also according to report published by international energy agency IEA's EBCP that categorized educational buildings as high energy consumers (El-Darwish & Gomaa, 2017). Following statement will lead us to believe that existing university buildings provide a great potential for applying energy conservation strategies in attaining government's 2023 targets which aimed at energy usage reduction by 20% (K.K.T.C. Enerji Verimliliği Strateji Belgesi 2016-2023, 2016). In conclusion due to inexorable rise in energy cost and energy import dependency of the country and in line with energy efficiency plan for TRNC in 2014 a need for investigation to unveil the attractiveness of implementing buildings energy retrofit measures in North Cyprus is imperative.

Literature Review

Kolokotsa et al. (2009) defined energy retrofitting as necessary implemented action which will optimize building's energy and / or environmental performance. There have been several studies on cons and pros of energy retrofitting measures application which normally organized them within the social, environmental and economy groups (Artola et al., 2016; Jafari, 2018; Staniaszek, 2013). The general procedure of technical evaluation of implementing energy retrofitting on existing buildings is comprised of:

1. Inventory of fixture: referring to energy inspection through either or simultaneous application of Document collection, Technical visit, Interviews with occupants. This step also known as energy auditing which based on the intensity of implemented procedure could be overlapping with other steps of building energy retrofitting (ASHRAE, 2011).

2. Energy consumption evaluation: referring to energy performance assessment of a base case building. It implied to the process of energy performance modeling of the base case scenario which enable analysts to observe the impact of the selected retrofitting measure on the base case building. In this regard, Lee et al. (2015) reviewed the features and capabilities of 18 energy retrofit toolkits and classified them based on three major energy modeling method as Toolkits using empirical data-driven methods, normative calculation and physics-based energy modeling. Another study by Lee et al. (2014) focused on retrofitting stimulation engines from another point of view which can identify potential retrofit opportunities excluding public domain simulation engines such as EnergyPlus and DOE-2 which lack an accessible user interface for retrofit selection analysis for small and medium commercial buildings. Combination of all introduced and other existing retrofitting tools will provide a platform to assess the impact of each energy retrofitting alternative on the existing buildings as long as the base case scenario model is validated and calibrated with actual bills.

3. Recommendation of feasible retrofitting scenarios: this step alludes to retrofitting measures proposition with respect to identified deficiencies, climate circumstances, human behavior and governmental policy to identify most feasible retrofitting alternative. In this regard numerous recommendations have been proposed by variety of studies, researches and guidelines which normally the most effective categorization of retrofitting scenarios to improve building energy consumption are based on predictable parameters such as existing building deficiencies and geographical circumstances of the case study. However most of the guidelines are classified retrofitting measure according to depth of retrofit as well as weather condition for example USDOE (2015) grouped the climate as hot-humid, hot-dry, cold, very cold and marine and explicate each item in detail, others like Turzynski (2009) categorized it according to cost, environment, occupants comfort and the value of initiative to the owners. Kolokotsa et al. (2009) proposed different actions for improving buildings' energy efficiency in different group such as building service (HVAC, mechanical equipment, office equipment, electrical equipment), energy management tools including the tools for monitoring and controlling of the building during its operation and improvement in building envelope and design aspects (roof, walls, glazing, passive solar heating, daylight and reduction of cooling load). Another study by Mata et al. (2010) considered 23 types of measuring upgrades include technical (reduction of power for lighting and appliances and Upgrade of ventilation systems with heat recovery), building envelope below and above the ground improvement (change of U-value of knee walls, slope roofs or replacement of windows) and retrofitting of attics and roofs (attic joists, knee walls, slope roof, flat roof) based on their cost. Rabani et al. (2017) summarize the retrofit measures for building envelope and insinuated that almost most of studies dealing with envelope retrofitting emphasizes on insulation and renewable technologies. El-Darwish and Gomaa (2017) concluded that since, thermal comfort plays a crucial role in energy consumption; hence by adding slight modification to the building exterior envelope as the surface which is totally exposed to external environment such as building insulation and sir tightening, solar shading and windows glazing it is possible to improve the thermal comfort as well as energy conservation in the buildings.

4. Evaluation and interpretation of the impact of retrofitting scenarios on the existing building: as a final step in technical evaluation of all the proposed measures will be applied on calibrated base case model and eventually the impact of application of each retrofitting measure on the existing case is obtained and ranked and finally optimal selection from energy demand reduction point of view will be determined.

Considering all aforementioned steps in evaluation of retrofitting measure on the existing buildings this study intended to present an assessment of specific notions in the domain of both active and passive retrofitting measure with particular concentration on building envelope improvement. The main target of this study is to enhance general insight in applicability and efficiency of both type of retrofitting alternatives as well as demonstration of interaction of each alternative on alteration of heating and cooling load of the building as crucial elements for building energy demand.

Methodology

Site description and data gathering: In this study department of civil engineering in Eastern Mediterranean University (EMU) selected as a case study. The total area of the building is 8660 m^2 in which 6000 m^2 is a covered area. The building is comprised of three floors which accommodate nearly 800 students and staffs and facilitated with offices, classrooms, laboratories, computer centers and other facilities associated with the programs. It is located in Famagusta in east of Turkish republic of Northern Cyprus (North Cyprus). The building coordinates sits on latitude 35 degree north and longitude 33 degree east. Famagusta climate according to Koppen-Geiger falls into subtropical (Csa) type and the north eastern region of the island is considered partly Semi-Arid (Bsh) which means Famagusta shows mild characteristics of Mediterranean climate. Amalgamation of all these characteristic indicates that hot and dry summer and on the contrary wet and moderate winters are known as cohesive climate characteristic of Cyprus which directly affect the energy demand of annual heating and cooling (Ozarisoy & Elsharkawy, 2008). The process of data collection in the building performed through two particular stages. In the first stage with respect to existing building inspection Table 1 to 4, summarized building envelope components and the specification of HVAC (Heating, Cooling and Ventilation) system obtained through walk through energy audit.

In second stage an interview conducted with technical and managerial staff of the department which following results are obtained based on two prospective of building deficiencies and occupants' behaviors.

- Most of the windows in office areas will left open during working hours while the air conditioners are still working. And there is no supervision for checking the building for lights, appliances or ACs once the operational hours are finished.

- There are too many lighting bulb or tubes are out of order and maintenance of the HVAC is rarely performed on scheduled time.

- The HVAC system will be shut down by the end of operational hours each day.
- Since the heating system start only once the cooling system completely shut down, hence, there is no overlapping on cooling and heating process in a year.
- The working hours of the building officially starts at 8:00 and finishes at 17:00
- During the week, each day about 30% of total classrooms and labs are occupied by students in average.

Table 1. Envelope specification.

Envelope structure	**Type**	**Envelope component**	**Remarks**
Wall structure	Exterior wall	Clay blocks, cement plaster 3 cm , finishing cement plaster 1 cm , paint	No insulation
	Interior wall	Clay blocks, cement plaster 2 cm , gypsum plaster 2 cm, paint	No insulation
	Partitioning wall	Aerated cement blocks , gypsum plaster board 2 cm , paint	No insulation
Roof structure	Ceiling	Concrete slab 15 cm , gypsum plaster 2 cm , paint	No insulation
	Rooftop	Concrete slab 15 cm , mortar 3 cm , damp roof membrane 1 cm	Water resistant insulation
Floor structure	Floors	Concrete slab 15 cm , sand 5 cm , mortar 2 cm , mosaic 4 cm	No insulation
Windows structure	Single glazed	UPVC frame 6 cm , single glazed	No thermal break
	Double glazed	UPVC frame 6 cm , double glazed	No thermal break

Table 2. Boiler specification.

Capacity	800000	Kcal/h
Operating pressure	5.2	Bars
Rated output power	930	Kw
Design pressure	6	Bars
Test pressure	8.5	Bars
Flow temperature	90	Degree C
Return water temperature	70	Degree C

Table 3. AHU (Air handling unit) specification.

Heating load	40	Kw
Cooling load	59	Kw
Asp air Debi	6600	m3/h
Motor power	1.5	Kw
Van air Debi	6600	m3/h
Motor power	0.75	Kw

Table 4. Air chilled coolers specification.

Unit number	**1**	**2**	**3**
Number of compressors	5	2	6
RLA	44.9 (1)-46.8 (1)- 65.5 (3)	67.9 (2)	46.8 (3)-65.5(3)
LRA	134 (1)-152 (1)-207 (3)	207 (2)	152(3)-207 (3)
Refrigeration system	60.3 and 62.1 kg	23.6 and 24.5 kg	69.4 and 73.5 kg
Number of fans	10	6	10

Base case energy performance modeling and validation: In this study thermal modeling of the existing building performed using Design Builder as dynamic thermal stimulation software due to its unique characteristics and interactive interface which built around the most competitive and accurate energy stimulation engine called Energy Plus. The entire collected data through previous stage such as building architectural model, construction material, updated weather data, building function schedule and activities and other related inputs are introduced to the software and thus the energy consumption stimulation process including all the detailed result of the base case scenario obtained and demonstrated. Figure 1 illustrated a schematic view of the building in design Builder software. From the results total annual energy consumption of the building is estimated 417820 Kwh where building cooling with 149,395 KWh has the most contribution in terms of building energy consumption and respectively heating, lighting and appliances energy consumption ranked after that with 114,425, 98,356 and 55,644 KWh.

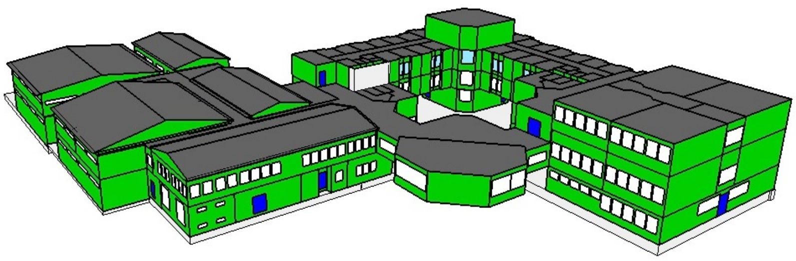
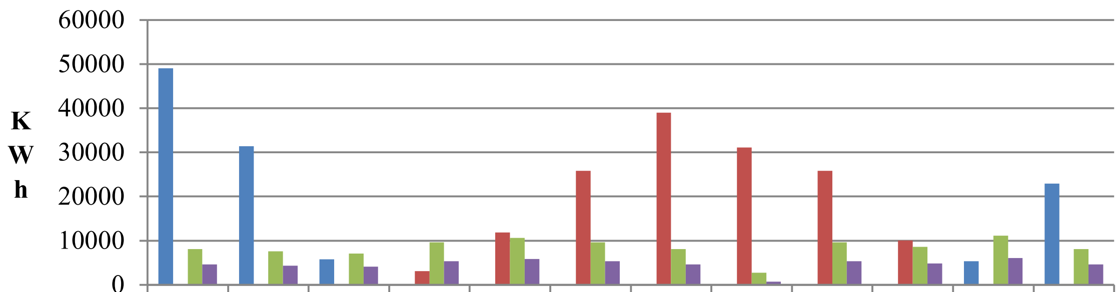


Figure 1: Building schematic view in Design Builder.

From two existing source of energy (electricity and LPG) identified for the building, the share of electricity from the total energy consumption is 322848 Kwh which is 77% while LPG produces the rest of 94973 Kwh or 23% of total energy demand in the building. The stimulated monthly energy consumption breakdown of base case scenario is presented in figure 2 which explicitly demonstrated heating requirement for 6 months and cooling requirement for 7 months. In terms of stimulation result validation the results for total deviation of stimulated base case energy consumption from real bill energy consumption indicated less than 5% deviation which is considered within the acceptable range and justifies the model validity for further evaluation of change in energy consumption by application of the retrofitting measure on the base case model.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Heating	49031	31375	5743	0	0	0	0	0	0	0	5322	22954
Cooling	0	0	0	3078	11876	25793	38976	31110	25803	10038	0	0
Lighting	8112	7605	7098	9633	10647	9633	8112	2721	9633	8619	11154	8112
Appliances	4609	4297	4119	5322	5835	5322	4609	686	5322	4854	6058	4609

Figure 2: Monthly energy consumption breakdown by end users.

Recommendation of retrofitting scenarios: According to Aste and Del Pero (2013), appropriate retrofitting alternatives have to address following major criteria as compatibility with instant restructuring necessity, adaptability of alternative with continuity of tasks inside the building, cost effectiveness of intervention and budget constraints at least to a certain extent, and only when these criteria met by a retrofitting option, it could be analyzed and assessed eventually. Therefore, considering aforementioned criteria and moreover the fact that in this study retrofitting alternatives assumed to be selected from both the groups of active and passive retrofitting measures, amalgamation of all considered scenario are classified as follow:

Scenario 1: insulation of flat and slope roof by applying 5 cm of Extruded polystyrene foam board (XPS).
Scenario 2: improving glazing to double low-e insulation for those single glazed windows.
Scenario 3: mobilizing the entire building with lux and lighting control sensors and T-5 dimmable fluorescents lighting.
Scenario 4: combination of all aforementioned scenarios
Finally through application of each scenario on prepared base case model, the entire scenarios have been analyzed and the results are discussed in detail.

Results and Discussion

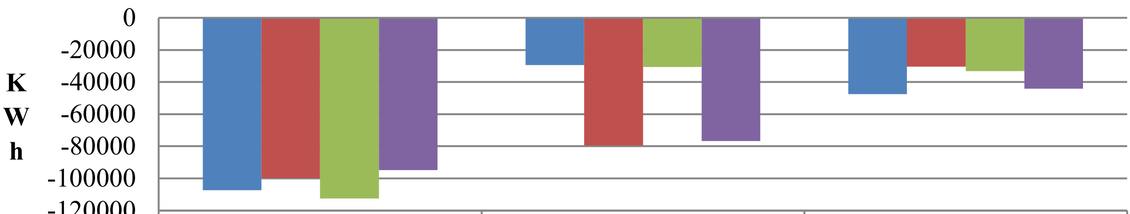
The result from pre and post retrofitting energy stimulation of the existing building summarized and presented in table 5 From the total energy consumption point of view obviously application of all the retrofitting scenarios simultaneously (Scenario 4) will result in maximum energy demand reduction (14.84%) but since application of all the scenarios at the same time is not always financially feasible for investors, therefore, it is more realistic to assess the impact of each retrofitting scenario (Scenario 1, 2 and 3) solely on the existing building.

Table 5. Pre and post retrofitting energy consumption.

Annual energy consumption (Base case)			
Heating (kwh)	114425		
Cooling (kwh)	149395		
Lighting (kwh)	98356		
Appliances (kwh)	55644		
Total (kwh)	417820		
Annual energy consumption (Scenario 1)		**Annual energy consumption (Scenario 3)**	
Heating (kwh)	81400	Heating (kwh)	114425
Heating saving %	28.86%	Heating saving %	0.00%
Cooling (kwh)	140976	Cooling (kwh)	149395
Cooling saving %	5.64%	Cooling saving %	0.00%
Lighting (kwh)	98356	Lighting (kwh)	91676
Lighting saving %	0.00%	Lighting saving %	6.79%
Appliances (kwh)	55644	Appliances (kwh)	55644
Appliances saving %	0.00%	Appliances saving %	0.00%
Total (kwh)	376376	Total (kwh)	411140
Total saving %	9.92%	Total saving %	1.60%
Annual energy consumption (Scenario 2)		**Annual energy consumption (Scenario 4)**	
Heating (kwh)	103843	Heating (kwh)	67501
Heating saving %	9.25%	Heating saving %	41.01%
Cooling (kwh)	150833	Cooling (kwh)	141004
Cooling saving %	-0.96%	Cooling saving %	5.62%
Lighting (kwh)	98356	Lighting (kwh)	91676
Lighting saving %	0.00%	Lighting saving %	6.79%
Appliances (kwh)	55644	Appliances (kwh)	55644
Appliances saving %	0.00%	Appliances saving %	0.00%
Total (kwh)	408676	Total (kwh)	355825
Total saving %	2.19%	Total saving %	14.84%

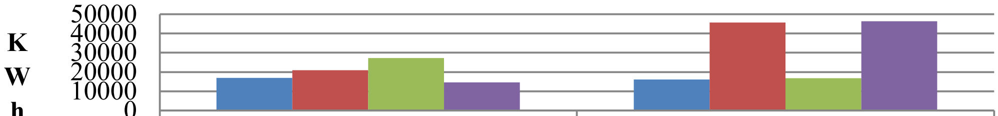
From the stimulated result scenario 1 with total 9.92% and scenario 3 with total 1.6% reduction in total energy demand of the building demonstrated as the best and worst retrofitting measure which itself indicated the dominancy of passive retrofitting measure (building envelope improvement in this case) over the active retrofitting measure. Analysis of heat transfer in the base case scenario indicated roof and glazing with respectively 64% and 20% of total heat gain are the major causes of heat gain in the building on the other hand walls, roofs and external infiltration with respectively 37%, 30% and 17% of total heat loss are the major causes of heat loss. Post retrofitting heat transfer analysis of roof insulation (scenario 1) on the existing building demonstrated drastic decrease in heat loss (61%) and heat gain (65%) in roof which respectively generated 28.86% and 5.64% heating and cooling energy demand saving. Heat transfer analysis after substitution of double glazing window (scenario 2) on the existing building demonstrated remarkable decrease in heat loss through external infiltration (30%) which eventually resulted in heating energy consumption reduction of 9.25%. while regarding heat gain application of scenario 2 on the existing building inversely increased 30% heat gain through glazing and other involved components remained more or less the same which resulted in almost 1% increase in cooling energy consumption. This result obtained from scenario 3 stem in the affectless change in building lighting control on building heat transfer, which is considered as primary cause of reducing heating and cooling load in order to decrease total energy consumption. As a result of application of scenario 4 heat transfer analysis demonstrated following notes that simultaneous application of scenario 1 and 2 will not interfere with heat loss and heat gain reduction as it could be seen in figure 3 and 4. However regarding heat gain due to the interaction between substitutions of double glazing windows (scenario 2) along with application of roof insulation it seem that the impact on glazing heat gain is intensified in compare to other two scenarios. Also from the total energy demand reduction point of view application of combination of different alternatives on energy demand reduction seems to approximately following algebraic sum of each alternative demand reduction.

Figure 3: Heat loss results from Design builder.



	Walls	Roofs	External Infiltration
Scenario 1	-107327	-29437	-47389
Scenario 2	-99751	-79481	-30465
Scenario 4	-112586	-30602	-33089
Base case	-94797	-76795	-44145

Figure 4: Heat gain results from Design builder.



	Glazing	Roofs
Scenario 1	16959	16108
Scenario 2	20963	45627
Scenario 4	27243	16830
Base case	14611	46369

Conclusion

The general aim of this study was to present a general overview of energy retrofitting measures in order to scrutinize the impact of different retrofit variables on total building energy demand and analyzing the internal interactions caused in heat transfer as a result of implementation of each scenario hot arid climate of North Cyprus. In conclusion, as it expected combinational implementation of all scenarios (Scenario 4) generated 14.84% of total energy saving followed by roof insulation with 9.92% and other two alternatives as substitution of single glazed windows with double glaze and utilizing the building with lux and lighting control system have ignorable impact on building energy demand saving.

The contents of this study covered technical evaluation of active and passive energy retrofitting methods. It is believed that due to major contribution of commercial building is energy consumption and considering the fact that energy bills are one of the outmost expenses among institutions this study could provide a platform for further evaluation of financial and environmental impact of such or other retrofitting alternatives to assist stakeholders in decision making process for funding in such projects.

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A Stakeholder Management Model for Large-Scale Construction Projects

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Abstract

The Large-Scale Construction Projects-LSCPs have been increasingly appearing in Turkey as it has been all around the world in recent years. Numerous internal and external stakeholders who have distinct interests, expectations and attitudes take role in these, complex or megaprojects. This creates conflicts and probable competition between them throughout the whole project life. The success of projects mainly depends on not only providing of targeted time, cost and quality, but also effectively stakeholder management for all participants' satisfaction. This research paper includes the literature review's findings in context of stakeholder analysis, stakeholder management strategies, stakeholder engagement and the proposed models. Research finds that effective communication in *stakeholder engagement is vital; being effective refers to three key points: (1) delivering the correct messages to appropriate stakeholders, (2) using a suitable means of communication, and, (3) clarifying the project value and benefits clearly.*

Keywords: *Critical Success Factors-CSFs,Large-Scale Construction Projects-LSCPs, Literature Review, Stakeholder Management*

Introduction

It has been observed that LSCPs go ahead in the construction sector of Turkiye as similar to global development in recent years. They are also called megaprojects or complex projects which are completely different in terms of their level of aspiration, size, huge costs, lead times, impact, complexity and stakeholder involvement (Flyvbjerg,2017). The overall project success requires an effective stakeholder management and satisfaction, besides targeted time, cost, quality and projects' objectives. It can be achieved by implementing accurate, continual and effective stakeholder management throughout the whole project lifecycle. The critical success factors due to stakeholder management and projects' conditions and characteristics are taken into account for project success. The management of numerous internal and external stakeholders with distinct features, interests, expectations and attitudes including conflicts or competition between them, requires a comprehensible and applicable model for stakeholder management. The literature review has a critical role insupporting scholars to identify the current body of knowledge, research trends and shaping future directions. These issues, obtaining from the literature review, are as follows:

- The large-scale construction projects-LSCPs
- Basic issues in stakeholder management
- Critical success factors-CSFs approach
- Proposed models for stakeholder management

The retrospect of stakeholder managementshows that the stakeholder and shareholder theory based on Corporate Social Responsibility debates by 1960s. In 1980s, Freeman's stakeholder theory underlines the individual attitudes and impacts of stakeholders instead shareholders.In the midst of 1990s stakeholder theories grow into different branches,models and criteria such as the three taxonomies of normative, instrumental, descriptive, or primary and secondary domains, typology of organizational stakeholders, the resource -based influential strategies, and the salience framework. After 2000s the scholars consider the complexity of relationship network, dynamism of stakeholders during the project life cycle. Stakeholders' moral, interest and cultural effects are described as critical factors in effective stakeholder management.

The Large-Scale Construction Projects-LSCPs

LSCPs are complex ventures, that typically cost USD 1billion or more, take many years to develop and build, involve multiple public and private stakeholders, are transformational, and impact millions of people (Flyvbjerg,2014). Examples of LSCPs are airports, seaports, hospitals, high speed rail lines, suspended bridges, large-scale signature buildings, nuclear power plants, dams etc. LSCPs are so attractive to decision makers that the answer may be found in the so-called "four sublimes" (Table 1).

Table 1. The Four Sublimes that drive megaproject development (Flyvbjerg,2014).

Type of Sublime	Characteristics
Technological	Excitement, engineers and technologists get in pushing the envelope for what is possible in "longest, tallest, fastest" type of projects
Political	Rapture, politicians get from building monuments to themselves and for their causes, and from the visibility this generates with public and media
Economic	Delight, business people and trade unions get from making lots of money and jobs off megaprojects, including money make contractors, workers in construction and transformation, consultants, bankers, lawyers, investors, landowners, developers
Aesthetic	Pleasure, designers and people who love good design get from building and using something very large, also iconic and beautiful

Policymakers particularly support to invest LSCPs, if done right, because of their following benefits;

- creates and sustains employment,
- contains a large element of domestic inputs relative to imports,
- improves productivity and competitiveness by lowering production costs,
- benefits consumers through higher-quality services,
- improves the environment when infrastructures that are environmentally sound replace infrastructures that are not.

The Mc Kinsey Global Institute (2013) estimates global infrastructure spending at USD 3.4 trillion per the year 2013-2030, or approximately 4%of total global gross domestic product, mainly delivered as large-scale projects.According to The Economist 2008, the global construction market will grow up about 6-7% per year until 2025, which is the biggest investment boom in history. On the other hand, cost overruns, delays and benefit shortfalls are mentioned so-called "Megaproject Paradox" for LSCPs (Flyvbjerg, 2017).

Decision making, planning, and management are involved multiple stakeholders,either public and private or internal and external with conflicting interests in LSCPs. Complicated and uncertain relations, variable and dynamic characteristics, multiplicity related to stakeholders are described as some of the causes in the complexity of LSCPs. The huge size and high complexity of mega projects bring about three major challenges in project management; (1) the involvement of numerous stakeholders leading the complex stakeholder interrelationships and conflicting interests, (2) the dynamics and growing capacity leading to high project uncertainty, (3) their governance by a stringent multi-role administrative structure leading to high public attention and controversies (Mok et al.,2015).

In recent years, LSCPs have been also appeared in the growing amount and business capacity inbuilding sector of Türkiye.These projects are generally implemented by Public-Private Partnership (PPP), Joint Venture (JV) and Consortiums with international partners. It is known that there are planned projects more to be constructed in the near future in Türkiye.

Basic Issues in Stakeholder Management

The stakeholder term is mentioned in different ways by several researchers. It is basically defined as " any group or individual who can affect or is affected by the achievement of a corporation's purpose" (Freeman, 1984). *Construction projects' stakeholders* are individuals or groups/organizations who have some aspects of right or ownership in the project and can contribute to it; or will incur or justifiably perceive they will incur a direct benefit or loss as a result of either the works during the project or the outcome of the project. They distinguish between *internal* and *external* stakeholders

- *Internal stakeholders* are project owners in the sense they have overall managerial responsibility and power, usually linked to a financial stake; and organizations, teams or individuals who have a contractual relationship with the project owner.The project owner maybe a consortium, that may delegate significant management responsibility via contractual structures, and may transfer significant financial responsibility,but that retains overall control.
- *External stakeholders* are who may be positive or negative about a project, and who may seek to influence the project through political lobbying, regulation, campaigning or direct action. They might include local communities, local government, potential users, regulators, environmental groups, and the media.

It is revealed that some basic issues related to stakeholder management from literature review such as (1) stakeholder identification and analysis, (2) stakeholder influence strategies, (3) stakeholder management strategies, and (4) stakeholder engagement (Nguyen et al., 2018)

Stakeholder Identification and Analysis

Stakeholder analysis (SA) refers to stakeholders' identification, classification and assessment.The research from literature, indicates that stakeholders are classified and described through their characteristics such as *power, interest, position andattitudes*.These approaches are given in Table 2.

Table 2. The relations based on Power/ Interest,Predictability,Dynamism for Stakeholders

Power/Interest Matrix (Johnson et al.,2005)	Low Power	High Power
Low Interest	only monitored (min.effort)	keep satisfied
High Interest	keep informed	managed closely (key player)
Power/Predictability Matrix(Newcombe,2003)		
Low Predictability	unpredictable/manageable	greatest danger/opportunities
High Predictability	few problems	powerful but predictable
Power/Dynamism Matrix (Mendelow,1981)		
Dynamic	periodic scanning	continuous scanning
Static	nil	irregular scanning

Stakeholders' attitude and behavior are critical factors that influence decision-making strategies and processes. They can be defined as the perception of stakeholders towards projects that are supportive, marginal, non-supportive and mixed blessings. The associated SM strategies suggest involving the supportive stakeholder, monitoring the marginal stakeholder and defending against the non-supportive stakeholder. Mixed-blessing stakeholders who rate highly on both potential for cooperation and potential for threat, are best managed through collaboration.

Stakeholder position toward project is another classification model, based on stakeholder position on a project, which has been proposed by Mc Elroy and Mills (2007).

In this model, five levels of stakeholder attitude are as follows:

(1) active position,(2) passive position,(3) noncommittal,(4) passive support, (5) active support.*Stakeholder Salience Model* proposed by Mitchell et al. (1997), classify stakeholders in terms of whether or not they possessthe *power* to influence (P), *legitimacy* relative to other stakeholders (L), or an *urgent* claim on project management's attention (U). Seven types of stakeholders' combinations according to salience model are classified as follows:

- Power only, *dormant*; they may not exert any pressure on the project.
- Legitimacy only, *discretionary*; when they form alliances with other stakeholders, they can mount some pressure on the project.
- Urgency only, *demanding*; they require management attention for their problems.
- Power and legitimacy, *dominant*; they occupy an important place in management's consideration.
- Power and urgency, *dangerous*; they may become the opposition to the project.
- Urgency and legitimacy, *dependent*; they need other stakeholders to impose their will.
- Power,legitimacy and urgency, *definitive*; they are dominant decision making groups.

Power is defined asthe probability that one actor within a social relationship would be in a position to carry out his will despite resistance. *Legitimacy* is defined as a general perception or assumption that the actions of an entity are desirable, proper or appropriate within some socially constructed system of norms, values, beliefs and definitions.(Park and Lee, 2015). *Urgency* refers to how urgentstakeholders' claims are; such urgent claims are based on time sensitivity and criticality. Urgency also determines the dynamics of stakeholder salienceand the interactions between stakeholders. Highly salient stakeholders who possess all three attributes are defined as *definitive stakeholders* to whom managers must give first priority. According to their positive or negative attitudes towards the project,they are appraised in different manners.

Table 3. Stakeholders with positive /negative attitude toward the project (Park and Lee,2015)

Positive Attitude	Low Power	High Power
Low Legitimacy	affective stakeholder	supportive Stakeholder
High Legitimacy	reasoned stakeholder	empowered stakeholder
Negative Attitude		
Low Legitimacy	antipathetic stakeholder	aroused stakeholder
High Legitimacy	attentive stakeholder	definitive stakeholder

Stakeholder Influence Strategies

Stakeholder Influence (SI), can be considered as strategies for stakeholders that might be applied to increase the likelihood that their requirements will be considered in the project management's decision- making process. (Aaltonen et al.,2008). These strategies include:

- *direct withholding*; stakeholders restrict projects' access to critical resources which are controlled by the stakeholder to increase their perceived power
- *indirect withholding*; stakeholders influence projects' access to resources that are not directly controlled by the specific stakeholder to increase their perceived power
- *resource building;* stakeholders acquire and recruit critical and capable resources to their group to increase their perceived power.
- *coalition building;* stakeholders build alliances with other projects stakeholders to increase their perceived power and legitimacy.
- *conflict escalation;* stakeholders attempt to escalate the conflict beyond initial related project causes (e.g. political). Through this process the project may become an arena for non-project related battles. This may introduce a new institutional environment in which stakeholders' claims are perceived as more legitimate.
- *credibility building;* stakeholders increase their perceived legitimacy by acquiring credible and capable resources, for example, capable individuals with good reputation or networks.
- *communication;*stakeholders use different types of media to communicate and increase the perceived legitimacy and urgency of their claims.
- *direct action strategy;* stakeholders organize protests, road blockades, etc. to increase the perceived urgency oftheir own claims.

These strategies can help the stakeholders to maximize their power and enhance the legitimacy of claims. Coalition building and communication is the most common that stakeholders use to influence decision makers (Nguyen et al., 2018).

Stakeholder Management Strategies

Stakeholder Management Strategies (SMS) are undertaken by the project management team and can be seen as activities that may change the level of stakeholders' salience or stakeholders' positions towards the projects. Managers should differentiate their SMS based on the positions of stakeholders.These strategies are as follows:

- *collaboration strategy*; support stakeholders to prevent potential dangers and motivate them for the project.
- *involvement strategy;* it is argued that managers should demonstrate the advantages of the project to stakeholders, then encouragestakeholders for active engagement.
- *monitor strategy;* it is recommended that managers need to observe stakeholders during the projects and continuously verify their change.
- *defense strategy;* it suggests the managers to reduce or eliminate any negative effects that might originate from stakeholders.

In addition to these strategies, information and ignorance for managing stakeholders are also known as "stakeholder response strategies".They can be understood as the strategies project managers may apply in response to stakeholder pressure (Aaltonen and Sivonen,2009).

- *adaptation strategy;* obeying the demands and rules
- *compromising strategy*; negotiating, listening, offering
- *avoidance strategy;*loosening attachments to stakeholders,transferring the responsibility
- *dismissal strategy;* ignoring, not taking into account
- *influence strategy;* shaping proactively the values, sharing information and building relationship

Stakeholder Engagement

Stakeholder Engagement (SE) includes communicating, involving and improving relationships with stakeholders to ensure that their participation in the decision-making process throughout the project lifecycle. The main purpose of engagement is to achieve a transparent decision-making process, with greater input and feedback from stakeholders and stakeholder support for the decisions that are made. In addition, stakeholders have been given the opportunity to voice their views,influence the project plans and know what has been decided. The two main levels of SE are *involvement* and *participation* (Nguyen, T.S. 2018).

Involvement: It contains both informing and consulting as a means to increase stakeholders ' knowledge about the project. The five levels of involvement are as follows:

- *information;* involves an explanation of the project to the stakeholders.
- *consultation;* involves presenting the project to stakeholders, collecting stakeholders' suggestions,then making decisions with or without considering the stakeholders' input.
- *co-decision;* involves cooperating with stakeholders towards an agreement for solution and implementation.
- *empowerment;* is the process of gaining influence over events and outcomes of importance to individuals or groups.It fosters power,that is, the capacity to implement, in stakeholders.It involves delegating decision makingfor the project development and implementation to the stakeholders.
- *collaboration;* is a creative process embarked upon by two or more individuals or groups, sharing their collective skills, expertise, information (knowledge) and

understanding in an atmosphere of openness, mutual respect, honesty and trust to jointly deliver the best solution that meets their common goals.

Participation: It encompasses a higher level of engagement to reduce potential stakeholders' conflicts and resistance to the project.

Listening: It is used actively to reduce misunderstandings and other miscommunication.

The Critical Success Factors-CSFs Approach

Understanding the factors related to stakeholder, can enable appropriate decision making strategies during project execution. There are several factors that influence the outcome of a successful stakeholder management process. Thirty-five CSFs were found as useful for the study and categorized into seven groups of related factors or activities as follows.

Table 4. Proposed CSFs and categorization for stakeholder management(Eyiah-B.et al.,2016).

No	CSFs Groups	Critical Success Factors- CSFs
1	Pre-conditions(External Factors)	Managing stakeholders by considering first pre-conditions of political/cultural environment (in addition to economic, legal,social, and ethical issues already identified)
2	Pre-stakeholder identification	Good feasibility studies.Selecting the right project / Clear project brief and design development / procurement approach
3		Detailed project planning
4		Strong commitmentby both parties after education to embrace SM
5		Competitive /transparent/procurement approach
6		Good leadership and entrepreneurship skills
7		Clear goals and objectives
8		Top management support
9		Public/ community support
10	Stakeholder identification	Early and proper identification of all stakeholders
11		Formulating appropriate strategies for the management of stakeholders
12		Predicting stakeholder reactions to implementation of the strategies
13		Project managers'competence (experience,trust, technical ability, leaderships)
14		Project team related factors
15	Stakeholder assessment classification prioritization	Exploring stakeholder needs to projects
16		Assess attributes(power, urgency,proximity) of stakeholders
17		Understanding area of stakeholder interest
18		Predicting stakeholder reactions to implementation of the strategies
19		Accurately predicting the influence of stakeholders
20		Assessing stakeholder behaviour

Table 4 (Continued). Proposed CSFs and categorization for stakeholder management(Eyiah-B.et al.,2016).

No	CSFs Groups	Critical Success Factors- CSFs
21	Stakeholder engagement	Communication (with and engaging stakeholders properly and frequently,open and constant communication)
22		Keeping and promoting a good relationship and trust
23		Information and communication approach/ dissemination
24		Analysing conflicts and coalitions among stakeholders
25		Engaging stakeholders by considering critical success and barrier factors
26		Clarity of roles and responsibilities among members
27	Implementation, monitoring and evaluation	Implementing fully stakeholder management process and strategies
28		Identify and analyse changes in stakeholder influence
29		Identify andanalyse changes in stakeholder interest
30		Consistently monitoring and feed-back
31		Evaluate attainment of objectives stakeholder needs and satisfaction
32		Consider documentation and implementation of feed-back
33	Continuous support	Realize stakeholder changes, communicate and engage with frequently, adapt new strategy where necessary
34	Continuous Support	Continue top management support, increase PM and stakeholders knowledge in SM
35		Formal SM process (Establish an approach profile and SM process conducive to procurement approach and project type)

Proposed Models for Stakeholder Management

The literature review indicates that the proposed models for stakeholder management have generally four major components such as; (1) *stakeholder analysis* (characteristics, attitudes,interests, power,influence etc.), (2) *stakeholder management process and implementation,* (3) *stakeholder engagement*, (4) *stakeholder monitoring and control, feedback*. The models can be seen as a management tool, i.e. as a source that managers can apply to improve the quality of decision-making processes of their organization by identifying the concerns of related stakeholders. Some proposed models for stakeholder management from previous researches are compared as follows.

Model 1: Conceptual research model, (Nguyen,T.S. and Mohamed,2018)
Model 2: 10-Step model for stakeholder management for decision making, (De Colle, 2015)
Model 3: A process model for stakeholder management, (Park and Lee,2015)
Model 4: Stakeholder-based project management model, (Rajablu et al., 2014)

According to proposed models which mentioned above, the importance of *effective communication* in stakeholder engagement is underlined; being *effective* refers to three key points: (1) delivering the correct messages to appropriate stakeholders, (2) using a suitable means of communication, and (3) clarifying the project value and benefits clearly.
As with any other management tool, by no means the models are not perfect or unique. To be really effective, the models' steps should be adopted by every project according to its own specific nature and quality of the existing relations among the stakeholders.

Table 5. The comparison of some proposed models for stakeholder management

	Stakeholder Management Components	Model 1	Model 2	Model 3	Model 4
Stakeholder Analysis	Identifying attributes		X		X
	Classifying (power)	X	X	X	
	Mapping all stakeholders		X		
	Assessment (legitimate, claims)		X	X	X
	Stakeholder expectations (interest)	X	X		X
	Stakeholder attitudes(proximity,position)	X		X	X
	Prioritization (based on influence)		X	X	
	Stakeholder relationships			X	X
Stakeholder Management & Stakeholder Engagement	Understanding clear project objectives	X	X		
	Agile response to change- dynamism	X		X	
	Effective communication	X	X	X	X
	Participation strategy	X			
	Compromising strategy	X		X	
	Continuous engagement		X	X	X
	Involvement stakeholders	X	X	X	
	Information strategy	X	X		
	Consultation strategy	X	X		
	Collaboration strategy	X	X		
	Co-decision strategy	X	X		
	Empowerment strategy	X		X	X
	Building trust and confidence		X		
Control, Evaluation	Direct observation			X	
	Monitoring, feed-back	X		X	X
	Surveys, interviews			X	
	Measure performance		X		
	Risk control				X

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Conclusions

The main purpose of Stakeholder Management is to deal with the stakeholders for realizing project success and objectives. It is a process of identifying, negotiating, engaging them and developing relationships among stakeholders to prevent the conflicts, project risks and problems. The complexity of LSCPs is defined through technical,organizational, goal, cultural, and environmental aspects. Another source of complexity is derived frommultiple stakeholders and interrelationships among them in LSCPs. Stakeholders' dynamics and different cultures due to long term and internationalnature of these projects should be taken into consideration in the stakeholder management process. In addition, Public-Private Partnerships (PPP) have become a popular choice for the delivery of these projects, its effects should be paid attention to proposed models for stakeholder management. Stakeholder management depends heavily on communications management: (1) Clear intentions, (2) appropriate attention to communication processes, (3) two-way high quality communication and short communications lags can build trust and understanding on mutual realities (project value and benefits). Managers of PPPs can focus more on analysis and engagement of stakeholders as well as control and evaluation of the process if they want to increase effectiveness of stakeholder management. Stakeholder management functions can facilitate the complex processes and guide the project managers in achieving project objectives. Furthermore, other researchers can improve the effectiveness of the models by focusing on the gaps.

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An Assesment of Lean and Agile Principles in Building Life Cycle Phases

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Abstract

In today's construction world it is no longer enough to just deliver a project, it is also aimed that the project is delivered in the timeliest manner, with the highest quality and with the most feasible budget. In order to do so, people involved in project management have developed new ways such as lean and agile delivery methods. Lean management aims to reduce all waste (defects, over production, waiting, not utilizing talent, etc.) possible, whereas agile management aims to respond problems as quickly as possible. However, it is not easy to introduce these methods into traditional management techniques. In the beginning, they usually cannot be implemented on the whole lifecycle of the project, but on different parts/phases of the project. This study investigates the use of lean and agile tools in project management during each step of the building lifecycle which are categorized as; initiation, design, planning, construction, maintenance, reuse/refurbishment, demolition/recycle. It also categorizes which wastes can be reduced as well as which agile principles can be applied during which lifecycle phase.

Keywords: *Agile, Building life cycle, Lean, Project management.*

Introduction

Currently, the construction industry is trying to find and adapt new methodologies for more efficient building production and human-force utilization. The pressure for higher profit/benefit from the clients and constantly increasing costs of construction forces the industry to leave outdated methods and open new paths to replace traditional processes. Considering the rapidly changing circumstances of building projects, the aim of completing projects within targeted schedule and budget is most likely to fail when only traditional approaches are used (Howell & Ballard, 1998). This creates financial and efficiency pressures on the construction industry which affect every step of the construction life-cycle, from initiation to demolition. Thus, new methodologies are developed and presented for overcoming the ineffective, inefficient, fragmental and wasteful nature of the construction industry. Two of these innovative methodologies are Lean Construction and Agile Construction.

The aim of this paper is to examine whether or not lean and agile principles are applicable for each phase of the building production process, based on a literature review. A study was carried out by compiling the information obtained as a result of the literature research carried out by 7 students enrolled in Istanbul Technical University, Project and Construction Management Doctorate Program, Lean and Agile Management course in the 2019-2020 academic year. In line with the determined goal, 7 students researched whether the principles of lean and agile management are applicable for each phase of the building production process – which are categorized as; initiation, design, planning, construction, maintenance, reuse / refurbishment, demolition / recycle. 312 articles published between 1996 – 2020 were reviewed in total. The literature review then has been categorized in a cross match compatibility of each building phase to lean and agile principles and tools.The results obtained were brought together within the scope of the lesson and may be considered the output of this course.

Use of Lean Principles in Building Life Cycle Phases

The root of lean thinking depending on the Toyota's Production System and used mainly in automotive industry; and the lean concept firstly introduced by Womack et al in 1991 (Picchi et al, 2004). Koskela (1992) defined lean construction as a new production philosophy with various advantages in productivity and quality as well as ability of rapid diffusion into the current system. Howell (1999) explains lean construction as consuming less resources in the way of satisfying the requirements of customer. The lean wastes can be listed as: Defects, Over production, Waiting, Non-Utilized Talent, Transportation, Inventory, Motion, Extra Processing (Mazlum and Pekeriçli, 2016).These wastes, and which can be reduced at each phase of the lifecycle has been summarized in table 1.

In the initiation phase of a project it is possible to reduce defects, overproduction and non-utilized talent by keeping a lean state of mind. According to Picchi et al. (2004) the definition of value in the lean thinking application is also updated from the employer’s perspective to the whole enterprise by understanding the main characteristics and properties of the product and employer’s benefit. With this perspective, the processes are reviewed and could be improved by reducing waste and increasing the desired results. The improved version allows cost reduction, increase the understanding about project value in the beginning phase of the project, and enables a being team (creating culture) (Picchi et al., 2004). If the project focuses on increasing the value from the first step many wastes can be avoided on the product side (defects, overproduction), as well as non-utilized talent by creating a team.

Table 1: Use of Lean Principles in Building Life Cycle Phases

LEAN WASTES	Init.	Design	Plan.	Const.	Maint.	Reuse Refurb.	Demol. Recycle
Defects	x	x	x	x	x		x
Overproduction	x	x	x	x		x	
Waiting			x		x		x
Not utilized talent	x		x	x			
Transportation			x		x	x	
Inventory			x	x		x	x
Motion			x		x		x
Extra processing		x		x		x	

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According to the literature review on lean design management, there are four important factors related to reducing waste and increasing the value: " interaction, Value and value stream mapping, Lean culture and assembling the team, Information flow" (Reifi & Emmitt, 2013). According to Mazlum and Pekeriçli (2016), considerable effects of the architectural design process that progresses with lean thinking on the construction process are mostly neglected. It is very important to increase the level of lean thinking efficiency in design processes in order to increase the efficiency in the construction process. To increase the efficiency of the entire construction process, it is necessary to identify waste items that cause inefficiencies in the design process (Mazlum and Pekeriçli, 2016). By using lean principles at the design phase defects, overproduction and extra processing can be avoided from an early on stage. This will also improve the efficiency of the whole building life cycle.

In the planning phase, defects and overproduction is reduced by last planner with integrated control mechanisms, Blockchain with automated digitalization (incorrect knowledge), BIM with clash detection and digitalization. Waiting and motion are reduced by Blockchain with erasing intermediaries in supply chain, BIM with digitalization and implementation of supporting tools like UAV, AR, and VR. Inventory waste is reduced by eliminating paperwork in BIM and Blockchain. Non-utilized talent waste is reduced by last planner with great collaboration with field personnel and subcontractors. Transportation waste is reduced by Blockchain.

The most basic principle of Lean Construction is to reduce non value adding activities which can also be defined as wastes. According to the study of Bossink and Brouwers (1996) on waste in Dutch construction industry, 9% in weight of total materials are wasted on site and from 1% to 10% of each construction material leaves the construction site as solid waste, while up to 30% of purchased materials end up as waste in Brazilian construction industry. Maturana et al. (2003) argue that a 30% reduction in the number of work-force is possible to obtain throughout the schedule when multi-skilled workers are used. Project-based employment of labor, simultaneous implementation of different tasks and high training costs create a barrier for this application in the construction phase of building projects.

Building maintenance is the longest phase in the building life cycle. Total productive maintenance method is usually used to support lean manufacturing. However, it can also be used in lean building maintenance. Defects and management variations can be eliminated at source (Ahmed et al., 2004). Similarly, various wastes such as waiting, transporting, processing, inventory can be reduced by satellite workshops / stores, lineside trays etc, decentralized lineside maintenance, escalation capping, (i.e., capability guidelines), first in - first out spare parts, respectively (Davies and Greenough, 2010). One should aim for the continuous improvement which in the long run would decrease wastes and improve efficiency (Bicheno, 2000).

In the reuse / refurbishment phase, several wastes can be reduced using lean methodologies. For example, Horman et al., (2003) examined the usage of buffers in the production system of the Pentagon renovation project. Short interval production scheduling (SIPS) was used to plan activities of the interior construction. The planning method is applied in the project segmented into small work zones to improve production workflow. Mitropoulos & Howell, (2002) studied on the investigation of the problems of an office renovation project during the design process and proposed approaches in order to mitigate design duration and rework. The acceleration of the discovery of existing conditions, the identification of the project constraints as well as improvement of the iterative design process with a team-based involvement identified as approaches to deal with design duration and rework. Agyekum et al., (2013) stated that recycling of materials which causes the waste on site and reusing of surplus materials are appropriate to prevent and reduce wastes in construction. Also, they stress the critical role of proper storage and handling of building materials in eliminating waste in construction.

Finally in the demolution / recycle phase, present activities and patterns in the disposal of construction materials are based on the whole building life cycle and the idea of reincarnation. Strategies on this subject involve integrated recycling, zero waste, international approaches, resource optimization, reuse of materials, waste reduction and deconstruction (Kralj and Marki, 2008). Reuse and recycle strategies seem strongly match with lean understanding and principles. For reuse, it is encouraging to include subcontractors and other stakeholders as a shareholder for time and cost benefits. Moreover, some green building certification processes have also positive effect on back to back principle in terms of recycle. If the main contractors follow the requirements of certificate, they could force the related subcontractors and suppliers, i.e. to use materials with higher recycle percentages.

Use of Agile Principles in Building Life Cycle Phases

Agile management was born in the software industry to increase flexibility; then, many other industries, including the construction industry, have also adapted the agile approach. Koskela et al. (2006) defined lean as a collection of repeatable and focused responses to a constrained and competitive environment with limited resources; while agile is a strategic and proactive response for continuous change and unpredictable situations. According to Sohi et al (2015), agile methodology includes objectives in planning, quality, risks, changing requirement and value. Instead of upfront planning, incremental planning should be selected to choose most current available information. Quality standards ought to be up fronted and also technical risks should be addressed in the process as early as possible to reduce the effect of changing requirements. Additionally, in order to give power and trust to the staff, increase the involvement of the client and communication between project team and working environment the value of the business should be continuous and frequent.These principles and their effect in project lifecycle phases can be seen in table 2.

Table 2: Use of Agile Principles in Building Life Cycle Phases

AGILE PRINCIPLES	Init.	Design	Plan.	Const.	Maint.	Reuse Refurb.	Demol. Recycle
individuals & interactions over processes and tools	x		x	x	x		x
working software over comprehensive documents		x	x	x			x
customer collaboration over contract negotiation	x					x	
responding to change over following a plan		x	x	x	x	x	

As an example of how individuals come before processes in an agile management environment in the initiation phase of a project, Rascanis et al (2015) studied adaptation of agile project management methodology for project team in terms of people’s emotional status. Motivation of personnel of an IT firm, which started to use Agile Scrum in their last project, is investigated by means of a questionnaire which has questions grouped depending on the hierarchy of human needs in Maslow’s pyramid. Study results shows that group members have high regard for the working in a team with group members; while, they are disappointed in terms of reward (like social guarantee, remuneration). The firm could improve project team by improving reward mechanism to achieve higher level motivation (Rascanis et al, 2015). The same idology can also be applied to clients/customers as agile repetitively mentions how people’s involvement is the cornerstone of agile mentality.

Agile management can also have a positive effect on the design phaseas well. Bellomo et al. (2014) highlight two main consept for agile architecure:

- Flexible, all-purpose, easy to improve and replace system or software that will not be affected by several changes,
- Agile way uses an iterative lifecycle to define an architecture and also to figure out the problem and restrictions that allows the architectural design strategically improve over time.

Agile architecture is not only a process of dividing architectural work into iterations, but also recurrently and often concurrently elaborate development proceeds as the requirements, architecture, and design/implementation. (Bellomo et al., 2014). It could be understtod that by using agile in design working system that is open to change can be established.

In planning phase, since the greater collaboration and interactions is established between individuals, responding to change will be quicker in Last Planner system. Also, in Blockchain and BIM, change is noticed with vivid, and updated system, thus it leads fast response. Moreover, BIM and Blockchain suit agile's working software principle.

In the construction phase, Krishna et al. (2020) conducted a data analysis research on implementation of Agile Construction on different infrastructure projects and provided results for the effects of agile management in construction industry. In order to overcome t delay causatives, several agile enablers were applied to the cases: kick-off meetings, scrum development, sprint meetings, backlogs, fixed time, short cycle planning, flexibility, communication, integration, iteration, technology and continuous learning. After theoretical application of these agile enablers, it was concluded that they may reduce delay for about 70% to 80% percent per case if adopted and implemented properly. Koskela et al. (2006) analyzed the potential of Agile management for the pre-design, design and construction phases based on several criteria and concluded that "implementation of Agile management in the construction phase is expected to be harder because the consequences of changes may cause big impacts on the project objectives."

In the maintenance phase, preventive maintenance could be carried out even before a failure arose which is a great example of the agile principle of responding to change over when following a plan. The maintenance strategy aims to reduce the probability of a failure or increase the functionality of an item (Fouladgar et al., 2012). In this strategy, fixed operating time interval and the number of output units are the main basis of the maintenance activities which are performed without the consideration of the current condition of the investigated item. Also, in this strategy, performance and/or monitoring parameters such as corrosion and electric current monitoring, lubricant and vibration analysis, leak and crack detection, and ultrasonic testing could be another base for the maintenance activities to be performed (Mostafa et al., 2015).

Agile management is mainly about responding to the needs quickly in line with the changing needs of occupants and to provide satisfaction to occupants. Similarly, the term refurbishment is mainly about responding to the needs of existing buildings which loss of their function. Notably, rather than demolishing and new build, refurbishment is a rapid approach to respond to the needs of existing buildings as well as their occupants. For instance, the NewTrend project based on the integrated retrofit design methodology (IDM) aims to guide all involved stakeholders in the retrofitting projects (Khoja et al., 2017). This study considers the required communication and participation mechanisms between all involved stakeholders in all phases. The early involvement of occupants is critical to understand the occupants' needs and problems to retrofitting that can eliminate the possible rework and distributions in retrofitting (Khoja et al., 2017). In terms of agile thinking, this study covers the involvement of all project participants, communication, and collaboration among all stakeholders which play a substantial role in construction, management as well as decision-making to all phases of refurbishment projects. Also, rather than purchasing new materials, reusing existing building material is a rapid solution to respond to the needs of the projects. The responsiveness of reusable materials is supportive in terms of agile methodology.

Similar studies have not been encountered in the literature regarding the full assessment of the building demolition phase within the scope of agile principles. However, as a result of executing the building deconstruction process through the developed 5-dimensional BIM model, coordination between all stakeholders is ensured with a single model. In this context, the planning phase is created with high accuracy and it is ensured that the workers in charge at each stage of the demolition respond quickly to changes and an efficient interaction emerges. Besides, the collection of all projects and programs on a single model minimizes the number of documents created.

Use of Lean and Agile Tools in Building Life Cycle Phases

In order to apply lean and agile management principeles into the phases of building life cycle various tools have been used. In this section an array of these tools will be investigated according to the appropriate building phase they have been used as can be seen in table 3. Each tool is beneficial for a different purpose at a different phase. While researching these tools, it was recognized that some projects would use tools that would make their projects more lean or agile without even realizing it.

Table 3: Use of Lean and Agile Tools in Building Life Cycle Phases.

TOOLS	Init.	Design	Plan.	Const.	Maint.	Reuse Refurb.	Demol. Recycle
BIM		x	x	x	x	x	x
Pull (JIT) production				x	x	x	x
Last planner system		x	x	x		x	
Scrum				x			
Blockchain			x				
Digitalization	x			x	x		
Standardization	x			x	x		x
5 Whys	x						
Value Stream Mapping		x					
Set based design		x					
Cross functional charts				x			
Hejijunka Box						x	
Kanban Cards						x	

Building Information Modeling (BIM): A very common tool that can be used in many phases of the building lifecycle is BIM. The use of BIM and lean design management not only increases the value realization of the customer, but also allows the visualization of the content of the design work and the detection and removal of non-value design tasks (Tauriainen et al., 2016). According to Eastman (2008), effective use of BIM in projects can improve design, improve buildability and establish faster project completion, and can save time and money for both the business owner and the project team. In addition, studies prove that the use of BIM results in increased construction efficiency, greater employee involvement in the project and reduced unexpected situations (Azhar et al., 2008).

It can be argued that, if implemented properly, even the most basic BIM applications may favour the lean construction purposes (Sacks et al., 2010). Even though this application is generally classified under design phase in the literature, the continuous and simultaneous nature of BIM models and processes serves the continuous flow process aspect of lean construction. Proper and dedicated implementation of BIM can carry the project from beginning to demolition phase with lower cost, reduced project duration and higher quality of application which leads to an unintentional lean construction in BIM projects.

Implementation of the lean thinking in the process of maintenance might be a complex approach. Integrating the BIM with the lean thinking might provide a better understanding for this complex approach. The lean thinking and the implementation of the BIM in the maintenance process can create a virtual environment that allows for a comprehensive analysis of the entire facility. It will allow to the business to be managed in much more detail. Integration of the BIM with the lean thinking enable to focus on completion of the process, increament on the process transparency and decrase on the number of non-value adding activities (Shou et al., 2014).

BIM is especially useful during the demolition process. It provides a systematic and sustainable model on the planning of demolition process and building inventory, and how the demolition process will be planned in the most efficient way. At this stage, given the developing scanning technology and 3D design possibilities,BIM applications can make a significant contribution to solving the problem (Marzouk et al. 2019). When BIM applications are considered together with interactive visualization techniques, managers can visualize which materials are placed where; determine deconstruction sites that need to pay heed or special implementations. Also, safety precautions and waste amount can be estimated. In this context, the principles required for the demolition process can be detailed and a new process for building deconstruction and waste management can be described (Ge et al. 2017).

Just-In-Time (JIT): During the construction phase, Lean Assembly includes fabrication & logistics that overlaps with Lean Supply, installation and commissioning. The coordination of fabrication & logistic between Lean Supply and Lean Assembly leads to Just-In-Time (JIT) management which is back-and-forth between Lean Project Delivery System stages. JIT in Execution Phase require the Lean Supply to meet the need of Lean Assembly “just-in-time” which is only possible if Lean Design can feedforward and Lean Assembly feedback Lean Supply “just-in-time”. Ballard (2000a) promotes multiskilling in shops and site installation, changing the front-line supervisor’s role to coaching and managing improvement from giving orders, in-process inspection in shops and on site and incorporation of First Run Studies into site assembly.

In order to make ethe demolition phase more lean, traditional “Demolition” methods shall be abandoned and “Deconstruction” method, which allow the selection, separation, reuse and recycling of the material, should be preferred in the sector. For this purpose, the "Make-To-Order" approach could be apllied to deliver recyclable and usable materials to enduser. “Make-

To-Order" is a pull system similar to JIT. "Make-To-Order" method is the most suitable method for building deconstruction projects actually means that using the Pull-planning principle in building deconstruction projects would yield highly efficient results, since the inventory is minimum. (Marzouk et al. 2019)

Last Planner System: One of the tools that are commonly used in lean and agile management is the Last Planner System. LPS is the most known tool of lean management in planning and design phase of construction. LPS is a method that aims to succeed the lean goals like decreasing waste and obscure parts of construction, and increasing productivity. The goal of LPS is that succeeding these aims with making plans and collabrative excution by responsible individuals for final assignmet of work (Ballard et al. 2009). LPS, is the making of promises—or commitments—by individuals to do something within a specified amount of time LPS is a method that simply formalizes the coordination process in a planning context to help focus the attention of individuals involved in work, regarding what the project aims are and how best to succeed it through teamwork and collaboration (Tilley, 2005).In the construction phase, traditional planning systems schedule the project with a push-driven approach. Executions of the activities are decided without taking into account what else can be done. On the other hand, LPS distinguishes activities that will be performed from the activities that should be performed (Ballard, 2000b). In a study conducted by Heinonen & Seppänen (2016), Last Planner System is implemented for a refurbishment project. The results show that productivity increased to 380% of baseline, quality defect reduction of 99%, as well as the project lead time reduction of 73% (Heinonen & Seppänen, 2016).

5 Whys: During the initiation phase, Tsao et al (2000) studied to improve the installation of metal door frames at a prison project by considering lean and agile perspective. In the study, they try to understand how to eliminate the time consuming process on future projects. In order to solve this case, they tried to use 5 WHYs, which is a practical technique to determine root causes. By reviewing and trying to improve the system, the method statement of an installation could be improved and it could be embedded to the process in the beginning for future projects. Also by implanting a solution to a method in the beginning of the project is directly affects the design, manufacturing and construction phases as well.

Standardization: According to Picchi et al (2004) , standardization is also an important tool while applying lean and agile methodologies. The quality standards includes Quality Management Plan, Check Lists, Quality Check Forms and Method of Statements; including their format, procedure and period, too. Method of Statement is a crucial document to define the process in the construction phase one by one and should be prepared for the first rank contract works in the beginning. Moreover, it is a good tool to perform continuous improvement by establishing systematic and improved procedure.

Value stream mapping: In the design phase, waiting for information at the stage of detailing the projects and the disruption of the work of the designers due to external variables causes the waiting time to increase. For this reason, creating a visual and accessible database allows designers to provide the necessary information when needed (Leite, Neto, 2016). Value stream mapping is a lean management tool based on visualizing the steps required from the creation of the product to the delivery to the customer. This tool helps to understand the process analysis and process improvement. According to Leite and Neto (2016) by decreasing costs and the lead time Value Stream Mapping is a beneficial method to envision how the the design is improves in the company, to indentify the several acitivties and recognize the wastes.

Set Based Design: According to, (Singer et al., 2009), Set Based Design is an application that keeps design options as much as possible during the design development process. It proceeds over not a single design solution as in the point based design, eliminating weaker options over time, identifying multiple options and researching them simultaneously (Figure 5). After considering the options, the most optimum solution is achieved by continuing with more effective solutions.

Scrum: This is a method applied in the management of complex and software projects open to change. Scrum does not explicitly state the steps to be followed during a project. Instead, it offers a flexible management style with its own rules. The most important feature of Scrum is that it aims to reveal the failing points in the process by introducing a transparent production process. In this way, it provides continuous improvement by solving the problems. It can be beneficial in the design phase, but there are various problems in using Scrum at the design stage of construction projects such as; indetifying the owner, various deliveries of work packages, unclear tasks on a scrum board, hard to usewith team of more than 20 people, teams working remotely cannot meat for a daily sprinting (Demir & Theis, 2016).

Digitalization: This is a very helpful tool in the most phases of the building lifecycle. For example, in the maintenance phase, the maintenance processes are measured, managed and analyzed by using the Computerized Maintenance Management System (CMMS). This includes the task planning and scheduling, inventory control and management, labor and material cost accounting, and historical data of the asset (Mostafa et al., 2015). The maintenance tasks are efficiently planned and executed with the usage of related softwares by CMMS to ensure the maximum uptime for the critical equipment to maintain the operations of the company (Aniki & Akinlabi, 2013). In the demolution phase, Liu and Pun (2004) brought up the idea of creating a web-based catalog where products likely to salvaged from building deconstruction were presented to the endcustomer and through that the demand can be determined comfortably, while also contributing to the planning of the demolition process.

Blockchain: Blockchain is a new developing technology that has great potential to synchronize and accelerate other industries with a lot of advantages to companies, industries, clients, and society (Nawari & Ravindran, 2019). Blockchain has a distributed network that allows us to share, recreate, and synchronize data without any geographical border. The distinctive basic feature of blockchain technology is that no center or centralized data storage exists (Perera et al., 2020). Core technologies behind blockchain are peer to peer, hashing algorithm, key cryptology, and consensus algorithm. The implementation of Blockchain technologies in the planning phase could increase effectiveness of distinctive industries, also use of several supporting tools would cause efficiencies, cultivate business manner, and promote modern technologies (Mathews, et al., 2017).

Cross Functional Process Charts: This is a tool utilized in lean construction that is used for defining implementation steps and processes. This chart includes the responsible parties on the where each responsible party fall under a “row” while two or more “columns” define the project phase (Tuholski et al., 2009) These charts may help identifying unnecessary and non-value adding steps along with complex connections between steps which can be simplified and may pass onto future works in forms of documentation and improve waste reduction with less effort which is another lean thinking aspect.

Visual Tools (heijunka box, kanban cards): Various visual tools can be used to make building lifecycle phases more lean and agile. In the casestudy conducted by Bryde & Schulmeister

(2012), to implement lean thinking in this refurbishment project selected lean approaches were applied including: minimizing stock held on site: JIT delivery of materials, pull-driven scheduling: heijunka box, levelling of workload: process mapping and analysis of performance indicators, visual management: floor plans as well as kanban cards, team work: weekly meetings . The implementation of visual management strategies such as visual zoning of the site with using the heijunka box, performance charts as well as kanban cards and conducting of structured weekly meetings were found as successful to refurbishment project in terms of collaborative teamwork as well as empowerment of workers especially (Bryde & Schulmeister, 2012). The considerations of cultural, project-related as well as human-related issues play a critical role to accomplish lean targets during the application of lean thinking in refurbishment projects.

Conclusion and Discussion

After reviewing 312 articles on lean and agile management systems, it could be concluded that using lean and agile definitely affects the building production in a positive manner. However, use of these methodologies is very primitive and not at all at full capacity. In summary the points below could be made for this study:

1. Lean management is more commonly used than agile management in the industry and therefore there is more research on the benefits of lean management.
2. Amongst the tools of lean and agile management BIM is the most commonly used system followed by LPS, JIT and standardization. The reason BIM is most commonly used is that it allows a holistic project management system.
3. BIM is not directly an agile or lean tool. It has been used way before these management styles were integrated into construction. Since BIM optimizes the building process it aurtomatically serves some aspects of lean and agile management.
4. Tools vary according to the phase they are used in. Organizational tools and visual tools are mostly used in the begiingng phases such as initiation, planning design etc. whereas tools to make the production / assembly easier are used in the construction, maintenance, reuse and demolition phases.
5. Most businesses incorporate some sort of lean and agile management into their project without even realizing that those methods are lean / agile.

It should not be forgotten that lean and agile management are fairly new concepts and there are new research and tools conducted everyday. This study is just a review of what has been established so far and not what could be done in the future. As the use of lean and agile becomes more common, the approach towars these management styles would also change.

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Common Barriers of Green Building Production and Solution Recommendations: An Overview

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Abstract

Global warming, which threatens the environment and the future of the human race, has emerged as a result of the increase in resource consumption for production industries, water usage, hazardous gas emissions, and waste generation. Construction and operation of buildings have a critical role in this, with 30% of raw material consumption, 25% of water consumption, 40% of greenhouse gas emissions, and 25% of solid waste generation worldwide. In order to decrease the impact of the construction and operation of buildings on the environment, the concept of green building has been introduced. Green buildings are structures with properties, which allow reducing energy, water and raw material consumption as well as providing a healthy environment for occupants who aim to obtain a sustainable environment. Green Building Certification Systems (GBCSs) were developed by national and international organizations in the world for promoting green building production. There are a number of barriers for green building production with GBCSs such as unawareness about the environmental effects of buildings, high cost for green building projects, the lack of standards, codes and regulations and the lack of experience in the application of sustainable methods. In this study, a literature review has been performed for obtaining and comparing the solution practices for overcoming barriers to implementing sustainable methods in construction projects.

Keywords: *barriers of green building production, construction industry, green building production, green building rating systems, green standards and regulations, project and construction management in green building production, sustainability*

Introduction

Sustainability is a word that is frequently used nowadays. The term sustainability had been arisen by Hans Carl von Carlowitz in 1713, who is a German scientist in forestry, with the idea of only as many trees should be cut down as trees grow and the word used in the German language was "nachhaltigekeit" which is translated into English as "sustainable development" by the United Nations World Commission on Environment and Development in 1987, known as Brundtland-Commission (Wilderer, 2007; Kuhlman & Farrington, 2010). Sustainable development term was described as “development that meets the needs of the present generations without compromising the ability of future generations to meet their own needs” (Brundtland, 1987). However, Wu and Wu (2012) stated that the description in Brundtland Report is the description of sustainable development and they added that sustainability is to maintain the human-nature system at a desirable level for current and future generations.

Sustainability was frequently mentioned in the literature with economic, social and environmental concerns. Also, descriptions of the term sustainability were presented relevance with economic, social and environmental problems. Thus, Alhaddi (2015) remarked a triple bottom line construct that is related to sustainability and it consists of economic, social and environmental aspects. Alhaddi (2015) additionally stated that the triple bottom line construct was cogitated by Elkington in 1997, however it was cogitated in 1999.

The construction industry is one of the biggest industries which is frequently related to term sustainability because of its effects on the economy, society and environment worldwide. Asif (2016) stated that the construction and building industry plays an important role in material consumptions with a portion of 40%. Alnasser et al.’s report (as cited in Asif, 2016) denoted that the construction industry covered 42% of energy use, 40% of atmospheric emissions, 30% of raw material use, 25% of solid waste generation, 25% of water use, 20% of water effluent generation, 12% of land use and 13% of other emissions globally in 2008. In order to reduce those ratios of consumption and bad environmental effects of the construction industry, which indirectly affect the economy and society, green or sustainable building term has arisen recently. Yudelson’s study (as cited in Dwaikat & Ali, 2016) described green buildings as structures with a design of reducing energy and water use of traditional buildings during the operation, additionally reducing the life cycle impact of used material on the environment. As a summarize, green building can be described as a structure with reflecting the term sustainability; containing the triple bottom line of sustainability, which consists of a sustainable economy, society and environment, during the processes of design, construction and operation of the building. In order to popularize this environmental approach in the construction industry, to standardize the green methods, and to encourage people to pursue new approaches and methods, various green building measurement and rating systems have been introduced all around the world (Komurlu & Arditi, 2017). To characterize a building as a green building, Green Building Certification/Rating Systems have been founding and improving all around the world. BREEAM in the United Kingdom, LEED in the United States, CASBEE in Japan, Green Star in Australia, GRIHA in India, ESTIDAMA PEARL in Abu Dhabi and BEST in Turkey are examples of those GBCSs.

Evaluation of building projects based on sustainability-related aspects is the main focus of green building rating systems. The certification process is based on the performance with regard to these aspects. The site, energy, water, resources, natural habitat, relationship with the surroundings, transportation are the most commonly used aspects (Komurlu & Arditi, 2017). For proper sustainability evaluation, the energy performance of a building should be tracked at all stages of a building’s life cycle (Komurlu et al., 2014). On the other hand, building performance evaluation should be performed from various angles, i.e. social, economic, environmental, and technological (Kim et al., 2013, Cole, 1998). For a proper evaluation from these angles, codes, standards, regulations, and guidelines are required (Komurlu et al., 2014).

Obstacles could occur during the design, construction and operation processes of green buildings. Those obstacles are named as barriers in the literature. However, solutions to those barriers have been conceived rapidly to promote green building production all around the world. This paper reviews the barriers of sustainable green building production according to developing and developed nations in related literature in order to create an inclusive view for the construction sector about effects on green building production.

Literature Review of Barriers in World's Different Countries

There is a significant number of reasons that prevent wider green building production and the adoption of green technologies in the construction industry which are generally called barriers in the literature. Samari et al. (2013) investigated barriers on green building production in Malaysia and they listed frequently encountered barriers in the Malay construction industry as the risk of investment, higher final cost comparing to traditional constructions, low demand ratios in the market, lack of credit costs to provide front cost, and lack of building codes and regulations.

According to a study investigated by Liu et al. in 2012 in China, obstacles of green building production are high manufacturing costs in the design process, cost control mistakes in the construction process, lack of application experience of green building technologies, low number of green building professionals in the sector and lack of knowledge in regulations of green building certification systems.

Lack of incentives, high cost and lack of interest from clients are the critical barriers in the Indian construction industry (Potbhare et al., 2009).

Sever et al. (2012) stated that one of the biggest barriers in the Israeli construction industry is to convince shareholders for constructing buildings with sustainable and environmentally friendly properties.

Unsupportive governmental policies and regulations, resistance to change the culture, and lack of professionals are the main barriers in Saudi Arabia. Also, another important barrier is that unconcern to the consumption of electricity due to the low prices of electricity (Mosly, 2015).

A study performed by Wimala et al. in 2016 demonstrated that Indonesia's main barriers in green building production are the burdensome implementation of green building features, lack of supportive atmosphere caused by occupants, and resistance of companies to change.

In Italy, 55% of construction investment is made in residential buildings and 96% of construction firms, which generates residential building production, are small-medium sized enterprises. This situation is a barrier in green building production in Italy (Albino & Berardi, 2012).

Winston (2010) indicated that high levels of residential turnover, rising levels of tenancy, poor quality designs, and a lack of affordable accommodation to suit are barriers that obstruct green building production in Dublin, the Republic of Ireland by the method of converting existing buildings into sustainable buildings.

Table 1. Barriers of green building production according to the countries.

Author	Country	Barriers
Samari et al. (2013)	Malaysia	Risk of Investment Higher Cost Low Demand in the Market (Customer Unawareness) Lack of Building Codes and Regulations
Liu et al. (2012)	China	Higher Cost Cost Control Mistakes During the Construction Process Lack of Experience in Construction Companies Lack of Professionals in the Sector Lack of Knowledge in GBCSs Regulations
Potbhare et al. (2009)	India	Lack of Governmental Support Higher Cost Low Demand in the Market (Customer Unawareness)
Sever et al. (2012)	Israel	Resistance of Construction Companies to Change
Mosly (2015)	Saudi Arabia	Lack of Governmental Support Lack of Building Codes and Regulations Resistance of Construction Companies to Change Lack of Professionals in the Sector
Wimala et al. (2016)	Indonesia	Difficult Implementation of Green Building Features Low Demand in the Market (Customer Unawareness) Resistance of Construction Companies to Change
Albino and Berardi (2012)	Italy	Domination of Small-Medium Sized Enterprises
Winston (2010)	Ireland	Poor Quality Designs
Nguyen et al. (2017)	Vietnam	Lack of Building Codes and Regulations Lack of Explicit Financial Mechanisms
Chan et al. (2018)	Ghana	Higher Cost Lack of Experience in Construction Companies Lack of Financial Mechanisms Unavailability of Green Building Technologies
Bond (2011)	New Zealand, Australia	Higher Cost Low Demand in the Market
Gundogan (2012)	Turkey	Lack of Governmental Support Lack of Professionals in the Sector Lack of Experience in Construction Companies
Komurlu et al. (2014)	Turkey	Lack of Inspection Agency, Lack of codes, standards, regulations, guidelines Lack of adversities about usage, Lack of Education, Lack of technical know-how, Lack of experience Lack of renewable energy supply
CEC (2008)	Canada, Mexico, The U.S.	Higher Cost Risk of Investment Lack of Experience in Construction Companies Lack of Investment in Research Studies

A research study conducted by Nguyen et al. in 2017 indicated that slow and unwieldy administration processes in policy-making, lack of comprehensive code package to guide action in sustainability, and lack of an explicit financing mechanism are the main barriers in the adoption of green building in Vietnam.

Higher cost, lack of databases, information, financing schemes in green building technology, and unavailability of green building technology supply are the main barriers in the Ghanaian construction industry (Chan et al., 2018).

The result of a study that investigates New Zealand by Bond, in 2011 demonstrated that larger homes with smaller households' numbers, the initial cost of sustainable properties implementation, and lack of consumer information about benefits and savings of green building systems are the main barriers of expansion of green building production in New Zealand and Australia.

Lack of governmental support, shortage of experienced professionals, faulty contracting and tendering processes, and inadequate experience of construction companies are economic, educational, market and organizational barriers against the number of green building projects increase in Turkey (Gundogan, 2012).

According to Komurlu et al (2014) a general comparison of energy-related certification systems in Turkey, India, and Abu Dhabi is analyzed under the criteria of (1) inspection agency, (2) standards, (3) adversities about usage, (4) education, (5) technical know-how, (6) experience, and (7) renewable energy supply. The long term success of a certification system depends heavily on these seven criteria because these criteria affect the development, adoption, implementation, and updating of certification systems. Komurlu et al. (2014) focus on the difficulties that arise in the application of green building certification systems. According to this study, based on their maturity levels, developing countries either prefer importing and modifying a green building certification system introduced by an industrialized country, developing a brand new green building certification system based on local conditions, or introduce legislation and develop standards to encourage the construction industry to adopt sustainability measures.

Separate capital and operating budgets, higher perceived or actual costs, risk and uncertainty of green building systems and technologies in the real estate community, lack of experience in the workforce, and lack of investment in research studies are the main and common barriers of the green building industry in Canada, Mexico and the United States of America (CEC, 2008).

Discussion and Suggestions

Table 1 represents barriers of green building production according to the country represented in both developing and developed nations. The most common barrier is the higher cost of green building production which includes either the projects' cost of the design phase in China or the final cost of projects in Malaysia, India, Indonesia, Ghana, and Mexico. A higher cost barrier is generally a matter in developing countries due to the low concern of environmental problems. Lack of governmental support in economic meaning plays an important role in overcoming this problem. However, a study conducted by Mytafides et al.

(2017) in Greece demonstrated that only the installation cost of green building technology for preventing high energy consumption at a university building could be provided by reduced heating and cooling expenses in a 2 to 8 years term.

Applicability of green building properties in construction projects is met with the lack of building codes and regulations barrier as well. Many countries, especially developing countries without a valid GBCS, have old building codes, standards and regulations due to slow updates in their construction industry since the green or sustainable building term is currently becoming popular worldwide.

Green building certification systems assess and reward different processes and aspects of a construction project, including energy, water, resources, natural habitat, relationship with the surroundings, transportation, etc. These certification systems generally refer to standards and regulations. Industrialized countries have introduced environmentally sensitive regulations in order to regulate the construction industry. In addition, standards have been introduced in these countries to serve as a guideline for sustainability efforts. Therefore, regulations and legislation should be set in place in developing countries to regulate their construction industry, standards should be developed to function as a guideline for effective sustainability efforts, and green building certification systems should be introduced that are sensitive to environmental issues as well as local conditions (Komurlu & Arditi, 2017).

In addition to that, construction companies tend to sustain old construction methods and perform old building features on new projects rather than implementing new methods due to their risks. One of the reasons for the risk is the lack of experience in construction companies in green building applications. The resistance of companies to change, one of the most common barriers, prevents the construction industry to gain experience in green building production. Nonetheless, lack of green building professionals in the construction industry, which is another common barrier, make adoption of companies in the application of green building technologies more difficult than as it is.

Table 2. Alternative solution suggestions for barriers.

Barrier	Solution Suggestion
Higher Cost - Governmental Support	Reduction of property taxes for certificated green buildings Reduction of sale taxes for green technology products and green materials in the market
Lack of Building Codes and Regulations	Creating committees to promote codes and regulations for green building
Lack of Experience in Construction Companies	Educating the company staff with the help of institutions and the universities
Low Demand in the Market	Educating the public and advertising about the benefits and savings of green buildings to increase awareness
Lack of Professionals	Promoting professionals to get educated in the green building field by institutions and universities.
The resistance of Construction Companies to Change	Promoting companies, which produce green buildings, with tax reduction in annual profit

Low demand in green buildings in the market is a barrier that is related to the educational deficiency of occupants about benefits and savings of green building technologies, and unawareness of climate change being caused by global warming where old building technologies have a massive portion in that issue.

Table 2 represents alternative solution suggestions for the most common barriers of green building production in the world's different countries. Furthermore, Lean Construction Method, which was first mentioned in 1992 by Lauri Koskela (Bashir et al., 2010), might be another efficient solution to the higher cost barrier of green building production. The main benefits of this method are improving the quality of the construction process, the efficiency of the construction process, construction materials, and workforce which provide elimination of waste and additional costs. By means of this, the profit of construction projects can be maximized, thus higher cost of green buildings can be reduced where construction companies could be able to get sufficient profit after decreasing the higher price of the construction process.

In order to produce a green building, additional issues such as energy efficiency, quality management systems, environmentally friendly products, etc. need to be managed. Thus, a cost-based analysis should be performed to compare the benefits of green building certification against cost and schedule implications of the process (Gurgun et al., 2016). Considering the relatively long period of time a project takes, green building production needs to be managed as a process (Komurlu et al., 2013), and a holistic project management approach needs to be established (Komurlu & Arditi, 2017). Since construction projects affect the environment heavily, sustainability requirements should be stated in addition to traditional requirements and should be addressed by the project manager accordingly. Sustainability issues require more interdisciplinary effort (Komurlu & Arditi, 2017).

Conclusions

The term green building was explained in this study. Main and common barriers related to the economic, governmental, educational, organizational, and market in both developing and developed countries against the implementation of this method in the construction industry were investigated. This is a significant step to classify the responsible parties with related problems and solution suggestions. The most common and crucial barrier of green building production in most countries was determined as higher cost. Moreover, the complexity of GBCSs regulations and codes is another barrier that prevents construction companies to engage with green building production. One of the most important barriers is the lack of standards, codes, regulations and guidelines. Therefore the green building certification systems should be developed according to the local conditions and the local construction industry. A further study about making details of GBCSs regulations and codes clear can be conducted in future research studies in order to ease the implementation of GBCSs.

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An Exploratory Study on Utilization of BIM for Risk Management

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Abstract

It is a well-known fact that BIM application in construction projects enables several advantages such as better collaboration and communication, effective project visualization before construction, more efficient cost estimation and scheduling, and an increase in productivity. Although many of these advantages that BIM contributes to construction projects may result in opportunities for better risk management, there are limited studies in the construction management literature that investigate this subject. For this purpose, a study was conducted to explore the utilization of BIM for risk management and its impact on the level of risks in construction projects. Consequently, a survey was prepared and administered to experts knowledgeable in the construction project management area and BIM. The survey was responded by 65 experts. The results show that BIM's integration in the risk management process is considered as beneficial for many reasons. BIM is found to be an application/tool that may primarily lead to the reduction of risks at the design and construction phases of projects. Moreover, survey findings indicate that BIM is interpreted as not only beneficial to reduce risks during design and construction phases, but also can effectively be used to store risk-related information and share experience between the parties of a project. The findings of this research can be used by practitioners to integrate BIM with their risk management practices and also by researchers that aim to develop tools/methods to enhance risk management, particularly by BIM.

Keywords: *BIM, project management, risk management.*

Introduction

The Architecture, Engineering and Construction (AEC) industry has witnessed rapid developments in recent years due to the emergence of new technologies in the area of IT and globalization of construction activities. The scale of the projects is increasing, new methodologies for project delivery are being utilized, and innovative construction approaches, methods, and materials are being introduced (Zou et al., 2017). Nevertheless, with complex and dynamic project environments that make the construction industry more vulnerable to risks, risk management becomes more indispensable than ever. In the project lifecycle, different risk factors are emerging because of the increase in the project size, complexity, and new construction methods (Shim et al., 2018). Risk management is defined as the process of identifying, analyzing, and responding to project risks. The utilization of risk management in the construction industry follows a systematic pattern as identification, assessment, and mitigation. Risk identification is about the definition of risk events, sources, and their relationship. The risk assessment process is carried out to quantify the probability of occurrence and impact of risk factors and then estimate the consequences of risk factors on project success (e.g., cost, time, and quality). Finally, the risk mitigation process encompasses risk response planning, formulating response strategies to eliminate/reduce threats, and/or maximize opportunities.

Current research shows that the implementation of the traditional risk management methodologies can be heavily reliant on the experience and manual undertaking that may decrease efficiency in the work environment (Hartmann et al., 2012; Shim et al., 2012; Zou et al., 2017). To suggest solutions for these problems, a new research trend has emerged as utilizing Building Information Modeling (BIM) and BIM-related technologies for better risk identification, risk communication, and more efficient risk assessment in the planning and design phases (e.g., Tomek & Matejka, 2014; Zou et al., 2017). The general scope of this paper is to evaluate the possible benefits/disbenefits of BIM during risk management processes.

The BIM and BIM-related applications have become a source of growing interest for both researchers and practitioners. Eastman et al. (2011) indicates that BIM technology ensures one or more accurate virtual models of a building that can be constructed digitally. Many current studies show that when the necessary data for a project is transferred well, BIM facilitates a more integrated design and construction process, which results in buildings with higher quality, lower cost, and shorter project duration. Many companies take advantage of BIM by using it for better scheduling, cost estimation, mitigation of risks through clash detection, coordination, and collaboration between parties of the project. Although there are several studies about BIM’s contribution to success and benefits in projects, there are limited studies that discuss its utilization for project management, especially for risk management.

Based on the definitions and concepts of risk management and BIM, this paper argues that BIM's main benefits in the industry should also be evaluated for risk management. In this regard, to provide sufficient information for the potential use of BIM in risk management and encounter the literature gap for this subject, a survey questionnaire has been developed and administered to experts in the area of construction management. The rest of the paper is structured as follows: In the next section, the concept of BIM and the use of BIM in the Turkish construction industry is explained. After that, by clarifying the research methodology that was used, the findings of the survey are presented. Then the research findings are critically discussed considering the current literature on this subject. Finally, suggestions regarding the use of BIM in risk management are depicted.

Building Information Modeling (BIM)

Building Information Modeling (BIM) can be defined as a process to generate and manage information of buildings during the project lifecycle. Mainly, in the construction industry, BIM allows projects to be built virtually in the 3D model before they are constructed, thus eliminates several inefficiencies, clashes, and problems that may arise during the construction phase of the project. Users can use the object-oriented and intelligent data-based model of the facility to make decisions in the early stages of the project (Azhar, 2011). BIM is a "rich model" that includes objects with properties and relationships and enables simulations, visualization of the model, and calculations using the model data. (CRC Construction Innovation, 2007).

According to such properties of BIM, the construction industry generally uses this information-based model to make processes faster and more effective. In the design phase, BIM provides building design recommendations that can be simulated and analyzed, thus enables more innovative and improved solutions from several point of views. Utilizing the software tools of BIM, cost estimating can be done more effectively. BIM facilitates generating quantity take-offs and measurements from the model. Built-in cost estimating features provide automated results and changes when any changes are made in the model. At this point, the detail of the information that is linked to the model becomes substantial. The information that BIM offers is directly linked to the information that the model has (Lee et al., 2014). Another major aspect of BIM in the construction industry is improved scheduling and sequencing. The schedule of the project can be prepared directly by linking objects and can be shared by members, thus offers a better understanding of time, helps eliminate space conflicts and scheduling mistakes, and improves coordination. During the design stage of projects, 3D models provide time-savings when compared to traditional working drawings. Shared models between the design and construction teams allow examination of design in the early stages of the project, thus reduces design errors. Another aspect is customer/ owner satisfaction. The cost estimation and scope of the project should align with the initial requests of the owner. Automated integration of design changes in BIM saves significant hours for the estimate, shows whether the model is as requested, and its progress can be controlled directly (Hartmann et al., 2012). Moreover, with cloud-based tools, BIM provides better collaboration and coordination, which is necessary for an industry where many disciplines work together. For instance, the design procedure in BIM becomes collaborative rather than a "linear" procedure (Carmona et al., 2007). Project models and ideas can be shared with project members by means of cloud-based tools in BIM, providing all stakeholders to have a common perception of the project.

Role of BIM in Turkish Construction Industry

The construction industry is one of the leading industries in Turkey. To trigger this industry in the long term and have a sustainable position in both the national and international markets, it is crucial to adjust new methodologies for construction management in Turkey. In recent years, BIM became a necessary part of projects all around the world. For instance, according to the McGraw Hill Company's report in 2010, nearly three-quarters of Western European BIM users (74%) stated a positive noticed return on their overall investments in BIM (McGraw Hill Construction, 2010). In 2014-2018 Development Plans in Turkey, the inclusion of BIM applications on behalf of the project was promoted. Moreover, Kalfa (2018) stated that in Turkey, 12 universities offer BIM courses that will increase interest in this subject for both academic and practical applications. Generally, in the design offices operating within the Turkish construction industry, BIM is used for 3D visualization, to provide time and cost efficiencies, inter-disciplinary collaboration and coordination, clash detection, energy and performance evaluations, smart objects, and for revisions (Kalfa, 2018). Aladag et al. (2016) stated that contract obligations and the need for collaboration, coordination, and interoperability between stakeholders of the project are the main reason for BIM implementation in Turkey.

Considering the globalization of the Turkish construction industry and mega projects being conducted in the domestic market, it can be hypothesized that BIM will be more widely used by Turkish construction firms. Any kind of potential conflict in the projects will damage the company, the industry, and even the national economy (Aladag et al., 2016). Thus, inter-disciplinary coordination and collaboration in projects are very important. As explained in the previous section, BIM can utilize the company's early awareness of the details of the project concerning its properties and benefits. Moreover, the awareness on sustainable buildings, energy efficiencies, and reducing the carbon footprint of projects have been increasing over the past years in Turkey. BIM also provides advantages for life cycle assessment, energy simulations and reducing documentation for projects. Digitalized models and especially drawing in 3D decrease the time and material that is used for the project lifecycle considerably.

BIM applications can support safety planning that includes falling prevention planning, understanding of works with significant safety risks, and 3D-4D plans that have viewpoints of specific hazardous work tasks and areas (Kiviniemi et al., 2011). In Turkey, most of the work accidents happen in the construction sector. In 2017, nearly 600 people died in the construction sector (SGK Statistics in 2017). By simulating the build process, construction methods that are risky for occupational health and safety can be detected before construction. Thus, safety management by BIM is also beneficial for the Turkish construction industry.

On the other hand, according to the research of Sarı and Pekeriçli (2020), the main barriers of BIM in the Turkish construction industry are regulative and legal problems, potential claims and disputes between stakeholders, and lack of clear standards and regulations. This research is conducted to investigate the net benefits of BIM and understand how risk management can be utilized by BIM. In the next section, the aims and methodology of the research are explained.

Research Objectives and Methodology

The exploratory research on the utilization of BIM for risk management started with an overview of the literature on risk management and BIM. Consequently, a questionnaire form was designed and conducted. The survey was designed to gather expert opinion on potential benefits/disbenefits of BIM during risk management in construction projects and to understand the opinions of experts about how BIM can be included in the risk management process in construction companies.

The survey has 4 parts and 40 questions. The first part of the questionnaire explains the purpose of the survey. In the second part, demographic questions are asked in order to understand the experience of respondents in the industry, especially in risk management and BIM applications. Then, opinion questions that have statements regarding utilization of BIM in risk management are presented and evaluated using a 5-point Likert scale (strongly agree, agree, neither agree nor disagree, disagree, strongly disagree). While preparing these statements, general utilization areas depicted in the literature as well as benefits of BIM such as visualization, clash detection, interoperability, integration, and transfer of knowledge, coordination and collaboration, alignment of design with scope and budget, controlling revisions, safety, and quality management, are associated with risk management. In the last part of the survey, the impact/potential of BIM to decrease or increase several risk factors are questioned.

Research Findings

The on-line questionnaire was sent to more than 70 people and answered by 65 experts experienced in BIM and risk management. Among the 65 respondents, 82% of them were engineers, whereas 8 respondents were architects, and the remaining 4 indicated themselves as academicians. Nearly 50 percent of the respondents have been in the construction industry for more than 10 years.

Participants of the survey were chosen among experts with high experience in project risk management, BIM and BIM-related technologies. The percentage of the respondents who are not familiar with BIM-related technologies is limited to 14%. However, according to the answers, even though respondents are highly experienced regarding BIM and risk management, more than 78% of them stated that they have never used BIM or BIM-related technologies for project risk management. This implies that BIM is hardly seen as a tool for risk management. In the second part of the survey, 23 statements were given to participants, and the level of agreement/disagreement is evaluated. Generally, respondents stated that BIM allows the identification and mitigation of risks during the project lifecycle from many perspectives. More than 70% of respondents strongly agreed or agreed on the benefits of BIM in risk management for almost all the statements. The statements that are mostly agreed by the respondents are summarized in Table 1. In other words, Table 1 lists the statements where the summation of percentages of strongly agree (SA) and agree (A) exceeds 80% and sorted according to average ratings calculated using the 1-5 Likert scale associated with strongly agree (SA), agree (A), neutral (N), disagree (DA) and strongly disagree (SDA) categories.

Table 1. Benefits of BIM agreed by the majority of the respondents.

	SA (%)	A (%)	N (%)	DA (%)	SDA (%)	Average rating (1-5)
BIM enables integration of multi-disciplinary knowledge so that more informed/effective risk mitigation strategies for design and construction risks can be developed	50.00	48.33	0	0	1.67	4.48
Shared environment in BIM improves communication and collaboration during project management and decreases risks due to poor communication between the parties	53.33	41.67	3.33	0	1.67	4.48
More collaborative decision- making process between stakeholders can reduce risks at the design phase	58.33	33.33	5.00	1.67	1.67	4.45
Through the clash detection process that BIM offers, risks during construction and implementation are decreased	53.33	36.67	8.33	0	1.67	4.43
5D model (3D+cost+schedule) effectively tracks the project so that risk mitigation can be performed more proactively	50.00	36.67	11.67	0	1.67	4.37
As BIM can be used to trace how design aligns with scope and budget of the project, it decreases project uncertainty	45.00	41.67	10.00	1.67	1.67	4.27

As BIM can be used to visualize risks at different phases of the project, it helps risk assessment and mitigation during the project life cycle	50.00	36.67	8.33	3.33	1.67	4.27
BIM facilitates the identification and mitigation of risks at the design phase of the project	44.07	40.68	10.17	1.69	3.39	4.24
Automatic rule checking decreases the probability of design mistakes in a project	48.33	35.00	10.00	3.33	3.33	4.22
BIM can facilitate sharing of risk-related information between project participants, hence, can increases awareness on risk sources for all parties	45.00	38.33	11.67	3.33	1.67	4.18
Storage of knowledge and experience through BIM helps learning-based risk management	36.67	45.00	15.00	1.67	1.67	4.13
Ability to control revisions regularly in a common platform enables change management	40.00	43.33	8.33	6.67	1.67	4.03
Construction risks can be decreased as BIM gives location spatial information on potential risk events	28.81	52.54	13.56	3.39	1.69	4.00

According to Table 1, over 98% of respondents believed that BIM enables the integration of multi-disciplinary knowledge; thereby, more effective and informative risk mitigation strategies can be developed for design and construction risks. This statement has an average rating of 4.48, where it is the highest rating (tied for the highest score with the second statement) among 23 statements. Furthermore, there are no undecided and disagreed participants on this issue. In other words, almost all of the respondents stated that the risk mitigation process could benefit from BIM's ability to transfer and combine the multi-disciplinary knowledge more effectively.

Another aspect of BIM is the storage of knowledge and experience in a common platform for learning-based risk management. Current research shows that outstanding challenges exist in the current risk management that mainly depends on an individual's subjective knowledge and experience. In the AEC industry, every project generates significant knowledge and experience that may be used in future projects for managing risks. So, a shared environment, storage of knowledge, and collaborative decision-making process become highly important for risk management. Based on this idea, participants were asked for different statements on the sharing of risk-related information and the utilization of collaboration and communication. As it is indicated in Table 1, 95% of participants stated that the shared environment in BIM improves communication and collaboration that provides a decrease in poor communication risks during project management. The average rating of this statement is also 4.48, sharing the highest score with the first statement. The correlation between the collaborative decision-making process and the reduction of risks at the design phase is another issue that has to be discussed. This statement has the highest strongly agree percentage (58.33%) and second in rating among 23 statements. From both of these findings, it can be clearly seen that BIM is accepted as an effective tool for enhancing knowledge communication and improving knowledge sharing for risk management processes.

The models created and automated by BIM technologies offer many benefits in risk management. Clash detection procedure is one of the techniques that BIM offers. Basically, clash detection provides an understanding of where and how two parts of the model are colliding with each other. As can be seen from Table 1, with a 4.43 average rating, the majority of respondents (90%) agreed with the statement about clash detection. In order to realize risks before construction or implementation, clash detection features in BIM may be beneficial. From the findings of the survey, it has been concluded that the clash detection feature, which is often used in most of the BIM applications, is important for managing risks, especially during construction and implementation. Another issue that follows this rating and related to the contribution of models in BIM to the construction industry is the time and cost factors that are integrated into 3D models. 87% of respondents agreed on tracking through 5D models would enable risk mitigation more proactively. Although the average rating on this question is 4.37, the percentage of participants who are undecided on this issue is 11.67%. Having mentioned the benefits of tracking projects through BIM, reducing uncertainty in the project by monitoring how the design aligns with the scope and budget of the project is another issue that most participants agreed on.

Nowadays, in line with the increasing scales and complexities in construction projects, visualization of risk-related information becomes a critical task. Nearly 87% of respondents expressed that risk visualization through BIM at different phases of the project may help risk mitigation and assessment during the project life cycle. As can be seen from Table 1, the statement related to this issue has a 4.23 average rating and appears as the 7th among 23 statements. Another remarkable finding is that 84.75% of respondents indicated that BIM facilitates the identification and mitigation of risks at the design phase, with a 4.24 average rating. Moreover, during the design phase of projects, automatic rule checking may be beneficial to notice design mistakes in advance. The percentage of those who do not explicitly agree on idea that automatic rule checking reduces the likelihood of design errors is limited to 16.66%.

As can be seen in Table 1 and explained above, the highest impacts of BIM on risk management in the survey results are the integration of multi-disciplinary knowledge and the shared environment that enables better communication. However, it was also observed that the percentage of the agreement drops slightly in other statements regarding this context. For instance, the average rating about the potential of BIM to increase awareness on risk sources for all parties through the sharing of risk-related information is 4.18. So, even though almost all of the participants believed that a shared environment in BIM enables more effective risk mitigation strategies and communication between parties, fewer participants (83.33%) thought that BIM increases the perception of risk sources.

Finally, nearly with a 4.03 average rating, many experts in the survey indicated that BIM provides the ability to control revisions for change management and understanding of construction risks by spatial information on potential risk events.

Having mentioned the statistics that mainly depends on the agreement of participants about BIM's advantages for risk management, there are also some points that respondents somehow did not agree or mostly undecided (less than 80% agreement). These results are tabulated in Table 2. There was no significant difference between average ratings, so, to examine the controversial statements, the ranking in Table 2 is based on the total disagreement. In this study, the total disagreement percentage includes the participants who strongly disagree, disagree and are indifferent (SDA+DA+N).

According to Table 2, the statement with the highest percentage of disagreement was BIM's contribution to safety management. Even though the percentage of disagreeing and strongly disagree were low, 30% of respondents were undecided about the utilization of BIM for mitigation of safety risks.

Table 2. Benefits of BIM disagreed/undecided by the respondents.

	SA (%)	A (%)	N (%)	DA (%)	SDA (%)	Total Disagree (%)
Safety planning can be done by BIM at the early stages of the project thus reduce safety risks	31.67	35.00	30.00	1.67	1.67	33.34
Interoperability through IFC standard and knowledge sharing platforms can facilitate risk management	25.00	41.67	20.00	10.00	3.33	33.33
Poor implementation of BIM can create secondary risks and even increase the risk level in a project	36.67	31.67	20.00	8.33	3.33	31.66
Clients can track project progress by virtue of monitoring risks and mitigate them by using BIM	21.67	48.33	28.33	0	1.67	30.00
BIM ensures monitoring and reporting the risk management process consistently	20.00	51.67	23.33	3.33	1.67	28.33
As BIM enables integration of special external project conditions to risk objects, it assists risk assessment	20.00	55.00	23.33	0	1.67	25.00
BIM based tools may facilitate quality control that provides realizing/tracking of risk of poor quality in a project	30.00	45.00	18.33	3.33	3.33	24.99
Ease of model updating through BIM's parametric modeling capability can support risk identification/ monitoring/ updating processes	33.33	43.33	16.67	5.00	1.67	23.34
BIM enables the transfer of risk-related information and learning outcomes from experience to future projects	41.67	35.00	18.33	3.33	1.67	23.33
Risk database and lessons learned during the risk management process should be maintained by BIM	33.33	45.00	13.33	6.67	1.67	21.67

The international Industry Foundation Classes (IFC) standards have the potential to encompass information regarding risk management. Interoperability in BIM through these standards and knowledge sharing platforms may support risk management. However, the statement related to this topic ranks second in percentage of total disagreement with 33.33%, and the highest disagreed percent (10%) among 23 statements. Moreover, the smallest average rating in Table 2 also belongs to this statement. So, it can be concluded that interoperability in BIM and its use in risk management is one of the most objected subjects in the results of the survey.

Unlike other questions, the 3rd statement in Table 2 is based on the fact that the problems in the implementation of BIM could create secondary risks or even raise risk levels. Although 68.34% of respondents agreed, this statement has a significant undecided percentage (20%) and 31.66% of total disagreement.

Another aspect of the utilization of BIM in risk management is about clients' potential to track project progress by monitoring. None of the respondents have stated that they disagree on the issue, but this statement has the highest undecided percentage among 23 statements, with 28.33%. This issue requires further elaboration. A similar issue that BIM ensures consistent monitoring and reporting has a percentage of 28.33% together with undecided respondents and an average rating of 3.8.

Transferring the project's exceptional conditions to risk objects through the model in BIM-related technologies can be useful for assessing the risks. According to Table 2, almost none of the participants contradicted with the idea. However, nearly 23% of respondents were undecided; thus, the total disagree is 25%, with an average rating of 3.95. In addition to transferring the external features of the project to the model, supporting quality management is one of the BIM's other contributions to project management. Quality management is basically the control of the materials and services used in the project and checking whether they meet the requirements. In the survey, 75% of the participants stated that BIM enables tracking of the risk of poor quality in a project.

Lastly, the last three statements of Table 2 are about updating the model, the transfer of risk-related knowledge to future projects, and the maintenance of a risk database. The average rating is around 4.00, showing that level of agreement is high; however, these statements are presented in this table to demonstrate that there are still some concerns regarding these benefits as the percentage of those agreed could not exceed 80% threshold used in this study.

In summary, when both Table 1 and Table 2 are evaluated, it can be concluded that most agreed statements in the third part of the survey are benefits of the risk mitigation process due to BIM's ability to transfer and combine the multi-disciplinary knowledge and benefit of BIM due to its shared environment to foster communication and collaboration that minimizes poor communication risks. On the other hand, the most opposed issues are about safety planning by BIM and the facilitation of risk management through interoperability and IFC standards.

In the fourth part of the questionnaire, risks that may be mitigated by BIM applications are evaluated. The percentages of answers for different risks are indicated in Table 3. In the overall evaluation of the results in this section, it is seen that BIM is considered to be an effective application, especially for mitigation of risks of loss of information, design reworks, and poor communication between the parties. On the other hand, the answers given to some questions showed that there are also ideas that BIM can somehow increase various risk levels (such as legal disputes, and cost overrun) rather than reducing them.

According to Table 3, the risk of loss of information, poor communication, and poor coordination-organization is the most significant risk factors that BIM helps to mitigate. 62.71%

of respondents stated that BIM might reduce the risk of loss of information, updates, or records at the end of the project, hence provides storage and transfer of risk-related knowledge. Also, this ratio is the most significant one among the other 12 risk factors. Moreover, nearly 43% of respondents indicated the risk of poor communication with parties might be significantly decreased by the applications of BIM on the projects. On the other hand, there is a lack of consensus about this issue. Nearly 35% of respondents believe that BIM may even increase the level of communication risks, which is considerable.

Table 3. Impact of BIM on various risk factors (ranked as listed in the survey).

	Significantly Decrease (%)	Decrease (%)	No Effect (%)	Increase (%)	Significantly Increase (%)	Undecided (%)
Risk of scope changes	22.41	32.76	17.24	8.62	13.79	5.17
Risk of loss of information, updates or records at the end of the project	44.07	18.64	8.47	6.78	22.03	0
Risk of poor communication between the parties	43.10	18.97	3.45	18.97	15.52	0
Risk of design errors rework	40.68	18.64	6.78	13.56	20.34	0
Risk of poor coordination and organization	37.29	23.73	5.08	23.73	10.17	0
Risk of accidents	11.86	23.73	32.20	18.64	11.86	1.69
Risk of poor quality	10.17	37.29	22.03	15.25	15.25	0
Risk of dissatisfaction of client	18.64	33.90	16.95	10.17	16.95	3.39
Risk of delay	16.95	37.29	13.56	18.64	13.56	0
Risk of cost overrun	18.64	35.59	10.17	22.03	11.86	1.69
Performance risk during the maintenance /operation phase of the project	23.73	30.51	10.17	11.86	16.95	6.78

Risk of legal disputes between parties	6.78	35.59	15.25	20.34	18.64	3.39

Furthermore, more than 50% of participants stated that BIM can help mitigate the risk of scope changes, reworks of design errors, project delay, client's dissatisfaction, and performance risk during the operation /maintenance phase of the project. Even though 54.23% of respondents believed that BIM applications decrease the level of cost overruns in the project, 33.98% of them stated otherwise, which is worth mentioning when it is compared to other statistics in Table 3.

Occupational accidents are the most important consideration that the implementation of BIM will not have an impact on its level. In Table 3, 32.2% of respondents stated that BIM does not affect the level of risk of accidents, which is comprehensible according to the results in Table 2 regarding the effect of BIM on safety planning and mitigation of safety risks. Since the construction projects are complex processes that involve several activities, individuals, and plans, the occurrence of legal disputes is undeniable. Therefore, a question was asked to measure the effect of BIM application in this regard. As can be seen in Table 3, nearly 39% of the participants thought that BIM might increase the level of risk of legal disputes for projects. This was the most important finding that the use of BIM could even increase the risk level instead of reducing it. This may be attributed to poor implementation of BIM and problems regarding the unsuccessful utilization of BIM by several project stakeholders.

When the data in Table 3 is converted to weighted averages for each risk on a 5-point Likert scale to find the most significant risk factors that may be mitigated by BIM, the summary of findings is shown in Fig. 1. According to the survey results, almost all calculated averages are above 3, which supports that the use of BIM in construction projects is seen as useful in terms of reducing risk factors. According to Figure 1, BIM may be used to mitigate the risks of loss of information and revisions regarding the project. Moreover, BIM has a positive impact on reducing the risk of poor communication between parties and design errors rework. The use of BIM during the design phase and the reduction of design risks were supported in both this and the previous section of the survey. On the other hand, respondents stated that BIM generally does not affect the level of accidents and may even increase legal disputes between parties.

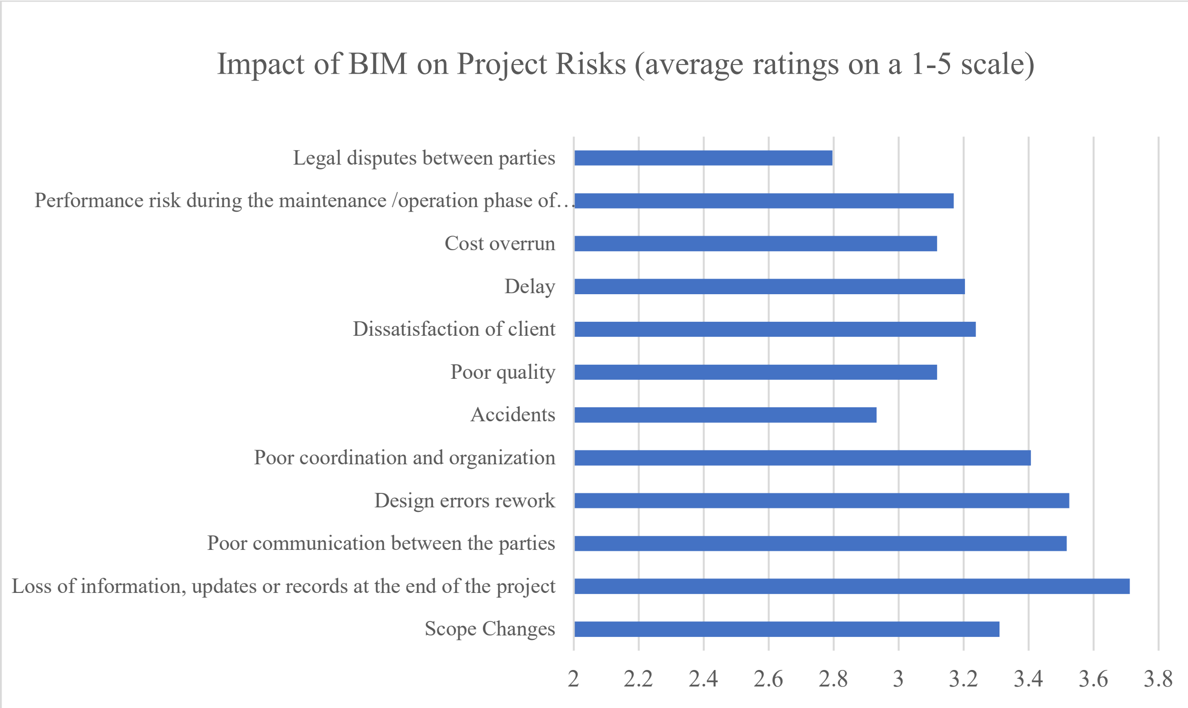

Figure 1: The average ratings for impact of BIM on reducing risks.

Discussion of Findings

The main aim of this research is to explore the main advantages/disadvantages of the utilization of BIM for project risk management as well as the impact of BIM utilization on several risk factors. The research findings show that BIM may contribute significant benefits to risk management throughout the life cycle of the project. Identification and mitigation of risks as early as possible, especially during design and planning phases, are among the most designated ideas of both for participants of the survey and the literature of the construction industry. Foreseeable risks can be managed, and mitigation of design errors can be fulfilled by the application of BIM. Similar to the findings of this research, a case study for steel-box arch bridges was conducted, and Liu et al. (2014) stated that BIM utilizes better conceptual design, the examination of design options, structural optimization and enables detailed modeling to avert risks at the preliminary and detailed design of the project. Besides, the clash detection procedure is useful for realizing the spatial conflicts for designed and existing objects. Our study shows that many participants believe that through the clash detection process that BIM offers, risks during construction and implementation can be decreased, which is in line with previous research findings. By the scanned-data of the facility, timely and informative assessments can be done before making decisions about the facility (Tang et al., 2011). Thus, such aspects of BIM significantly reduce risks of design error, rework, cost, and time overrun.

BIM is considered to be an effective application not only in identifying and mitigating risks but also in ensuring coordination and collaboration among project teams during the design phase. According to the findings of this study, many participants who have experience in the Turkish construction industry believe that BIM can facilitate the sharing of risk-related information between project participants; hence, it can increase awareness on risk sources for all parties. Also, by providing collaboration, BIM improves communication between stakeholders, thus decreases the risk of poor communication in projects. Research by Ho et al. (2013) also supported that, for more effective risk management, contributing and sharing the most up-to-date knowledge about the problems in the design phase is essential. Risk related knowledge and multi-disciplinary experience from previous projects contribute significantly to manage risks for future projects (Ho et al., 2013; Zou et al., 2015). A large database of risk information can be managed, communicated, and reused by applications of BIM. Thus, more effective and informative risk mitigation strategies can be developed.

Another important finding of the research is, BIM may be used in risk information visualization for different phases of the project. Most of the respondents find BIM useful for visualizing risks and thus helps risk assessment and mitigation during the project lifecycle. These results are also in line with the research conducted by Hartmann et al. (2012). According to this research, traditional risk communication methods such as risk inventories, Gantt charts, or written reports may be insufficient for visualizing risks and understanding the impacts of these risks in budget or schedule of the, especially complex projects. However, 4D models may contribute significantly to projects to understand how the model aligns with schedule and provide project managers to visualize risks in all stages of the project both in time and space. Hartmann et al. (2012) also indicated that viewpoints, text overlays, and risk specified objects are one of the visualization methods which ensure showing the potential risks in the project schedule in 4D models.

Quality management is another issue where the relationship between BIM and risk management is evaluated throughout this research and literature on construction management. As seen in the survey's findings, 75% of experienced participants in Turkey agree that quality management using BIM may reduce the risk of poor quality in a project. This finding also coincides with previous research of Cheng (2018), who indicated that BIM and BIM-related technologies are useful in order to record and examine construction defects for contractors.

As examined in the previous section, the utilization of BIM on safety management is a controversial issue among the respondents. Kiviniemi et al. (2011) stated that BIM technologies may improve occupational health by visualization of formworks that needs falling prevention, site safety communication, or automation in the safety analysis. On the other hand, our respondents did not reach a consensus about this issue. In fact, almost the majority of respondents indicated that BIM applications would not change the risk level of accidents in construction.

Conclusions

Designing and conducting a survey on BIM's contribution to risk management and its impact on the level of risks in projects, BIM's potential use for risk management has been explored in this study. From the research findings of the survey, it can be concluded that the most important aspects of BIM are the integration of multi-disciplinary knowledge and a shared environment that enables communication and collaboration for risk management. Consequently, the mitigation of risk of loss of information or updates, poor communication, and poor collaboration between the parties are aspects that are mostly highlighted in this research. On the other hand, safety planning, hence reducing the level of accidents and interoperability through IFC standards are the most conflicting issues regarding the utilization of BIM in risk management, where the respondents could not reach a consensus. Moreover, some of the respondents stated that legal risk may even arise when BIM is used in project management.

As a conclusion, the utilization of BIM, especially for risk mitigation and assessment during the project lifecycle, is seen as useful by those experts experienced in the Turkish construction industry. However, it has to be noted that findings reflect the Turkish construction industry and cannot be generalized. It is also possible that with a different population of experts, results could be different. Thus, this study should be seen as an exploratory study that provides some initial ideas about the utilization of BIM for risk management of construction projects, which may provide a background for further studies on using BIM in different contexts. It is expected that this research can provide a successful example for other exploratory studies on understanding BIM's role in project management and make a potential contribution to the literature of construction management. Similar surveys can be conducted in different countries, and results can be compared. As a potential research topic, the role of BIM for different risk management tasks (e.g., identification) at different project steps (e.g., design) and for different project delivery systems (e.g., design-build, PPP) can be investigated in detail, and its benefits can be demonstrated by real applications.

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Exploring the Adaptability of Daily Look-Ahead Meetings in the Construction Industry

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Abstract

Lean construction is a new approach, adapted from lean thinking, focuses an increase in productivity through control over the process to eliminate waste of project while maximizing the value offered by the project. The Last Planner System (LPS) is one of the production control and planning systems for project management in lean construction philosophy. It emphasizes reliable and optimized workflows by taking measures (Identification and resolving) for problems that may occur in advance collaboratively at the lowest level by breaking down tasks into more details, from the master schedule to the daily work plan. However, the application of daily look-ahead meetings is rather limited to both academically and practically in the construction industry. This paper aims to explore the efficacy of daily look-ahead meetings adaptation in the construction environment. Systematic literature review and expert interviews with senior and mid-level managers from the construction industry are carried out to evaluate the results of its implementation in construction projects. Although the literature perceives the positive impacts of daily look-ahead meetings on productivity and quality, practitioners emphasize the fundamental obstacles to adapt daily look-ahead meetings in practice. The paper concludes by revealing benefits and challenges and recommending several strategies to overcome the obstacles about productivity and quality in the construction industry.

Keywords: *daily look-ahead meeting, Last Planner System, lean construction.*

Introduction

Lean construction, adapted from lean thinking in the manufacturing industry, is a new form of production management to construction that primarily aims to improve performance reliability and productivity by minimizing waste such as material waste and schedule delay and maximizing value-adding activities such as customer satisfaction, safety hazard prevention in the construction life cycle (Howell, 1999). Different lean production control systems were introduced by researchers from academia and industry throughout the history of the construction industry. One of them was the Last Planner System of Production Control (LPS), designed by Ballard and Howell (2000). LPS aims several changes in a way that projects are planned and controlled. To achieve this goal, the functions of LPS creates more safely and faster delivery, productivity in the overall production process, predictable product development and workflow, reduction in cost, transparency and learning atmosphere in processes (Mossman, 2017). It is based on the principles of preparing all prerequisites for defined construction activity before assigning this activity to a workgroup. It means that reactive work planning executed at the lowest possible level in the hierarchy, the last planner (Ballard, 2000; Gao & Low, 2014;). According to LCI Last Planner System® Business Process Standard and Guidelines (2015), LPS is divided into eight key elements:

- Master scheduling (milestone planning): Team alignment with milestones, typically performed by the project managers.
- Phase planning (pull planning): Strategically planning segments of work, typically performed by foremen of that phase of work.
- Look-ahead planning (make work ready planning): Identify and removal of constraints to make ready the tasks that can be done, typically performed by foremen.
- Weekly work plan (production planning): Identify the tasks that will be done, control the flow and make sure assignments are ready by proactively, typically performed by foremen
- Daily huddles (production implementation): Identify the tasks that were being done, team check-ins, discussions based on the Weekly Work Plan.
- Percent plan complete (PPC): Number of completed assignments are divided by the total number of planned activities.
- Reasons for variance: Reasons for deviation from the planned schedule for that week and necessary actions to improve PPC for the next weekly work plan are identified.
- Team health, maturity, and effectiveness: The essence of collaboration, what really matters most?

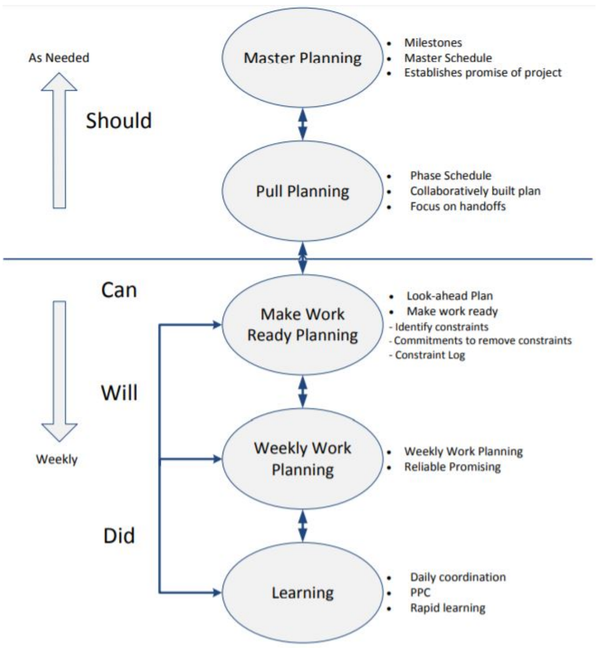

Figure 1: Planning stages /levels in the Last Planner System (LCI, 2015)

LPS focuses on the decentralized system (bottom-up way) that forces foreman or last planner to engage in the production and planning process more efficiently. This perception encourages to create a commitment to project and learning to trace the root causes of the reasons behind the problems. As teams are further involved in the process and took responsibility, better productivity and performance increase are obtained by decreasing uncertainty in the workflow (Gao & Low, 2014; Garza & Leong, 2000). The smallest initial action to implement LPS effectively is daily look-ahead meetings (Fig. 1). It helps to rapidly identify any deviation from the planned schedule and act quickly to correct the problem to achieve the desired performance

(Ferro & Gouveia, 2015). Although researchers from academia emphasize the positive effects of daily look-ahead meetings over productivity and performance reliability, there is still a dilemma about the adaptability of look-ahead meetings to the construction industry effectively. Therefore, this paper aims to evaluate the adaptability of look-ahead meetings in the construction context by reviewing the literature and interviewing with senior and mid-level managers from construction industry. Then, several strategies will be introduced to increase efficiency of daily look-ahead meetings in construction field.

Research Method

This research is divided into two phases. In the first phase, a literature review is carried out to reveal the challenges and the benefits of adaptation of daily look-ahead meetings into construction projects. In the second phase, expert interviews with senior and mid-level managers from the construction industry are conducted to evaluate the adaptability of daily look-ahead meetings in actual practices. The managers who participated in the survey have more than five years of experience in complex industrial construction projects as a planning and site operation executives. Finally, strategies are presented to alleviate the challenges and turn into these challenges to advantages for project performance. Challenges and corresponding advantages of daily look-ahead meetings are represented by arrow diagrams using defined strategies.

Phase I: Literature Review

Daily look-ahead planning is added LPS in the updated version of the Last Planner in 2003 by Ballard and Howell (Ballard & Howell, 2003). However, its application is rather limited in construction projects. In this part of the paper, a literature review of the implementation of the daily look-ahead meeting is evaluated in terms of the challenges and benefits in the construction industry. Although there are several pieces of research about the positive effect of the implementation of daily look-ahead meetings, a limited number of researchers have dwelled on the challenging aspects of the daily look-ahead meetings in construction. The benefits of daily look-ahead meetings are listed in Table 1.

Table1: Benefits of daily look-ahead meetings in the construction industry.

Number	Benefits	References
1	Creating a forum to develop a supportive atmosphere (As coordination and interaction increased, the opportunity to express thoughts and concerns relevant to the scope of work for that day and closer ties between participants) where the participants feel they are a part of a group.	Ghosh, 2014; Mastroianni & Abdelhamid, 2003
2	The transparent exchange of information helped them develop a common understanding of the overall project and identify, take action and solve problems in advance in a more structured way (such as safety hazards)	Ghosh, 2014; Mariz et al., 2019; Seed, 2015
3	Identify deviations daily in production or imminent hazards, enable to take immediate action to correct them thanks to being well informed of participants about the progress of the projects	Ghosh, 2014; Mariz et al., 2019; Mossman, 2017

4	Construction companies will take advantage of the learning of this project to expand this practice to other projects of the company.	Mariz et al., 2019
5	Increased interactions among the participants enable them to better understand the work assignments, increases their awareness about the project and their interrelatedness.	Ghosh, 2014; Mossman, 2017; Salem et al., 2005; Seed, 2015;
6	Identification of root causes of problems, minimizing the chances of unexpected events leading to problems by finding alternate solutions to reduce the problems, and focusing on successes and areas for improvement.	Gao & Low, 2014; Ghosh, 2014; Mastroianni & Abdelhamid, 2003;
7	Increased project team commitment that makes identifying and solving problems easily and take action.	Mariz et al., 2019; Seed, 2015

Apart from the benefits of daily look-ahead meetings in construction that are mentioned above, there is a little emphasis on the challenges of adaptation of daily look-ahead meetings in literature. Gao and Low (2014) states that team member that is involved in the construction process feel the Pressure due to tight schedule and client desires. It is mentioned that team members maintain "being busy enough" perception, and they do not have available time for daily look-ahead meetings for each day. Another perception is that team members consider daily look-ahead meetings as a waste of time. This perception results in a negative attitude towards the meetings and loses focus in the meetings (Stray et al., 2013). In another study, Salem et al. (2005) carry out a survey about daily look-ahead meetings. In this survey, results show that although two-way communication is the key to the daily look-ahead meeting process to encourage the involvement of each member in the project, most of the members are unwilling to give feedback and questioning any issue. Then, traditional one-way communication dominated the meetings. Additionally, the effectiveness of meetings decreases day by day as the project progresses and new team members involved in the project. The main reason is that new team members who join the Jobsite receive little information about lean construction.

Phase II: Interview with Experts

For the second phase of the study, an interview is arranged with senior and mid-level managers who have more than five years of experiences in complex industrial construction projects as a planning and site operation executives from the construction industry are carried out to evaluate the adaptability of daily look-ahead meetings in construction projects. Open-ended questions are designed and asked the managers. The questionnaire continues if the given answer is "yes" to question, "Have you ever participated in a project that daily look-ahead meetings are conducted?" Then, "What are the contribution of daily look-ahead meeting in overall project performance?", "What are the challenging issues while conducting daily look-ahead meetings?" "Can daily look-ahead meetings be implemented and maintained effectively in construction projects?" questions are asked to interviewees, respectively.

Interviewee A has more than 10-year experience in complex industrial projects as a planning and cost control engineer in different countries. Interviewee A stated that: "Throughout each project cycle, it was revealed that project performance is directly related to controlling and managing every single component in the project process, so daily look-ahead meetings give a chance to identify of root causes of problems, minimizing the chances of unexpected events leading to problems. Then, finding solutions to reduce the problems and focusing on improvement can be carried out at that moment without effecting successor events. However, as the project progresses and deadlines approaches, daily look-ahead meetings deviate from the main purpose, two-way communication, and lesson sharing-learning atmosphere are ignored. It transforms itself into formal one-way communication. Unless a perception is created among all participants about daily look-ahead meetings' positive effects on project performance, the performance can reach up to a certain point. If current dynamics of construction projects are considered, adapting daily look-ahead meetings looks almost unfeasible in terms of its efficacy".

Interviewee B has 8-year experience in complex industrial projects as a planning engineer in different countries. Although interviewee A believes that: "when daily look-ahead meetings are implemented effectively, they improve project members' devotion to the project and the company because they feel like their opinions are important, and they play an important part in the success of the project. Furthermore, daily look-ahead meetings are helpful to increase coordination between different disciplines", concludes that: "it is hard to implement daily look-ahead meetings in construction projects effectively. Daily look-ahead meetings last too long, and their contents deviate from major subjects that should be criticized for minor and non-critical subjects. A very high number of man-hours are spent in these meetings in order to discuss issues which can be solved by other methods, including mobile phones or e-mails. Also, most of the participants are not willing to attend the meeting due to their daily workload. In addition to that, construction projects are mostly long in duration, and project plans are created and updated weekly due to that it is more effective to hold weekly meetings rather than daily meetings".

Interviewee C who has 5-year experience in complex pipeline projects as a site executive stated that: "there are several benefits of implementing daily look-ahead meetings including the commitment to project goals, supportive work environment between participants, minimizing the chances of unexpected events leading to problems, etc., but there is no consolidated culture or atmosphere to maintain daily look-ahead meetings effectively yet. The main reason behind is that pressure of client and tight schedule does not allow daily look-ahead meetings. Moreover, foremen do not seem ready to engage in the planning process, as they are not yet comfortable with taking on responsibilities rather than taking orders. Being responsible for the tasks listed in daily look-ahead meetings, including failure, prevents them from taking the initiative in terms of planning".

Findings

Through literature review and interviews with experts from different backgrounds are carried out to investigate the benefits and challenges of daily look-ahead meetings and evaluate the adaptability of daily look-ahead meetings in practice. Both parties believe further positive effects of it on project performance, but there is no certain and effective application of it in practice. Furthermore, practitioners believe that it is hard to implement daily look-ahead meetings into each project process when current construction dynamics are considered, so strategies & techniques are provided to turn challenges into benefits for construction projects (Table 2). Strategies & techniques are based on analyses of interview notes, personal experiences, and literature review.

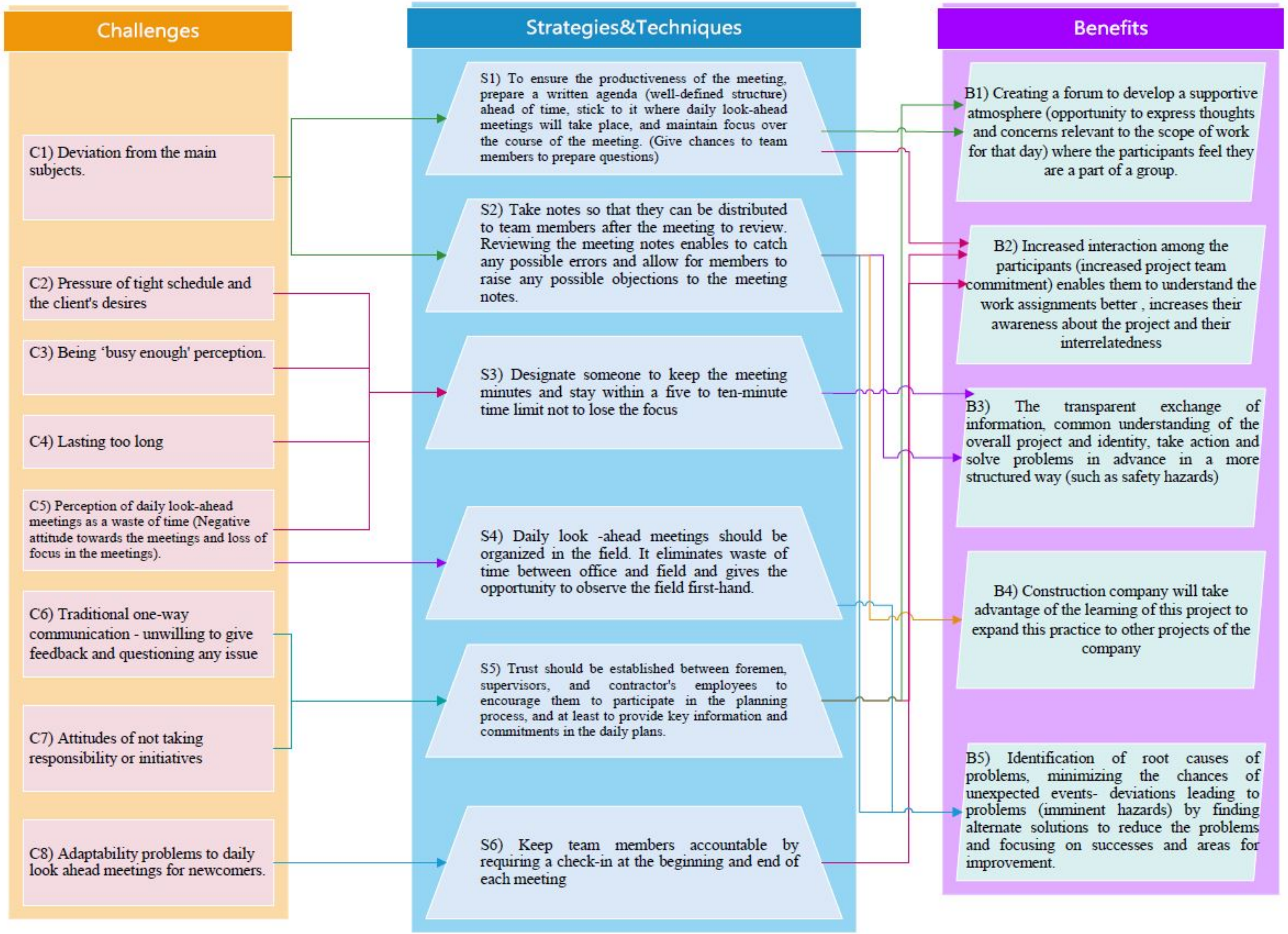

Figure 2: Challenges, strategies & techniques, benefits flow chart.

Conclusion

The Last Planner System is known as the functions of more safely and faster delivery, productivity in the overall production process, predictable product development and workflow, reduction in cost, transparency and learning atmosphere in processes, and LPS system is based on reactive work planning executed at the lowest possible level in the hierarchy, from master plan to daily look-ahead meetings. However, there is little evidence on the implementation of daily look-ahead meetings in construction projects in an effective way. In this study, the benefits and challenges of daily look-ahead meetings that are mentioned in the literature review are identified. Although the results of the literature review indicate that there are several benefits of daily look-ahead meetings compared to challenges aspects of it, execution of daily look-ahead meetings in practice is so limited. Managers who have been participated in interview believe that it is hard to implement it in an effective way unless the perception is changed toward planning in construction projects. Nevertheless, when the further advantages of daily look-ahead meetings on the productivity of projects are understood later, the challenges of implementation of it are not impossible to cope with these. Subsequently, suggestions and techniques to challenges are presented to improve the efficacy of daily look-ahead meetings.

This study also encountered a limitation. There were a limited number of experts participated in the study as there are not too many projects that execute daily look-ahead meetings, along with the Last Planner System, in the construction industry. If more participants are involved in research, reliability, and richness would be improved. In the long term, we expect a greater number of participants to disseminate their findings and comments on our findings.

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Ethical Behavior in the Construction Industry

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Abstract

This paper investigates the status and practices of ethical behaviour in the South African construction industry. Using a self-administered questionnaire,135 contractors and consultants in the construction industry in the KwaZulu-Natal province of South-Africa were conveniently sampled in relation to their perception and experience of unethical practices and behaviour. The most common unethical activities experienced by construction professionals were sexual harassment, favouritism, discrimination, fraud, corruption, fraud, bribery, and extortion. Findings from this study provides valuable insights to construction stakeholders on ethical issues confronting the South African construction industry.

Keywords: *Construction Industry; Corruption; Ethics; Ethical Decision Making; South Africa.*

Introduction

Ethical practices have been shown to have significant benefits such as promotion of economic efficiency and includes avoiding favouritism and nepotism, avoiding monopiles, avoiding fraud, bribery, and unfair conduct, honouring contracts, and providing accurate information (Bowen et al., 2007; Tanner et al., 2010). Ethical behaviour improves job performance and reduces employee absenteeism (Mayer et al., 2010; Piccolo et al., 2010). It is therefore an important pillar to efficient organisational operations, especially in countries where relatively higher cases of corruption are recorded (Conrad, 2013). Studies on ethical behaviour in the public sector such as the construction industry in South Africa have been neglected, as the majority of the studies on ethics have on the business environment and the private sector (Sinha et al., 2007). According to Conrad (2013) issues concerning the public sector directly affect the citizens.

The level of corruption is greater in the construction industry than in any other sector of the economy (Sinha et al., 2007). The issue of ethics has become a burning public issue because of reported cases of corruption and exercise of patronage to secure contracts and deviate from legal rules (Bowen et al., 2007). Corruption presents one of the greatest threats to sustainable development and pervades all sectors of social, civil, and political society (Bowen et al., 2007; Moodley et al., 2008). The ramifications of corrupt behaviour and its persistence in the construction industry, reach far into all levels of governance, and warrants deeper investigation into how widespread it is (Dala & Haupt, 2019). Corruption may lead to cost over-runs of public contracting, waste of public resources and an unstable business environment (Moodley et al., 2008)

The complex nature of the construction industry resulting from numerous levels of bureaucracy, opportunities for project delays , cost overruns and high competition for contracts make the sector susceptible to unethical behaviour (Moodley et al., 2008).Within the various areas of the construction industry, best practice guidelines are often given to professionals and service providers using the premise that these guidelines constitute business ethics (London & Everingham, 2006). However, ethics extends further than static business practice guidelines and veers into issues of morality and personal consciousness of what is right and what is wrong (Robinson et al., 2007). Although, this presents a vague and grey area, most especially in a profession that values discrete documentation, the construction industry provides a rich avenue to explore the deeper aspects of ethics in business (Dala & Haupt, 2019).

This paper aims to investigate the status and practices of ethical behaviour in the South African construction industry, commencing with a background of ethics and the construction industry. The knowledge gap indicates the lack of evidence regarding significant statistical differences between demographic groups on the experience of unethical behaviour. The scope of the study is limited to the construction industry in the KwaZulu-Natal province of South Africa. A quantitative descriptive survey design was adopted, followed by the analysis and interpretation of data from the survey. Based on the findings from this current study, issues of unethical practices in the construction industry were identified and probable interventions were suggested to address the unethical activities.

Ethics and the Construction Industry

Ethics and ethical behaviour are defined by the determinants which refers to judgements, standards, and rules of conducts as a set of moral principles and values that guide behaviour (Trevino & Nelson, 2011). Ethics are moral values of human conduct and of the rules and principles that ought to govern the social, religious, or civil code of behaviour of a group, profession or individual (Tagoe, 2006). Morals deal with either ‘good or bad human character’ or ‘with the distinction between right and wrong’ (Allen, 1990, p. 769). Ethics is a study of language, thought, judgement and reasoning which guides the choices and daily lives of people (Sebola, 2014). It is recognized that the concept of ethics is applicable in business because business exists not only for certain individuals but for the benefit of the general society as well (Vee and Skitmore, 2003). The decision to act ethically lingers on a combination of ethical frameworks, ethical leadership modelling by supervisors and personal ethical decision making (Samat et al., 2016).

Ethical decision making is a fundamental process in the management of any organisation (Fewings, 2009). It is a personal locus of control, where judgement and ethical action are individualised characteristics (Samat et al., 2016). Sebola (2014) suggests a strong cognitive component to ethical decision making, where the response from a person to an ethical dilemma presents as firstly deciding which course of action to take. This process weighs up the different ethical issues that we may have to confront in determining the decisions that are taken (Bowen et al., 2007). These decisions often have long-term effects and affect individual employees, professional consultants, or the reputation of companies their customers and stakeholders (Samat et al., 2016). Ethical decisions are made based on modelling of peers and superiors (Tagoe, 2006). While construction professionals look to model frameworks elucidated by professional boards, many ethical decisions turn out to have ethical implications and consequences (Bowen et al., 2007).

Globally, the construction industry has been previously regarded for being full of good, honest, and hardworking people, (Schwartz, 2013). Unfortunately, today people find the construction industry associated more frequently with negative perceptions (Moodley et al., 2008; Samat et al., 2016). With the advent of globalisation and industrialisation the current perception of the construction industry has become more complex in nature (Moodley et al., 2008). What was previously construed as relational dynamics and shared business relationships as best practice, currently has evolved into conflict situations (Adjei, 2015). This has given the impression of a problematic industry that sacrifices ethics and morality in lieu of profits and losses (Sebola, 2014). Construction projects include the efforts of many stake holders as human capital, as well as big monetary investments (Shakantu, 2006; Sinha et al., 2007). While it is inevitable that a construction project should maximise profitability, it should not be at the expense of ethics (Fewings, 2009).
1
In construction, a major ethical dilemma is associated with corrupt activities. It is argued that no other threat supersedes the danger of corruption in a society (Samat et al., 2016). It threatens democracy, economy, and the politics of a nation. (Sebola, 2014). Corruption is a major contributor to unethical behaviour which is not only unique to undeveloped countries but is evident throughout the globe (Sebola, 2014). Although almost all professions are governed by a code of conduct related to their respective disciplines, unethical practices continue to exist irrespective of the existence of a professional code of ethics in the construction environment (Adjei, 2015).

Attributes of Unethical Behaviour

Studies have shown that unethical behaviour in the construction industry usually takes the form of money laundering, extortion, bribery, cronyism, nepotism, and favouritism (Vee & Skitmore, 2003). The construction environment is particularly susceptible to cowboy practices (Fewings, 2009). Corruption is likely to appear commonly on a list that threaten and obstruct business practise and is identified as one of the main impediments to sustainable development in the construction industry (Moodley et al., 2008).

Favouritism

Favouritism deals with favouring someone over others who are more efficient because of personal involvement (Ozler & Buyukarslan, 2011; Nadeem et al., 2015). Favours can be tenders or contracts that are not awarded by merit alone (Bowen et al., 2007). The favoured may include family members, friends, prior business associates and those that may offer gifts such as money, objects, travel, or entertainment (Khatri & Tsang, 2003). One of the many attributes of corruption is favouritism and is pervasive world-wide (Trevino & Nelson, 2011). While many business environments allow employees to receive gifts, what sets this apart and becomes favouritism is the value of this gifts. These gifts should be nominal and should be accepted and declared on behalf of the organisation (Arasli & Tumer, 2008).

Family and friend relationships are social constructs that are mutable and the dynamics can change, an example being if one spouse acts upon favouritism and awards a contract to the other spouse, enmity or divorce might result in negative impacts on the contracts.

Nepotism

Nadeem et al. (2015) described nepotism as when relatives are preferred over other candidates who may be from the same blood relation. When a relation is given more emphases as opposed to competency, knowledge, and talent, there will always be some negative effect on the performance of other employees and the organisation (Arasli & Turner, 2008). Employees of organisations where nepotism is a high tend to underperform which makes the organisation less productive (Ozler & Buyukarslan, 2011). Employees do not have the incentive to work to their full potential with the knowledge that they do not belong in the inner circle and will in all intent and purposes be ignored when opportunities for promotion do become available (Fewings, 2009; Trevino & Nelson, 2011). Employee selection and promotion should be based on merit, knowledge, talent, abilities and efficiency for the development, prosperity, and success of the organisation.

Money Laundering

Money laundering and non-disclosure of funds are unethical activities that plagues the construction-built environment (Fewings, 2009). This involves hiding funds that have been illegally obtained usually in the form of cash or moving the monies into offshore accounts or hidden destinations (Trevino & Nelson, 2011). International laws govern the moving of monies in agreements with the United Nations, which run an anti-money laundering unit, but tracking of cash is often very difficult and time consuming, resulting in this corrupt attribute being pervasive worldwide.

Extortion

Extortion is referred to as blackmail, where payment is demanded, and the payee has no option but to comply (Shakantu, 2006; Dala & Haupt, 2019). An example is the demand of payment to site officials or local people living in the area to be silent about an environmental hazard that a construction project may exacerbate (Fewings, 2009; Trevino & Nelson, 2011).

This type of mafia or gang-controlled activity use peer pressure and bullying tactics to coerce others into doing something they might not necessarily do (Fewings, 2009). Within the scope of using monetary means to expedite matters, extortion also can be construed as a corrupt activity in business.

Bribery

Pay-offs and bribes contribute towards the most frequent source of anxiety to business owners (Trevino & Nelson, 2011). Bribery is offering an undue award or demanding a reward to get business favours (Fewings, 2009). These favours can be kickbacks, tenders, or contracts that are not awarded by merit alone. This also refers to the bribing of officials in governmental institutions to pass documents and plans or expedite the passing of such documents (Shakantu, 2006).

Research Methods

The survey explored the opinions of 135 conveniently sampled South African construction professionals in relation to their experience of unethical practices and activities. Self-administered questionnaires were distributed to potential participants were drawn from the available listings of professional contractors and consultants in the KwaZulu-Natal province of South Africa. The professions represented included architects, structural engineers, and quantity surveyors. Responses totalled 96 (71% response rate), comprising 63 contractors (65.6% response), 33 consultants (34.4% response). Table 1 presents a profile of the respondents that participated in the study.

A five-point Likert scale was used to rank the perception of respondents on their experiences of unethical behaviour and factors that influence ethical behaviour in the construction industry. To ensure the reliability of this study, the Cronbach's coefficient alpha was used to test the consistency of the obtained. The Cronbach's coefficient was 0.97, which satisfies the reliability test requirements. Descriptive and inferential statistics were used to analyse the data obtained. The technique adopted for inferential statistics in this study was the Mann-Whitney U test.

Results and Discussion

Experience of Unethical Behaviour and Activities

The study sought to investigate respondents' experience of unethical behaviour and activities in the construction industry. A 5-point Likert scale was used for this purpose where 1= Never and 5= Always.

Several forms of unethical activities exist. Engaging in unethical behaviour could result in the acceptance of favours or benefits. These benefits can be in the form of gifts, money while others could be in the form of nepotism, favouritism, money laundering, conflict of interest and so on.

The findings show that respondents in the sample reported high means in their experience of unethical activities in the construction industry. A mean range of 3.95 to 3.11 shows that respondents agreed with the list of unethical activities presented. Table 2 shows that the following unethical activities were ranked highest; sexual harassment (mean score=3.95), favouritism (mean score=3.93) and discrimination (mean score =3.88) were the activities that respondents regarded as the most practiced unethical activities. Other activities that were considered unethical as revealed in literature were corruption (mean score=3.86), fraud (mean score= 3.86), bribery (mean score=3.82) and extortion (mean=3.81).

Table 1. Profile of respondents.

Respondents	**No**	**%**
Contractor	63	65.6
Consultants	33	34.4
Total	96	100

Most of the respondents had experienced or witnessed sexual harassment, favouritism, discrimination, fraud, corruption, fraud, bribery, and extortion. Evidence from the survey suggested that unethical behaviour is pervasive and is an accepted practise within the construction workforce. To identify which group of construction professional experienced these unethical activities the most, a non-parametric Man-Whitney U test was conducted.

Table 2. Experience of unethical activities.

Unethical Activities	**Mean**	**Std. Dev.**	**Rank**
Sexual Harassment	3.95	1.65	1
Favouritism	3.93	1.53	2
Discrimination	3.88	1.69	3
Fraud	3.86	1.68	4
Corruption	3.86	1.69	5
Improper use of information	3.83	1.62	6
Bribery	3.82	1.64	7
Extortion	3.81	1.68	8
Money Laundering	3.80	1.67	9
Nepotism	3.77	1.68	10
Aggressive Accounting	3.69	1.58	11
Conflicts of interest	3.69	1.66	12
Use of intermediaries	3.68	1.52	13
Kickbacks	3.62	1.62	14
Receiving and gifts	3.20	1.57	15
Receiving and giving entertainment	3.12	1.54	16

Contractors and Consultants Experience of Unethical Activities Subjected to the Mann-Whitney U test

Table 3 shows the test of statistics in contractor and consultant’s experience of unethical activities. The test revealed no significant difference between the groups (p=0.29), indicating that there was no variance in the responses of contractors and consultants.

Table 3. Mann-Whitney U: Knowledge of unethical activities

Unethical Activities		**Mean Rank**	**Mann-Whitney U**	**Z-Score**	**Exact Sig. (2 sided test)**
	Consultants	52.68	1177.50	1.066	.29
	Contractors	46.31			

Ranking of Ethical Behaviour and Influences

Respondents were required to rank how important they regarded 20 factors on influences on ethical behaviour in the construction industry. Table 4 shows that respondents place most importance on their own contribution to group behaviour and norms when those in management and supervisory positions conducted themselves ethically (mean score=4.34) ; their dealings with others when those in management and supervisory positions conducted themselves ethically (mean score=4.32); the willingness of managers and supervisors to learn from their experiences (mean score=4.17) and good examples set by managers and supervisors (mean score=4.13). Furthermore, it was revealed that the ethical dynamics of supervisory and managerial influence is much stronger than that of inner personal values, attitudes, or most especially direct line peers. Findings also show that the role of managers and supervisors cannot be ignored as it is evident that the leaders are seen as role models and their behaviours serve as a benchmark for what is acceptable and what is unacceptable. There is a lack of two-way communication and top leadership do not engage often with their subordinates on several issues, for example, issues concerning business ethics and values as well as encouraging the workers to voice their concerns. Interestingly responses showed that employees tend not to emulate the behaviours and attitudes of unethical managers and supervisors.

Table 4. Ethical behaviours and influences.

Ethical Behaviour and Influences	**Mean**	**Std. Dev.**	**Rank**
I contribute to group or organizational performance when those in authority or supervisory positions are ethical and fair in their dealings with me	4.34	0.83	1
Because my manager and supervisors are ethical and fair I reciprocate with others I interact with in the same way	4.32	0.92	2
Managers and supervisors set and communicate high performance expectations	4.20	1.04	3
Managers and supervisors are willing to learn from their experiences	4.17	1.09	4
Good examples are set by managers and supervisors	4.13	1.23	5
Managers and supervisors emphasize a strong sense of purpose	4.09	1.18	6
My managers and supervisors set an example on how to do things the right way in terms of ethics	4.08	1.15	7
They speak up about issues of concern	4.06	1.17	8
My managers and supervisors are good for the collective	4.04	1.18	9
Managers and supervisors emphasize a collective sense of mission	4.03	1.18	10

They treat people with respect	3.97	1.31	11
Business ethics or values are discussed with employees by managers and supervisors	3.96	1.34	12
My managers and supervisors treat people fairly	3.90	1.34	13
Everyone at work performs tasks that are expected of them	3.90	1.17	14
They demonstrate appropriate role-modelling behaviours	3.90	1.28	15
Everyone at work adequately completes assigned duties	3.82	1.21	16
Employees speak up and encourage others to get involved in issues that affect us at work	3.75	1.30	17
Employees communicate their opinions about work issues to others even if their opinions are different and others at work disagree with them	3.68	1.26	18
They use rewards to hold people responsible for appropriate conduct	3.57	1.43	19
I emulate the behaviour and attitudes of managers and supervisors who are not ethical and fair in their dealings with me	2.98	1.64	20

Contractors and Consultants' Ranking of Subjected to the Mann-Whitney U test

The results in Table 5 show that no statistically significant difference exists between contractors and consultants on their perception of the importance of ethical behaviour and influences in the construction industry (p=0.59), indicating no variance in the responses between the groups. The asymp. Sig (p-value) was greater than 0.05.

Table 5. Mann-Whitney U: Knowledge of the importance of ethical behaviour and influences

Unethical Activities		Mean Rank	Mann-Whitney U	Z-Score	Exact Sig. (2 sided test)
	Consultants	52.68	954.0	-.540	.59
	Contractors	46.31			

Conclusion and Recommendation

To obtain maximum benefits in terms of economic contribution of the construction industry, for the development of the country, it is crucial to ensure that ethical behaviour is practiced. The construction industry in South Africa run this gauntlet of media attention of state capture, corruption and generally a whole list of unethical activities and practises. The relentless revelations of information relating to unethical practices runs the risk of the society accepting unethical behaviour as a norm. So far, the study shows that there are significant loopholes regarding ethical behaviour, indicating that limited interventions have been put in place to address unethical behaviour and practises in the construction industry. Current structures targeted to combat unethical behaviour which leads to corruption are found to be unsustainable and riddled with lack of accountability for the culprits.

A quantitative analysis may be sufficient for the purposes of initiating understanding and awareness in this study, but deeper examination in terms of in-depth qualitative research will further enhance and add substance to this relevant and important issue of ethics in the construction industry.

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An Example of Performance Management and Earned Value Analysis in Construction Projects

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Abstract

The construction industry has started to pay more attention to the concepts of performance measurement and performance management in order to meet the increasing competition, customer satisfaction and quality requirements similar to all other sectors. Compared to other industries, the construction industry is not a pioneer in performance management, on contrary it appears to be performing poorly. Due to the increasing technology of the projects carried out by the construction industry day by day and the intensive manpower, effective performance management necessity arises. Monitoring, evaluating and measuring the performances of the construction projects is very important for the completion of that project within the desired success criteria. In this study, firstly, a literature study will be conducted on performance management and information will be given on the subject. As an application proposal for performance management of construction projects, the project performance management process of the web-based software named "Joint Project Management Portal", which is also an academic study subject, will be shown in the context of the method of earned value analysis.

Keywords: *earned value analysis, key performance indicators, performance evaulation, performance management, performance measurement.*

Introduction

In Turkey, the construction sector plays a vital role for the country both in economic growth and with the employment it provides. Today, developments and innovations in technology and management necessitate construction companies to manage their business processes much better. In order to evaluate these processes, companies should be able to see their own good and shortcomings.

Therefore, one of the important conditions of competitiveness is to control the performance of the process, to monitor and measure the progress. Conceptual measurement frameworks and models have been produced by many industries to measure, determine and manage their performance. Increasing competition in the business world has forced the construction industry to measure its performance with approaches beyond financial quantitative performance indicators (Tekçe, 2010).

With the establishment of performance management systems, these processes can be managed more effectively. Leading companies know that the difference between success and failure is a powerful performance management system. Because, thanks to the performance management system, businesses can monitor how much they have achieved their goals and targets, create a quantitative decision-making environment, evaluate their employees more objectively, establish effective motivation systems and increase customer satisfaction and quality and efficiency. Establishment and implementation of effective performance evaluation systems depend primarily on managers, human resources departments and those who are assessed to fulfill their responsibilities (Uyargil, 2013).

Tekçe (2010), in her study, she stated that the organizational performance measurement systems and models included in the literature in general were created for the manufacturing industry and stated that these performance measurement systems and models were later adapted by the construction industry. The models developed are based on a review of production organizations in developed countries, except for a few. What is the performance in different conditions is also an issue that needs to be evaluated. As well as the performance targets change from company to company, from project to project, the importance weights of the dimensions that make up the performance within the firm's holistic performance can change for the reasons explained above (Tekçe, 2010).

In this study, firstly, a literature study will be conducted on performance management, and information will be given on topics such as concept, history and measurement methods of performance. The performance management situation in the construction sector will be revealed and the project performance management process of the web-based software named "Joint Project Management Portal", which is also an academic study subject, will be shown in the context of the method of earned value analysis, as an application proposal for performance management of construction projects.

Performance Concept

Performance Definition

Performance, in general terms, doing business is expressed as successful implementation. It is stated that performance, which is the main criterion for measuring success, is a broad concept that enables an organization to measure its success in achieving its goals (Sevimler, 2010). In an individual sense, Schuler (1995) has defined performance as how well the employee strives for his job.

According to the generally accepted definition, performance is "a quantitative and qualitative explanation of where an individual doing a job, a group or an undertaking can achieve, in other words, what it can achieve for the intended purpose" (Baş & Artar, 1991). Performance is the quantitative or qualitative consequences of the action and effort of the individual or group in doing a job within a certain period of time. When we look at the definitions, we see that there is an individual or group within the concept of performance, a certain amount of work is expected from them within a certain time period and the results are compared with the expectation. As a result of this comparison, the performance of the individual or group is obtained (Uysal, 2015).

The performance of any job refers to the result from that job or that job over a period of time. This result is expressed as the proper implementation of the objectives of the institution. Therefore, the performance of a business can be defined as all efforts to achieve the business's goals (Bolat, 2000).

Performance Measurement

Performance measurement is a method of measuring how tasks are performed objectively in the performance of products, services or processes (Yüreğir & Nakıboğlu, 2007). Neely et al. (1995) defined performance measurement as the process of determining the amount of activity and effectiveness of an activity.

Performance needs to be measured and evaluated systematically. To do this, first of all, the objectives and optimum performance indicators and standards should be determined in a way that enables an objective evaluation based on comparison, data related to these should be collected and measurements should be made with this data. Performance measurements are the methods used to measure the results / outputs performed by the institution in accordance with the performance indicators determined beforehand in order to reach the goals for improving the performance (Akçakaya, 2012).

Aktan (1997) defined seven criteria to be used in performance measurement as follows.

- Quality: The following dimensions can be mentioned in the measurement of quality; quality of people, quality of management, quality of products and services. These specified quality dimensions can be further analyzed more specifically. For example, incorrect product rate, machine failure, returned product rate, delays in the delivery time of the product to the customer, service related complaints and so on can be taken into consideration in measuring the quality of the product.
- Efficiency: In general, productivity refers to the relationship between production outcome (output) and production factors (input). When efficiency is mentioned; labor productivity, capital efficiency, total factor productivity, and so on efficiency dimensions need to be dealt with individually.
- Profitability: In the simplest terms, profitability is the ratio of earnings to the capital used to achieve this gain. The concept of profitability can also be divided into some sub-groups in technical terms. For example, sales profitability, equity, gross sales, net profit for the period, operating profit/loss, pre-tax/post-tax profit, and etc. profitability dimensions can be considered and measured.
- Cost: Organizational performance can be measured by looking at some basic cost indicators in the organization. Labor cost, capital cost, production cost, financing cost, material cost, etc. can be shown as an example in this regard.
- Innovation: One of the criteria that can be used to measure organizational performance is innovation. New discoveries in the organization, new products, life cycle of products etc. On the basis of criteria, it can be determined to what extent innovation and creativity exist in the organization.

- Customer Satisfaction: In order to measure customer satisfaction, some criteria such as customer complaints, number of new customers, delivery time of orders, and delivery of faulty goods can be taken as basis.
- Employee Satisfaction: In terms of employee satisfaction, performance indicators such as absenteeism, labor turnover rate can be looked at.

These performance criteria or performance indicators can also be sub-divided within themselves (Fig. 1).

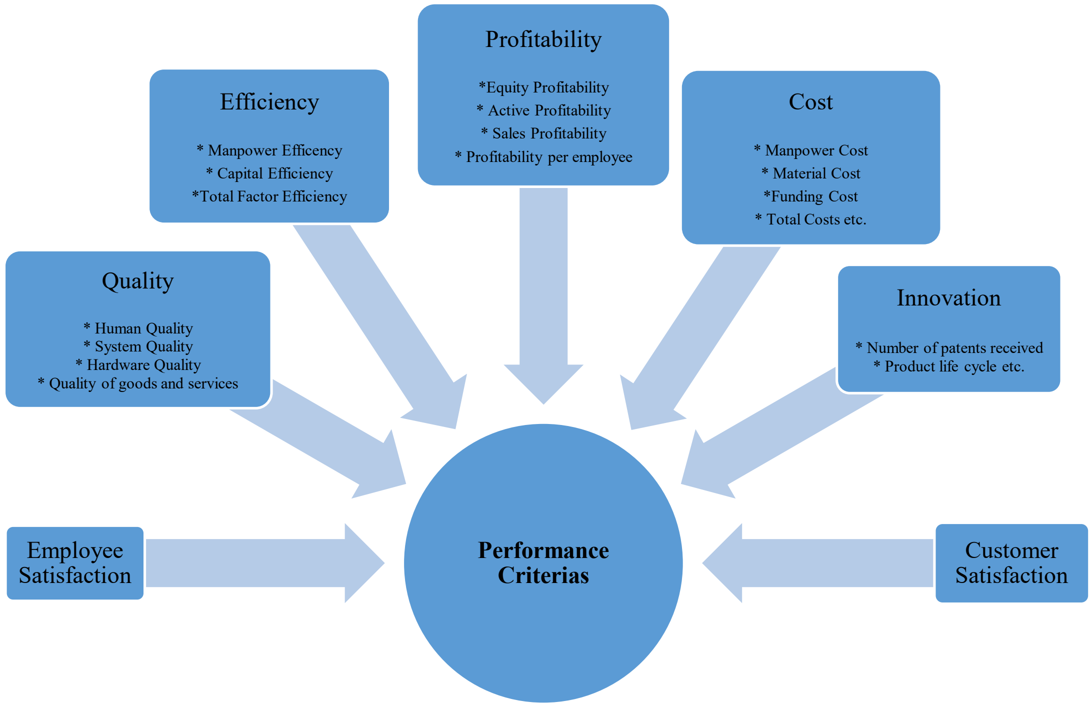

Figure 1: Main indicators for evaluating and measuring the performance of organizations.

Performance Concept and Measurement in the Construction Sector

For competitiveness, construction firms need to add value to activities, increase operational efficiency, reduce inefficiency, improve process efficiency, increase the level of satisfaction of all project stakeholders and improve the performance of the business (Nicoletti & Scarpetta, 2003). Competition and its performance are the two most researched concepts in the construction industry, as in many industries (Tekçe, 2010).

Project Performance

Performance measurement in projects reveals how successful the project is in line with its objectives. In terms of traditional project management, success is achieved when project performance indicators are realized at optimal value in the execution of a project. In this context, in order for the projects to be successful, the project must be completed in the desired quality, at the lowest possible cost and in the shortest possible time. Therefore, the first condition for a project to be successful is that the management plans the project in line with realistic goals (Navon & Sacks, 2007).

In project performance measurement, the real success of the project can never be determined. However, it is possible to obtain the most realistic results with good measurements. In addition, measuring the performance of a project generally increases the performance of that project (Kerzner, 2013).

Earned Value Analysis

Earned Value Analysis is a three-dimensional approach and is based on the following data sources (Son, 2015):

- *Planned Value (PV)* is the total budget of all planned jobs until any date of the project calendar. Also known as the Budgeted Cost of the Planned Job. The performance of the project is measured over PV. It is generally shown with an S-shaped curve graph that shows the budget against time.
- *Actual Value (AC)* is the sum of resources spent for all work completed at any time of the project. It is also known as the Actual Cost of the Work.
- *Earned Value (EV)* is the total value of work completed at any point in the Project. It is also known as the budgeted cost of the work done. This value is measured in PV.

$$EV= \sum_{beginning}^{present\ time} PV\ (completed) \quad (1)$$

EVA takes these three data sources and can compare the budgeted value (PV) of the planned job to the Earned Value (EV) of the completed physical job and the Actual Value (AV) of the job. Therefore, the performance data obtained using EVA is an objective measure of the real work performed.

Deviations and Performance in Earned Value Analysis

In order to evaluate the current situation in the projects, deviations should be measured, reported and corrected through corrective actions. The completion date of the project and how much budget it will be completed are estimated using the indices (Son, 2015).

Work Program Deviation (SV)

It corresponds to the difference between the value of the jobs planned for a certain period of time and the value of the completed jobs, and shows how far ahead or behind the project's work schedule. The minus value of the calendar deviation only shows that the project is behind the planned calendar, it does not give information about how late it is (Son, 2015).
SV = EV – PV

Cost Deviation (CV)

It is the difference between the value of the works completed for a certain time and the actual cost. The Deviation of Cost indicates that the project cost is below or above the planned budget. The fact that the cost deviation is minus indicates that the project costs exceed the planned budget by the amount of deviation (Son, 2015).

CV = EV – AC

Planning Performance Index (SPI)

It shows how effectively the time and calendar in the project are used. Planning performance index is calculated by dividing the value of the completed works by the planned value.

SPI = EV / PV

If: SPI = 1 Schedule of work performed is the same as planned
SPI> 1 Progress made faster than planned
SPI <1 Progress made is slower than planned

Cost Performance Index (CPI)

It shows how effectively the financial resources are used and is obtained by dividing the value of the completed works by the real cost.

CPI = EV / AC

If: CPI = 1 Cost performance is complete, the cost of the work performed is equal to the budgeted cost
CPI < 1 Cost of work performed above planned budget
CPI > 1 Cost of work performed below planned budget

Joint Project Management Portal as Example of Project Performance Management Application

Various performance measurement systems such as return on investment, customer value analysis, and performance pyramid are used to measure the success of the activities carried out within the framework of general management. It is possible to measure the performance of projects with these systems. However, projects are very different from ordinary organizations by nature. For this reason, measuring the performance of the project as an ordinary activity will not provide the correct data to the managers.

The performance of the projects should be measured in line with the specific goals and objectives of the projects. Therefore, it is necessary to measure the performance of projects involving activities in order to achieve a specific goal within a predetermined time, budget and quality constraint, taking into account the effective use of these constraints (Duran, 2016).

Naturally, the performance management process mentioned above requires a high amount of human resources. In construction companies, solutions are needed to reduce the human resources required for this job. The Joint Project Management Portal is structured as a web-based software that will serve construction companies under the main headings of organization management, contract management, project management, process management, risk management, internal control management and performance management (Figure 2). In this way, all necessary management work will be carried out under one software, saving labor and time, and the necessary interventions of the company management will be done in a timely and accurate manner (Kazaz et al, 2019).

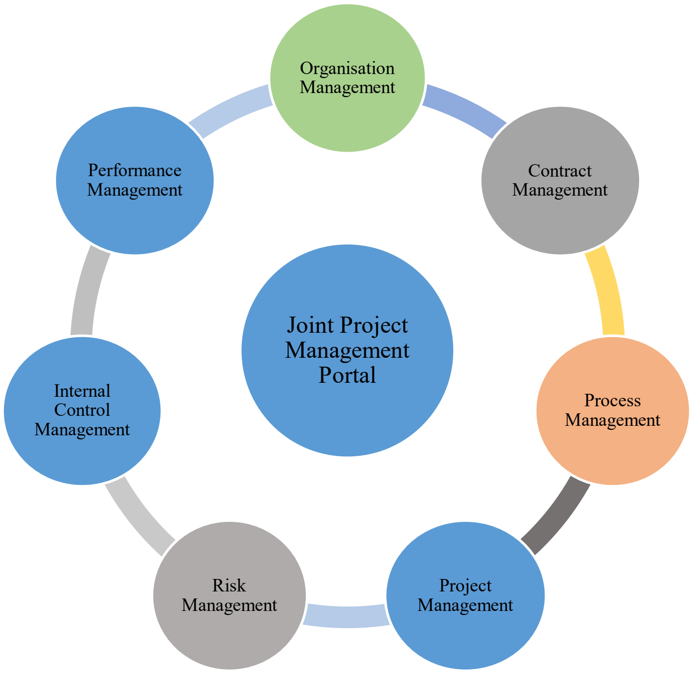

Figure 2: Joint project management portal modules.

The main page of the Joint Project Management Portal is shown in Fig. 3. The Joint Project Management Portal consists of seven main modules: organization management, contract management, project management, process management, risk management, internal control management and performance management. In addition, the screenshot of the performance management module is shown in Fig. 4.

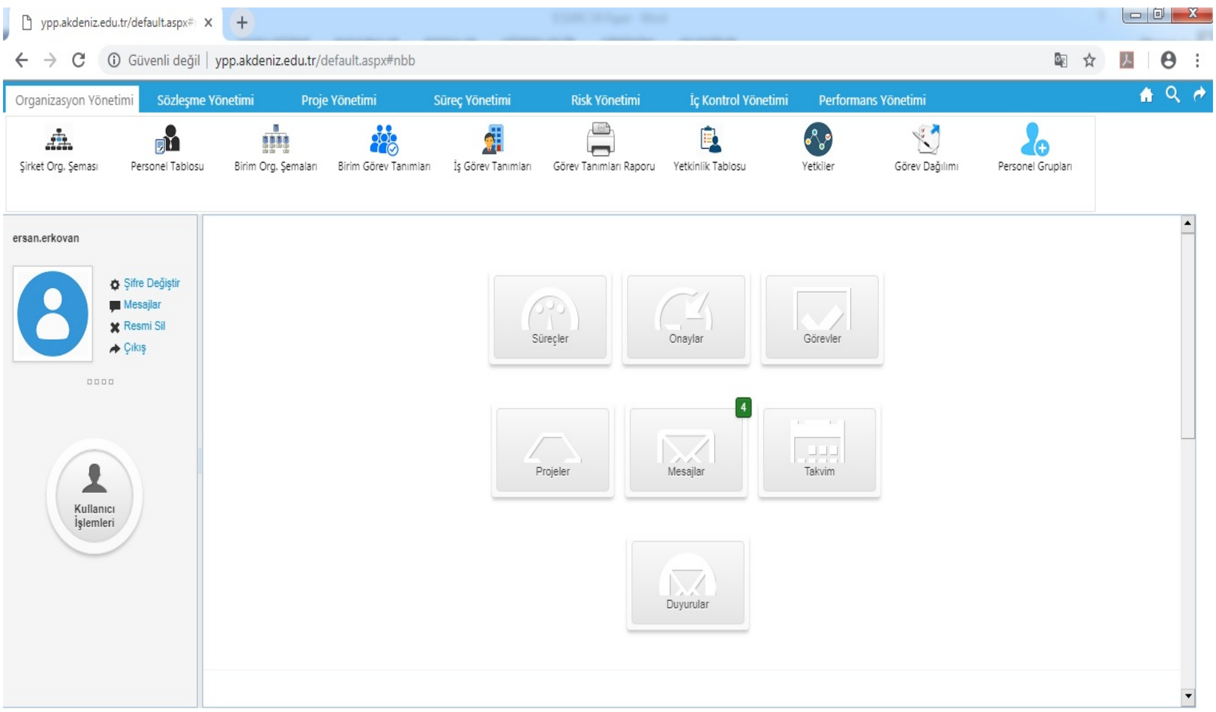

Figure 3: Main page of the joint project management portal.

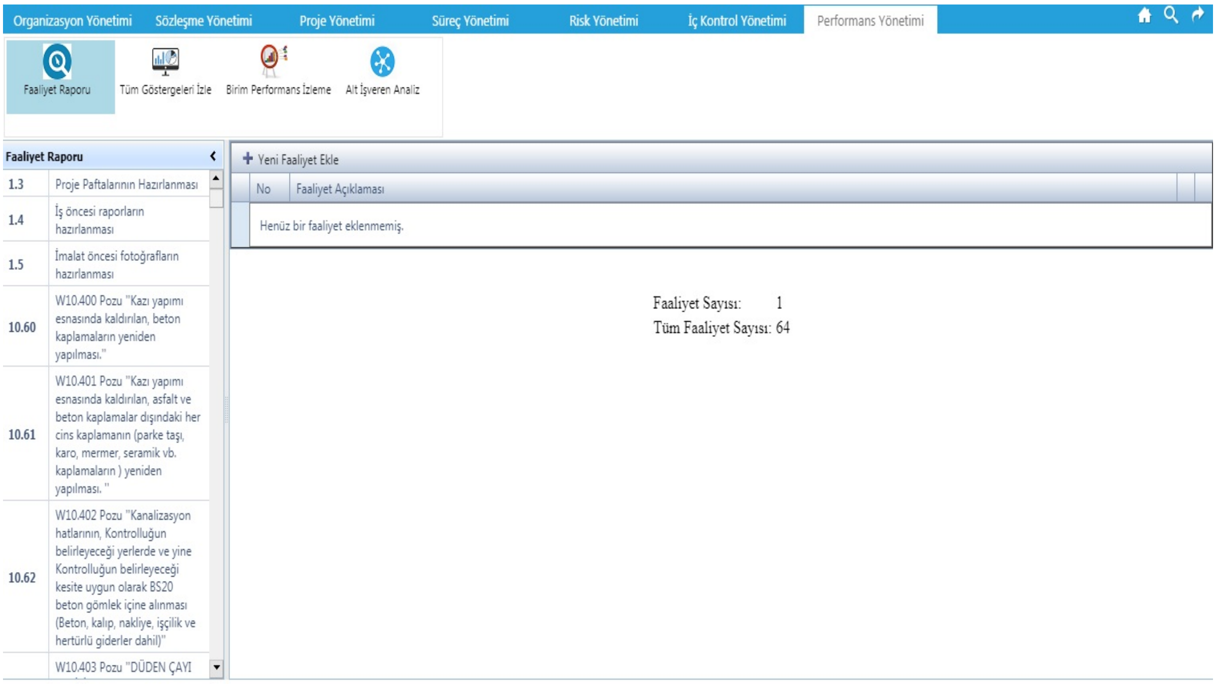

Figure 4: Screenshot of the performance management module.

Thanks to the Project Management modüle of the Joint Project Managemet Portal, cost and time controls such as time-out delays and budget exceeding points for the activities of the projects that the contractor construction companies have uploaded to the portal can be made with the Earned Value Analysis (EVA) method. Fig. 5 shows the calculated EVA deviations of the project activity of a wastewater sewerage network project under the project management module.

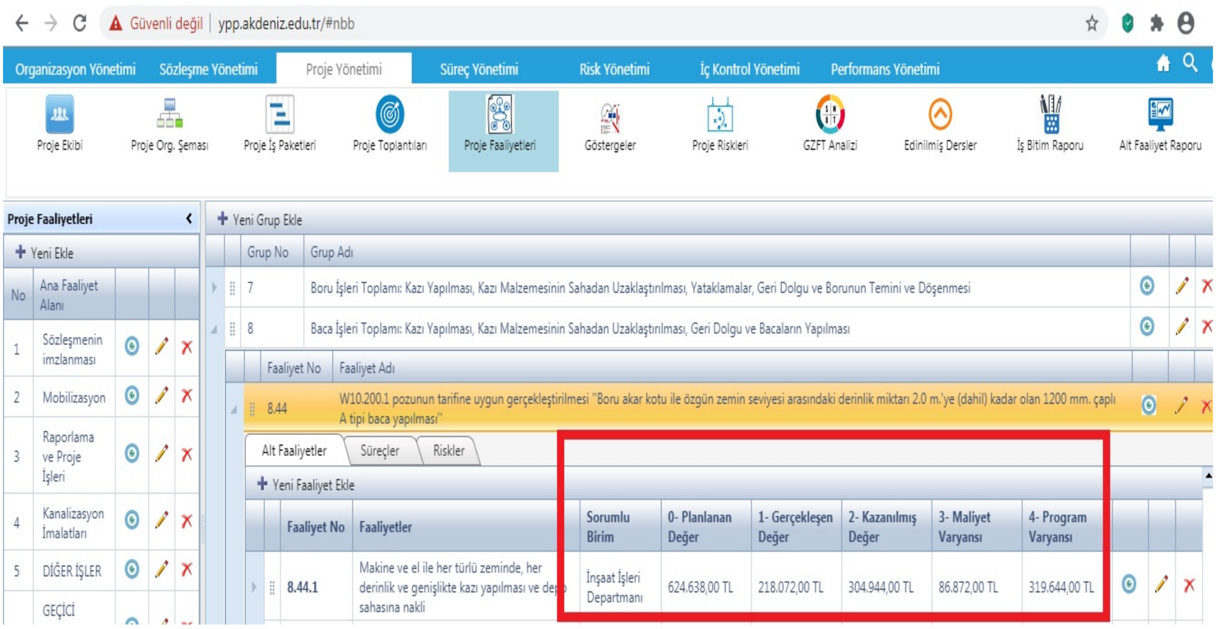

Figure 5: Screenshot of calculating EVA deviations of project activities.

Conclusion

In order for the projects carried out by the contractor construction companies to reach their planned targets successfully, the projects must be monitored with an effective system. By taking the necessary precautions regarding the activities carried out in the projects monitored in this way, the deviation of the projects from the intended targets can be prevented. As can be seen from the literature study conducted above, earned value analysis; It is a proven proactive method for controlling time and cost dimensions which are important project metrics. Project managers gain many advantages with the advantage of integrating the cost and time performances provided by the earned value analysis method. The earned value analysis system provides an opportunity for the project manager to compensate for deviations in the project plan and take the necessary measures.

The Joint Project Management Portal is designed as a web-based computer software that provides the performance management system they need thanks to the performance management module of construction companies. Joint Project Management Portal; uses the earned value analysis system, which is a proven method for monitoring cost and time performances, which are important components that determine the project performance, within the project management module. Thus, the Joint Project Management Portal, which started as an academic study, is intended to be an effective, proactive and dynamic implementation tool in the fields of organization management, contract management, process management, project management, risk management, internal control management and performance management for all construction companies in the industry.

Acknowledgment

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A View to Concept of Work Safety in Construction Industry from the Perspective of Hofstede's Cultural Dimensions Theory: Example of Turkey

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Abstract

The culture is one of the most fundamental elements that keep communities together, determines the mutual sharing of individuals in a society, their view of life, working styles, and association with future and traditions. The impact of culture on so many areas of the society allows the culture to have junctions in different areas in a multidisciplinary manner. The area of occupational health and safety is included in the areas that are related to the culture. Different cultural structures of societies enable them to gain different points of view of the concept of work safety. Due to these different points of view, incidence of work accidents in each society, measures taken for the work accidents and work safety practices differ. The purpose of this study is to interpret work accidents occurred in the construction industry in cultural terms in societies with different values for cultural dimensions. To this end, this study addresses the concept of work safety in Turkish construction industry from the perspective of Hofstede's cultural dimensions theory. The results of this study are expected to contribute to the construction industry in order to show the reflections of the cultural structure of societies on work accidents in the construction industry.

Keywords: *work safety, culture, construction industry, Hofstede's theory, Turkey*

Introduction

Although the concept of work safety was introduced in very old dates, it has gained more importance with recently increased turnover, particularly in the construction industry. As is known, the construction industry leads the way in industries where work accidents happen the most worldwide. The concept of work safety is therefore very important to any actor that plays a role in the construction industry. Interactions of all stakeholders with each other in the industry allow works to be complementary to each other and to form a whole, resulting in the dynamic structure of the industry. Besides, all the actors in the industry gather together to forms small groups. The behaviors and attitudes of these groups are effective in the operation of processes. What keeps these small groups together is their cultural structure.

The culture constitutes societies' perspective of life and lifestyles both as an individual and in groups. The relationships between the persons allow them to work together, form their perspective of concepts of success, tolerance and limits, determine the extent of their expectations from the future, and, identify the type of bond they have established with the past.

Therefore, the concept of culture is a multidisciplinary area and has junctions with many areas of work. The work accidents in the construction industry are critical for the structure of culture where such accidents happen. The perspective of countries with different cultural values for work accidents is also different. For example, the frequency of work accidents in societies where the performed job is taken seriously, legal requirements are met and necessary measures are taken is naturally different from the frequency of work accidents in societies where rules are stretched and measures are ignored.

At this point, the cultural structure of groups of different sizes in the construction industry considerably affects the concept of work safety in the industry. The purpose of this study is to interpret the work accidents occurring in the construction industry in cultural terms in societies with different values for cultural dimensions. For this reason, the concept of work safety in the Turkish construction industry was interpreted from the perspective of Hofstede's cultural dimensions theory. The methods of this study involved a description of Hofstede's cultural dimensions, the dimensions involving different countries were sampled, and it was described how cultural differences could affect work safety in the construction industry. The limitation of this study is that study provides an evaluation only across Turkey.

Methods

Although the cultures have been investigated by the anthropologist for many centuries, they have been largely ignored in different areas of research until several decades before Hofstede. The increased interest in management, psychology, education, and intercultural matters has been triggered by the Hofstede's (1980) "Cultural Dimensions Theory". Although similar studies have been performed previously (Haire et al., 1966; Kluckhohn & Strodtbeck, 1961; Kuhn & McPartland, 1954; Rokeach, 1973), Hofstede was the first person who provided a derived cultural model. Hofstede's study constitutes a very advanced, major international example for the time, research design, and data analysis techniques. The result of that study, also known as IBM study, now, defined and sequenced countries in various cultural dimensions with a number of quantitative indices. Hofstede's study is significant to provide a net model of the cultural differences, to allow culture to become operational, and to facilitate inclusion of the culture in various models as a variable. For these reasons, this study is based on the cultural dimensions defined by Hofstede.

First, Hofstede's cultural dimensions were examined as a study method. Second, how countries are scored by dimensions was described. Then, the scores of 31 different countries from Hofstede's cultural dimensions were analyzed. The position of different countries in cultural dimensions was sampled, and work safety-culture relationship in societies was investigated on the example of Turkey.

Hofstede's Cultural Dimensions Theory

The assumption that there is a cultural diversity in the world have been long adopted by the anthropologists. The anthropologists are believing that although human emotions and behaviors are diverse, each society is differentiated by specific emotions and behaviors. In other words, there exists no unique and universal model (Yüksel, 2013). Instead, each society has developed a cultural adaptation over time to define the emotions and behaviors of most members.

Although there is no consensus on the definition of culture, the researchers consider that culture is a series of perceptions shared by the members of a social unit (O'Reilly et al., 1991).

According to Hofstede, the culture is to collectively program the mind that distinguishes a group or group of people from the others. Hofstede defines culture as a structure. It means a concept that "cannot be reached by direct observation but is understood by verbal expressions and other behaviors, and that is used to predict other observable and measurable verbal/non-verbal behaviors" (Yüksel, 2013).

"Hofstede's Cultural Dimensions Theory" was suggested to measure the impact of culture on interpersonal communications in the social structure. This theory was first introduced into the literature by the sociologist Gerard Hendrik Hofstede and examines the impact of culture on the interactions between the persons that work together in different disciplines. The culture model of Hofstede is the most widely used model in the related literature (Kovačić, 2005).

Hofstede formed his studies between 1967 and 1973 through 116.000 questionnaires administered on IBM in 20 different languages and responders from 72 different nations (Yüksel, 2013). As a result of his study, Hofstede suggested 4 different cultural dimensions including power distance, individualism vs. collectivism, uncertainty avoidance, and femininity vs. masculinity. 2 cultural dimensions were added to these 4 cultural dimensions by studies in the following years. Subsequently added dimensions include long-term orientation vs. short-term orientation and indulgence vs. restraint. Figure-1 shows the Hofstede's cultural dimensions.

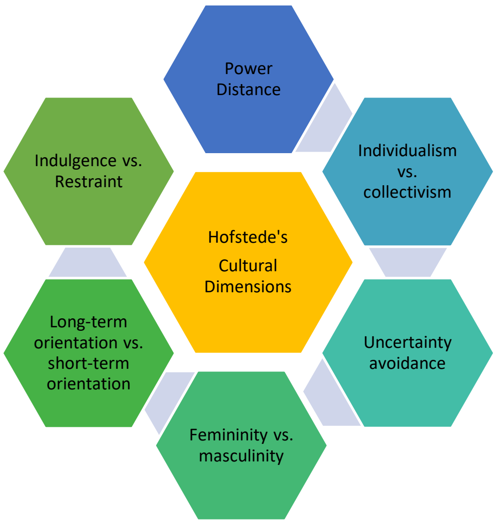

Figure 1: Hofstede's cultural dimensions.

Power Distance: Power distance is the extent to which the less powerful members of institutions and organizations within a country expect and accept that power is distributed unequally. In societies with high power distance, inequality of having power is supported by the followers as well as leaders (Hofstede, 2011). "Power Distance" refers to the degree of inequality of the people who live in the same society (Hofstede, 1993).

The countries that allow to maintain or increase the inequality have high power distance. The inequality increases over time in such countries. On the contrary, the countries that do not like that gap between their citizens are too unequal to have low power distance. Such countries use taxation and social aid programs to reduce the inequality and keep the number of unlucky members of society low. The countries with low power distance are concerned about preventing the broad gap between the poor and rich and inconsistency between the classes (Yüksel, 2013). The Eastern European, Latin, Asian, and African countries have higher power distance, and the Western countries that speak Teutonic and English languages have lower power distance (Hofstede, 2011).

Individualism vs. Collectivism: Individualism-collectivism is about the predisposition of persons in a society to be integrated into groups. In individualist societies, the ties between the individuals are loose, everyone is only tied to themselves and immediate family. In the collectivist societies, the persons are unquestioningly in the large families that look after them from the birth (Hofstede, 2011). Individuality and collectivism are opposite concepts. So, collectivism is the low individualism (Hofstede,1993).

The countries where individualism is effective, individual success, freedom, and competitive values are highlighted. In countries where collectivism is effective, the group consistency, loyalty, and cooperation are very powerful and the importance of understanding and solidarity between the individuals is emphasized. In the collectivist societies, a group is more important than an individual, and the group members follows the norms emphasized by the group, not their individual interests (Yüksel, 2013). The individualism prevails over the developed and Western countries, and collectivism prevails over the less developed and Eastern countries. Japan is in the middle position in this dimension (Hofstede, 2011).

Uncertainty Avoidance: Uncertainty avoidance is the extent to which the members of a society tolerate uncertainties. It indicates how members of a community feel uncomfortable in unstructured situations, or they are programmed to feel comfortable (Hofstede, 1993). The unstructured situations are new, unknown, and non-normal conditions. In societies that avoid uncertainties, the members strictly adhere to the rules and laws. The different opinions are rejected and there is absolute truth (Hofstede, 2011).

In countries where the degree of uncertainty avoidance is strong, the individuals prefer structured conditions because the sense of safety is assured. The people in such countries are more tensed, whereas in the countries where the degree of uncertainty avoidance is weak, people are more relaxed. The societies with a strong degree of uncertainty avoidance are considered “strict”, while the societies with a weak degree of uncertainty avoidance are considered “flexible”. In the countries where the degree of uncertainty avoidance is strong, the sense “what is different is dangerous” prevails whereas in the countries where the degree of uncertainty avoidance is weak, the sense “what is different arouses curiosity” prevails. In the societies with a strong degree of uncertainty avoidance, the people seek for stability and avoid uncertain, risky and suspicious situations. Therefore, the individuals of such society adhere to authority, hierarchy, written and formal rules in order to feel safe (Yüksel, 2013). Uncertainty avoidance tends to be higher in the Eastern and Central European countries, Latin countries, Japan, and countries where German is spoken, and tends to be lower in the countries where English is spoken, Scandinavian countries and Chines culture countries (Hofstede, 2011).

Masculinity vs. Femininity: The concept of masculinity-femininity appears in societies as a reflection of gender-specific attitudes and behaviors on the culture not as an individual characteristic. National cultural differences between masculinity / femininity dimensions affect the meaning of the live for working people (Hofstede, 2001). The societies with higher masculinity show competitive attitudes. The societies with higher femininity are humble and affectionate. The masculinity is higher in Japan, German speaking countries, Italy, several Latin countries including Mexico and lower in Scandinavian countries, and the Netherlands (Hofstede, 2011).

Long-term Orientation vs. Short-term Orientation: After 4 cultural dimensions suggested by Hofstede in the 1970s, the dimension "long-term orientation vs. short-term orientation", which can be associated with hard work, was suggested by Michael Harris Bond in the late 1980s. A questionnaire that was initially designed by Chinese scientists was administrated among the students in 23 countries. Since none of the 4 dimensions defined by Hofstede is related to economic growth, the results of that study were also approved by Hofstede and incorporated in the theory as the 5th Cultural dimension. The values of the long-term orientation are determination, economy, sorting relationships by conditions and sense of embarrassment. The values of the short-term orientation are mutual social obligations, respect for traditions, personal stability, and stability (Hofstede, 2011).

In the long-term orientation, and individual directs the values found (e.g., economy and persistence) to the future. In the short-term orientation, an individual directs the values found (e.g., respect for traditions and fulfilment of social requirements) to the past or to the present time. The long-term cultures are characterized by the patience, determination, respect for the elderly and ancestors, obedience for a greater benefit, and sense of duty (Yüksel, 2013). The East Asian countries have long-term orientation, followed by the Eastern and Central European countries. The Southern and Northern European countries have medium-term orientation. The USA, Australia, and Latin American, African and Muslim countries have short-term orientation (Hofstede, 2011).

Indulgence vs. restraint: After the 5th dimension, Michael Minkov, a Bulgarian linguist and sociologist, contacted Hofstede in the early 2000s to investigate the cultural dimensions in more depth. He included 3 additional new international value dimensions in his book published in 2007. The dimension universalism-exclusivism matches the dimension "individualism-collectivism" previously defined by Hofstede. The other two dimensions mentioned by Minkov in his book are the improved version of long-term/short-term orientation and indulgence vs. restraint as a new dimension. So, the dimension indulgence vs. restraint was included in the literature as the 6th Dimension. The dimension indulgence vs. restraint addresses the aspects related to "happiness" that is not covered by other five dimensions. Indulgence refers to a society that allows to relatively free human desires, either fundamental or natural, related to enjoying life and having fun. The restraint represents a society that controls the satisfaction of needs and is regulated by strict social norms (Yüksel, 2013). The indulgence tends to prevail in the Southern and Northern America, Western Europe and some parts of sub-Saharan Africa. The restraint applies to Eastern European, Asian and Muslim countries (Hofstede, 2011).

Assessment of Different Countries by Hofstede's Cultural Dimensions Theory

Hofstede formed his studies between 1967 and 1973 through 116.000 questionnaires administered on IBM in 20 different languages and responders from 72 different nations (Yüksel, 2013). According to the results of this questionnaire, the countries are scored ranging from 0 to 100 based on their cultural structure. Table 1 shows the description of all dimensions scored 0 to 100.

Table 1. Assessment of Hofstede's Cultural Dimensions on the 100-point scale (Url-1, Accessed in 2020)

0		100
More egalitarian	Power Distance	Embraces hierarchy
Collectivist	Individualism vs. Collectivism	Individualist
Comfortable with ambiguity	Uncertainty Avoidance	Ambiguity creates anxiety
Nurture more important	Masculinity vs. femininity	Power more important
Put short-term goals first	Long-term Orientation vs. Short-term orientation	Put Long-term goals first
Happiness can be bad	Indulgence-Restraint	Happiness is always good

Table-2 shows the scores for the power distance, individualism-collectivism, uncertainty avoidance, masculinity-femininity in the analysis of cultural dimensions conducted in 31 countries; the country scores for the long-term goals/short-term goals and indulgence-restraint obtained from Url-2 (2020); and the mean values according to the study performed by Yoo and Lee in 2019.

Table-2: Country scores in the analysis of Hofstede's cultural dimensions (Yoo & Lee, 2019; Url-2, Accessed in 2020)

Countries	Power Distance	Individualism-collectivism	Uncertainty avoidance	Masculinity-femininity	Long-term goals/short-term goals	Indulgence-restraint
Australia	38	90	51	61	21	71
Austria	11	55	70	79	60	63
Belgium	65	75	94	54	82	57
Canada	39	80	48	52	36	68
Chile	63	23	86	28	31	68
Czech Republic	57	58	74	57	70	29
Denmark	18	74	23	16	35	70
Estonia	40	60	60	30	82	16
Finland	33	63	59	26	38	57
France	68	71	86	43	63	48
Germany	35	67	65	66	83	40
Greece	60	35	100	57	45	50

Hungary	46	80	82	88	58	31
Ireland	28	70	35	68	24	65
Italy	50	76	75	70	61	30
Japan	54	46	92	95	88	42
Luxemburg	40	60	70	50	64	56
Mexico	81	30	82	69	24	97
The Netherlands	38	80	53	14	67	68
New Zealand	22	79	49	58	33	75
Norway	31	69	50	8	35	55
Poland	68	60	93	64	38	29
Portugal	63	27	99	31	28	33
Republic of Korea	60	18	85	39	100	29
Slovakia	100	52	51	100	77	28
Slovenia	71	27	88	19	49	48
Spain	57	51	86	42	48	44
Sweden	31	71	29	5	53	78
Switzerland	34	68	58	70	74	66
Turkey	**66**	**37**	**85**	**45**	**46**	**49**
United States of America	40	91	46	62	26	68
Mean	**48.61**	**59.45**	**68.51**	**50.51**	**52.87**	**52.51**
Minimum value	11 (Austria)	18 (Republic of Korea)	23 (Denmark)	5 (Sweden)	21 (Australia)	16 (Estonia)
Maximum value	100 (Slovakia)	91 (United States of America)	100 (Greece)	100 (Slovakia)	100 (Republic of Korea)	97 (Mexico)

As seen in Table-2, Austria had the lowest score for power distance with 11 points in the power distance dimension, and Slovakia had the highest score for the power distance with 100 points. So, it appears that Austria is the most egalitarian country and Slovakia is the most hierarchical country among the countries in Table 2. In the dimension individualism-collectivism, the USA had the highest score with 91 points among the countries in Table 8, and the Republic of Korea had the lowest score with 18 points. So, the USA is the most individualist country, and the Republic of Korea is the most collectivist country among the countries in Table 8. In the dimension uncertainty avoidance, Denmark had the highest acceptance of uncertainties with 23 points in the list. Greece is the first in the list to avoid uncertainties with 100 points. In the dimension masculinity-femininity, Sweden is the most feminine and most compassionate country with 5 points in the list whereas Slovakia is the most masculine country with 100 points in the list. There may be a significant correlation between Slovakia's masculine status (close to power) with 100 points and Slovakia's hierarchical status with 100 points in the dimension power distance. In the long-term goals/short-term goals dimension, Australia is close to short-term goals with 21 points. The Republic of Korea is in the long-term goals dimension with 100 points. In the indulgence-restraint dimension, Estonia is the most indulgent country with 16 points. Mexico is close to the dimension restraint with 97 points.

Work Safety-Culture Relationship in Turkish Construction Industry

The culture constitutes the lifestyle of societies both as an individual and in groups. The culture, a multidisciplinary area, has a junction with many different work areas. The area of work safety is also related to the culture. The work accidents that occur in the construction industry are directly related to the cultural structure of societies. For example, the view for the concept of work safety in hierarchical societies with high power distance and the view for the concept of work safety in more egalitarian societies may be different. Or the cause of a work accident that occurs in the individualist societies and the cause of a work accident that occurs in the collectivist societies may be different.

In the dimension power distance, Turkey is among the countries with high power distance with 66 points. The societies with high power distance are a hierarchical society where indirect communication is established and that is not open to new ideas. The employees in such societies trust in managers and will not question their decisions. The employees are notified of what to do by their superior of chief. In societies with high power distance such as Turkey, work accidents may occur because occupational safety companies receive instructions or orders from the employer, the associated problems are communicated to the employer, and the final decision-maker is also the employer.

In the dimension individualism-collectivism, Turkey is among the countries close to collectivist countries with 37 points. The concept of "we" is important in the collectivist societies, and the persons are expected to faithfully abide by the groups they are included in. It is important to adapt to your own group, and express conflicts are avoided. As a return of all these, interpersonal relationships may outweigh the required duties. The thought that "nothing would happen to us" in the collectivist societies such as Turkey makes interpersonal relationships more important than the responsibilities and causes to ignore the disturbances to prevent adaptation to own group, resulting in the increased number of work accidents.

In the dimension uncertainty avoidance, Turkey's score is 85 which includes it in the countries that avoid uncertainties. The societies that avoid uncertainties are not open to innovations, avoid anxiety, and look at the future with suspicion. In societies that avoid uncertainties such as Turkey, there is a tendency to establish beliefs and institutions to avoid uncertainties. There is a belief-based approach "Desire of God" to work accidents that occur frequently in our country, which could be a good example of it. After a work accident happens, the resulting consequences are not attributed to measures not taken, but rather to a divine power independent of persons and government agencies. This is a common practice.

In the dimension masculinity-femininity, Turkey is in the feminine area with 46 points. The societies in the feminine area avoid conflicts and care for consensus, and in such societies soft aspects of person such as sympathy are more prominent. The competition and success-orientation do not come to the forefront as in the masculine societies. From this perspective, the characteristics of a feminine society are also parallel to the characteristics of a collectivist society.

The legal regulations entered into force on occupational health and safety in the whole world and in Turkey are intended to prevent work accidents and reduce the loss of life and property in the construction industry as in any of the industries. However, enforcement of such legal regulations is directly related to the cultural structure of a society.

All the actors involved in the construction industry form a specific culture in their own groups in the construction industry as in any industry. No doubt that the cultural impact of their community dominates over the formation of culture in such small communities within the society.

It is important to understand such formed culture in order to determine the group dynamics and develop human-oriented, feasible, and sustainable policies. This is possible by regarding the groups working together not only as a structure that produces goods/provided services but also adopting an approach accepting that a group refers to a culture where it interacts with its members (Yılmaz, 2014).

Results

The concept of culture is a multidisciplinary concept that has a relationship with the area of occupational health and safety as in many areas. The cultural structure of different groups of persons involved in the area of occupational health and safety determines the perspective of occupational health and safety. This study examined the Hofstede's cultural dimensions theory, addressed the cultural characteristics of different countries, and interpreted the work safety-culture relationship on the example of Turkey.

The work safety in the construction industry requires actors from many different disciplines to work together. The cultural structure of societies also affects the way of working. The societies in different cultural areas address the concept of occupational health and safety in construction in different ways. The cultural structure ensures the stability of work safety in some societies but causes interruptions in practices in some societies.

According to Hofstede's cultural dimensions theory, Turkey has a high-power distance, is collectivist, avoids uncertainties, and bears feminine characteristics. The hierarchical structure brought by power distance; involvement in a group as required by a collectivist society, uncertain conditions caused by the avoidance of uncertainties, attribution to beliefs and prominent sense of sympathy brought by a feminine society appear to be parallel to each other. It is surely unavoidable that a society with a hierarchical structure is also a society that cares about adaptation to groups; and uncertain situations are accepted based on the belief systems in societies that avoid uncertainties and do not accept different opinions.

Since the cultural structure of societies would not undergo radical changes in short periods from today to tomorrow, the problems in the area of work safety may be remedied by different practices as in many areas. It is considered that work accidents may be reduced by regulations, practices and even penal sanctions that suit the cultural structure of society.

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Bright Green Buildings as A Green Marketing Strategy

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Abstract

Environmental problems experienced on a global scale are increasing rapidly day by day. As a member of the society, most businesses set their responsibilities to the environment as their primary goal and act with an understanding of reducing negative environmental impacts. As a result of this understanding, in line with consumer needs, the green marketing concept, which aims at long-term profitability and is an environmental and eco-friendly business strategy, gains importance. In the construction industry which is parallel to the developments in the other sectors, the operations on sustainable green building construction have accelerated in this context. However, in terms of initial investment costs, the demand for green buildings has not reached the desired level in Turkey. The main reason for this situation is the inadequacy of the strategies put forward in presenting green buildings to the users. The purpose of this study is to evaluate the applicability of green marketing strategies in sustainable green structures and to draw attention to one of these strategies, the Bright Green Building. For this purpose, green promotion strategies were examined and the necessity of its implementation in the construction sector was emphasized. Bright green buildings, which are proposed as one of the green marketing strategies and integrate the features of both green buildings and smart buildings, have been examined. The results of the study are aimed to raise awareness in the construction industry and contribute to the increase of Bright Green Building applications.

Keywords: *bright green building, sustainable architecture, green buildings, green marketing*

Introduction

Increasing industrial activities with the industrial revolution and the increase in the consumption of limited natural resources have caused global problems such as environmental pollution deterioration of the ecosystem balance. With the increasing environmental problems, today's people have taken responsibility for leaving a clean environment for future generations to lead a healthy life. As the buildings and the building industry cause significant damage to nature and natural resources as a significant energy and resource user, the construction industry also has a significant responsibility. Therefore, the concept of “sustainable architecture”, which has the least harm to nature, uses renewable energy sources, can be recycled, and aims using local materials, has emerged in the application, use and demolition stages. Green buildings, which are under many names such as sustainable, ecological, and eco-friendly, use technologies that support the efficient use of natural resources during their life cycle.

According to Dodge Data & Analytics' 'The World Building Trends 2018 Smart Market' report (2018), green projects have increased significantly in the last 10 years in the international construction market. According to the research conducted in various countries around the world, Australia, with 46%, China (Hong Kong) with 42% and Ireland with 40%, are among the top green countries (Dodge Data & Analytics, 2018). Today there are only 428 certified green buildings in Turkey (Turkish Green Building Council, 2020). This shows that green buildings are not widespread in Turkey although they are widespread in other countries and they have a very small market share compared to other countries. Because of Turkey is adapted to this situation late and lagging behind, green building projects should be encouraged.

Awareness has been developed among consumers about using eco-friendly, green products to prevent environmental pollution and reduce harmful waste. The consumer model, which questions all kinds of activities related to businesses, does not accept businesses to harm the natural environment. Businesses with social awareness and social responsibility gaining an important image in the eyes of consumers (Varinli, 2000). Since all these developments significantly affect marketing activities, the concept of green marketing has emerged. Green marketing: It is a business strategy that aims long-term profitability with a sense of responsibility in meeting the needs of society and consumers (Ottman, 1993). Businesses have developed green marketing strategies to maintain their continuity in the current competitive environment. On the other hand, the lack of implementation of these strategies in the construction sector leads to an increase of unqualified building stock and environmental problems in Turkey.

The purpose of this study is to evaluate the applicability of green marketing strategies in sustainable green buildings and to draw attention to one of these strategies, the Bright Green Building. For this purpose, green marketing strategies were examined within the scope of the study, and the advantages of bright green building applications as a marketing strategy were revealed. The results of the study are aimed to raise awareness in the construction industry and contribute to the increase of Bright Green Building applications.

Green Marketing

The concept of green marketing was first discussed in the seminar on 'ecological marketing' organized by the American Marketing Association (AMA) in 1975 and took its place in the literature. The concept of ecological marketing; is defined as the marketing of products considered to be environmentally safe. In addition, it has been stated that green marketing covers activities such as product differentiation, changes in production and packaging processes, and advertising strategies (Yazdanifard & Mercy, 2011). Until today, green marketing has been used as a marketing concept that handles the nature-friendly properties of products that are only recyclable, environmentally compatible, produced with natural materials, and do not damage the ozone layer. However, a green marketing strategy is not only limited to the product. Beyond this, it requires that all stages of the product's production, starting from the supply of the material after it reaches the consumer, until its recycling, be arranged in the framework of the green approach (Varinli, 2008). The fact that businesses are more aware that they use social resources has led to an increase in their social responsibilities as well as their economic responsibilities towards society (Dinçer, 1998). Therefore, the concept of green marketing has gained importance.

Four different stages are mentioned in the green marketing approach. In the first stage, green products are designed for environmentalist consumers. Alternative fuel technology cars and products that do not harm the environment can be given as examples. We can call this stage green targeting. In the second stage, green strategies are developed. For example, eco-friendly measures are taken, such as extracting less waste and increasing energy efficiency. In the third stage, the production of eco-unfriendly products is stopped, and only green products are produced. In the fourth stage, it is not enough to be green or eco-friendly. The business has now become socially responsible in every sense. The ability of businesses to reach green marketing awareness is developing depending on the business culture and environmental factors (Alagöz, 2007).

Green Marketing Blend

While traditional marketing emphasizes the use of the product, green marketing highlights how the product is produced and how it will disappear at the end of its life. Green marketing components could be analyzed in six categories as product, price, promotion, distribution, packaging, and labeling (Kuduz & Zerenler, 2013).

- **Green product:** It is an eco-friendly product that satisfies the demands and needs of the consumer, does not pollute the environment, does not harm the living creatures, can be recovered or protected, and consumes less natural resources (Türk & Gök, 2010). The concept of a green product is known as 4S formula; it is possible to explain it with the components; satisfaction, sustainability, social acceptability, and safety (Erbaşlar, 2012).
- **Green price:** Investments made to develop eco-friendly products, increase the final sales price by making additional contributions to the cost of the product. It should be explained to the individuals that the environment and healthy living also have a cost and their contribution to this cost by purchasing eco-friendly products will save them from irreversible vital consequences in the future.
- **Green promotion strategies:** Businesses should convince their current or potential customers about what aspects of the products they produce are green products, what benefits they will provide to the users and the environment, and the outcomes after the use (Duru & Şua, 2013). Among the green promotion activities that need to be the most important; claims about products are credible and presented by third parties, the product has eco-certification, and these activities are used to improve consumer knowledge (Tirkeş, 2008). The methods used in promotion strategies are: 'eco-friendly advertising strategy', 'public relations, and sponsorship strategy' and 'sales development' (Erbaşlar, 2012).
- **Green distribution:** During the distribution of the product, it is explored to use less fuel and to take up less space, and to locate the sales points in a more accessible way. For example, businesses that produce "concentrated formula" laundry detergents sell this modified version of the product in smaller packages, thereby reducing costs of loading and shipping (Varinli, 2008).
- **Green packaging:** In eco-sensitive packaging applications, measures such as reducing unnecessary packaging, developing packaging tools that can be used more than once and using eco-friendly packaging materials can be taken (Yücel & Ekmekçiler, 2008).
- **Green labeling:** In order to distinguish eco-sensitive products and achieve a certain standard, the International Organization for Standardization has implemented a series of ISO

14000 documents. Products with these documents are accepted by the consumers as eco-friendly products (Yücel & Ekmekçiler, 2008).

Benefits of Green Marketing for Businesses

The use of new technologies developed with a clean technology approach in production can decrease the amount of input needed, the amount of pollution and waste that occur. Such initiatives can reduce the cost of producing eco-friendly products (Peattie, 2001). Today, many marketers are aware that environmental innovations bring a competitive advantage. Royavac company first introduced reusable alkaline batteries and redefined the market for recharging. Compaq company has achieved the advantage of competitors by producing “Energy Star” labeled systems that use less energy by putting computers in stand-by mode (Yılmaz, 2003).

Green marketing provides many benefits to businesses. These benefits can be summarized as follows (Keles, 2007):

- Businesses become leaders as they develop unique and difficult to imitate environmental strategies.
- With an environmental awareness approach, it reduces long-term risks in areas such as consumption of resources, energy costs, pollution, and waste management.
- Being eco-friendly is important for the public relations and image of a business.
- Expenditures on health problems caused by industrial pollution can be reduced.
- Being eco-friendly makes businesses more secure against the law.

Many consumers demand eco-friendly products, packaging, and management styles. These consumers prefer businesses that approach the environment consciously.

The Necessity of Implementing Green Marketing Strategy in the Construction Industry

There are differences between the application of green marketing in the construction industry and other industries. The reason for this is that there are green buildings in the construction industry that we can already define as green products. Furthermore, starting from the decisions taken during the design process, during the implementation, operation, maintenance and elimination, and in waste management processes, control, monitoring and certification by the worldwide audit boards are among these reasons. Therefore, green marketing strategies in the construction industry focus on green buildings. Certificate programs play an important role in delivering the actual features of the technology used by the businesses and the products they offer to the market and ensuring the flow of information. The awards given by these organizations play an encouraging role as they promote the businesses positively. The "green product design - product development - product differentiation" strategies of the companies operating in the construction industry can be realized with the help of the certificates issued by these organizations (Utkutuğ, 2011).

One of the points to be considered in the differentiation strategy will be implemented in the construction industry, which green products that give importance to what extent the nature of the potential users of green buildings is predetermined. Otherwise, any investment realized above the expectations will be an extra cost (Utkutuğ, 2011). According to the World Green Building Trends report of McGraw-Hill Construction covering 62 countries in different parts of the world; The importance of the factors in the green building preferences of the companies in 2012 is as follows (McGraw-Hill Construction, 2013):

- Reducing energy consumption: 72%
- Reducing greenhouse gas emissions: 27%
- Protection of natural resources: 27%
- Reducing water consumption: 25%
- Increasing the air quality inside the building: 17%.

According to this report, the most important factor in choosing green buildings is the savings it provides in energy consumption. Based on this study, the selection of artificial and natural lighting systems that provide savings in electricity usage can be given as an example. According to the research conducted by the U.S. Department of Energy in 2009, energy is spent on residential heating at the rate of 26.4% at the most as of 2006. This is followed by area cooling with 13% and water heating with 12.4% (Department of Energy, 2010). In the light of this information, the use of heating and cooling systems that provide high energy saving in living rooms can be used for differentiation strategy (Utkutuğ, 2011).

Advertising campaigns with informative content should be included in order to increase the environmental sensitivity of consumers. For example, in the advertisement of a tablet dish detergent company, it is noted that it will save 57 liters of water in every washing by simply passing the water out of the dishes before throwing it into the machine. Such advertising campaigns should also be adapted for green buildings.

Green buildings offer attractive results for investors in commercially. According to the data of Northwest Multiple Listing Service in America, it has been observed that eco-friendly houses are sold 24% faster in Seattle and 5.9% more appreciate in value than other houses. According to a similar research conducted by McGrawHill Construction, it was observed that eco-friendly buildings appreciate 7.5% more in value compared to other buildings. According to the research results published by CoStar Group in 2008, it has been revealed that LEED (Leadership in Energy and Environmental Design) certified buildings have a 4% increase in occupancy rates compared to other buildings and sales prices are $1,710 more per m2 (Ilıcalı, 2012). Based on the results of these researches, investors should be informed about the investment advantages of green buildings and encouraged to implement green buildings.

Various incentives have been defined and implemented all over the world in order to spread green buildings. In Turkey, the government, public institutions, and municipalities must work on tax incentives and supports and put forward concrete proposals to provide green transformation. In the literature, constitute an example of this, tax proposals, which have a positive impact on environmental protection, described as pollution tax and green tax, have been made. The main purpose in this practice is to deter people or companies that harm the environment rather than earning income (Tax Policy Center, 2014).

Bright Green Buildings as a Green Marketing Strategy

Bright Green Buildings integrates both the properties of green buildings and the properties of bright buildings, thereby creating a strategy that increases the perceived value of the product on the consumer side by creating a niche market. Such structures can provide energy management, space utilization, integrated design process, sustainability, renewable energy, a healthy and comfortable environment, and high secondhand sales rates (Frost & Sullivan, 2008). In pricing of either green buildings or added green revision services, energy and resource saving high material costs increase the market value of these structures. By adding bright building features to these buildings, the preferability of the building can be increased.

In bright green buildings, fully networked systems allow independent systems to work collectively to ensure interaction between all systems. It optimizes the performance of the building and constantly creates an environment suitable for the occupants' goals. In order to achieve this, it combines security, heating, ventilation, air conditioning, lighting and other electronic controls on a single network platform, by using data, voice and imaging systems. Figure 1 shows the similarities between bright and green buildings that form the basis of a bright green building (Frost & Sullivan, 2008).

Figure 1: Integration of green buildings and bright buildings (Frost & Sullivan, 2008).

The advantages of bright green buildings were evaluated based on the research findings of Frost & Sullivan Research and Consultancy Company in 2008. In this study, an evaluation system for bright green buildings has been determined. This evaluation system is based on key factors such as energy saving, greenhouse gas, operation and maintenance, water saving and efficiency. These factors can be summarized under the following headings (Frost & Sullivan, 2008);

- **Energy Saving:** Bright buildings provide better monitoring and control of energy-based systems such as heating, ventilation, air conditioning (HVAC) and lighting. Energy Star building managers state that bright green buildings use 50% less energy than other buildings.
- **Decrease in Greenhouse Gas Emission:** Climate change has prompted the industry sector to reduce greenhouse gas emissions using energy efficient technologies. Investors are concerned about current legal and regulatory trends that threaten to impose direct environmental damage costs to consumers, such as British Columbia's carbon tax, which threatens to impose restrictions on greenhouse gas emissions and carbon taxes. Many companies should act according to consumer preferences arising from increased awareness of climate change risks.

- **Decrease in Maintenance and Repair Cost:** Operating costs represent 50-80% of the total life cycle costs over the estimated 40-year life of a building. Therefore, even a modest reduction in lifetime operating costs can increase the asset value of a building. In rental systems, people are redirected to bright green buildings after the building sales, as they reduce energy operating costs. Energy Star stated that in the case of investing in energy systems and technologies, these costs can be a minimum 20-30% return on investment.
- **Saving Water:** Water scarcity is expected to be a permanent problem in many regions in the near future. Therefore, there is a huge market potential for water saving technologies and products. This option, which has the potential to grow, is provided with low flow / no flow technologies and the use of sensors to control water use.
- **Comfort and Efficiency Increase:** Financial expenses caused by users in buildings affect the building life cycle costs to a large extent (up to 85%). It was observed that the user productivity was high, and the absenteeism rate was low in bright green office buildings compared to other buildings. For example, according to the US Green Building Council, the efficiency of office workers in green buildings increases on average by 2-18%. Thus, higher rents were observed in these buildings.

Building owners often think that green and bright buildings will cost more. But the cost of building a bright green building is not much different from that of an ordinary building. Applications such as smart technology and cabling are less costly than traditional infrastructure in several ways. This is because in the case of wiring, labor costs are lower where smart designs are used. However, integrating all components of the system will require additional investment. For example, integrating the access control system into lighting and heating-ventilation-air conditioning (HVAC) systems will cost more than installing non-integrated systems. It was determined that the initial investment cost return of the buildings constructed with green and smart design in all the sample buildings examined was in a short time considering the lifetime of the building.

Today, there are many bright green building applications. One of them is Providence Newberg Medical Center (PNMC), a 175,500 square meter facility. This center is a 40-bed hospital with health offices. Smart systems have been implemented in order to reduce energy consumption, resolve environmental concerns and provide indoor air quality comfort. It has integrated the heating-ventilation-air conditioning (HVAC) systems, which is one of the smart systems. User safety, comfort and productivity are increased with this system. Providence Newberg Medical Center, a LEED Gold certified facility, has reduced the total energy consumption by 26% compared to the 90.1 energy code of the American Association for Heating, Cooling and Air Conditioning Engineers (ASHRAE) (Frost & Sullivan, 2008).

Results

After the industrial revolution that took place in the second half of the 18th century, the relations between human and nature deteriorated over time and environmental problems emerged. Consumers', which approaching environmental problems with a sense of responsibility and seek solutions, purchasing behaviors have changed and have led to environmentally friendly products. Green marketing practices have gained importance in businesses that act with social awareness. Buildings are important resource and energy consumers during the construction, usage and demolition phases starting from the design process. Due to the negative environmental impacts created in the long term, studies have been carried out for sustainability in the construction industry.

In this study, which aims to evaluate the applicability of green marketing strategies in sustainable green buildings, it was revealed that Bright Green Buildings can be used as an green marketing tool. It has been observed that bright green buildings guide the users to make the right decisions about space and energy management using technology. Bright green buildings reduce operating costs because they pay attention to resource conservation and energy efficiency by providing healthy and comfortable spaces. At the same time, they do not compromise the principle of minimum harm to the environment by ensuring the sustainability of the resources. Thanks to the technological solutions contained in bright green buildings, they increase the value of green buildings in the eyes of consumers. The study results reveal that bright green buildings provide many benefits to users, such as increasing energy efficiency, creating low greenhouse gas emissions, providing low maintenance and repair costs, saving water, and increasing user efficiency. It has been observed that there are advantages that attract investors such as high second-hand sales rates and finding tenants in a short time. For these reasons, it has been concluded that bright green buildings are an effective green marketing strategy and their share in the market is large in terms of the spread of green buildings. It is thought that these buildings will become widespread in the light of future studies on bright green buildings.

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Differences in Neutral and Preferred Classroom Temperatures during Cooling Seasons

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Abstract

This study aims to investigate preferred classroom temperatures in air-conditioned university classrooms. Within this context, a field study was conducted in two typical classrooms at the Civil Engineering Department of Ege University located in Izmir, Turkey. This field study included objective and subjective measurements that include the monitoring of indoor environmental parameters and thermal comfort surveys, respectively. A total of 109 occupants participated in the study. The measurements were used to calculate the Predicted Mean Vote and Actual Mean Vote. In addition, the neutral and preferred temperatures were compared. The results show that the PMV values and the AMV values showed discrepancy in 50% of the tests. The preferred temperatures in classrooms during the cooling season were lower than the neutral temperatures which were calculated based on the thermal sensation votes of the occupants. In addition, the neutral and preferred temperatures of occupants were theoretically equal at 25.62°C.

Keywords: *classroom, neutral temperature, preferred temperature, thermal comfort.*

Introduction

It is stated that thermal comfort in educational buildings affects students' attention, perception and learning levels (Jiang et al., 2018; Singh et al., 2019). In order to maintain a comfortable indoor environment, neutral temperature and preferred temperature of occupants need to be investigated. Neutral temperature is the temperature at which people would feel comfortable, whereas the preferred temperature is the temperature people want and at which an individual would prefer neither warmer nor cooler temperatures for thermal comfort (Fanger, 1973). Thermal comfort standards such as ISO 7730 (2005) and ASHRAE Standard 55 (2017) provide a prediction of neutral temperature of occupants via the PMV indices. In particular, the PMV indices is used to calculate whether a closed environment is perceived as thermally comfortable by a large group of people. The PMV indices is calculated based on the field measurements. Preferred temperature of occupants can be investigated via surveys. The responses of these surveys provide the base for calculating the AMV indices, which is defined as the occupants' thermal sensation in a given comfort space. It should be noted that the surveys need to be designed according to the 7-point scale of the ASHRAE Standard 55 from "very cold" to "very hot" (Nikolopoulou et al., 2003). The literature generally reports discrepancies between the PMV and AMV values (Broday et al., 2019; Broday et al., 2017; Yu et al., 2017). Martinez-Molina et al. (2017) investigated thermal comfort of students and teachers in a primary school located in Spain through field measurements and surveys. The results show that the PMV values are higher than the AMV values for both teachers and students. The results of the study carried out by Yang et al. (2018) at a school building in Sweden showed that students' AMV values are higher than the PMV values. Similarly, Papazoglou et al. (2019) found that the AMV of students at a school building located in Greece are higher than the PMV values. Moreover, the results of a case studies conducted at a university building located in Turkey showed that the AMV values are higher than the PMV values and the difference between the indices is statistically significant (Calis & Kuru, 2017). The discrepancy between the PMV and AMV indices result in a difference between the neutral temperature and preferred temperature of occupants (Shahzad & Rijal, 2019; Singh et al., 2017; De Vecchi et al., 2017; Wu et al., 2019). Liu and Yu (2019) conducted a study in naturally ventilated university classrooms in north west China during winter. The results show that the preferred temperature by students is 22.78°C, which is 2.18°C higher than neutral temperature. Fang et al. (2018) conducted a study in air-conditioned university classrooms in Hong Kong. The results show that the preferred temperature is higher than the neutral temperature by 0.44 °C, resulting in a value of 24.58 °C. In addition, the results of a study which is conducted in naturally ventilated university classrooms in India during summer show that the preferred temperature was found to be 26.8°C while the neutral temperature was found to be 29°C (Kumar et al., 2018). The literature review shows that there is a discrepancy between occupants' neutral temperature, preferred temperature, and the recommended values in the standards.

This study aims at (1) evaluating the indoor environmental conditions of classrooms in the cooling season against ASHRAE 55 and ISO 7730 standards; (2) investigating thermal sensation, thermal satisfaction and thermal preferences of occupants; (3) comparing the actual and predicted thermal comfort of occupants; (4) calculating the neutral and preferred temperature of occupants. Within this context, a total of 4 test campaigns which consist of objective and subjective measurements were carried out simultaneously in the classrooms in July 2019, which is the cooling season. The following sections describe the test bed building, introduce data collection procedures and present findings. Finally, conclusions are provided.

Test Bed Description

This study is conducted in an educational building located in Izmir, Turkey. According to Köppen climate classification, Izmir province is classified as C climate zone and Csa-Mediterranean climate type. The summers are dry and hot whereas winters are mild and rainy.

Two classrooms with an area of 140 m^2 are selected for the case study. The building is heated, cooled and ventilated by a fan coil, which is controlled via built-in thermostats that have 3 phases (low, medium, high). In addition, the classrooms have split air conditioning to support the cooling plant especially during summer seasons. Windows are manually operable. However, it was observed that none of the users changed the status of the doors/windows during the tests.

Data Collection

This section explains the test campaigns which consist of objective and subjective measurements. Two test campaigns in each classroom were conducted.

Objective Measurements

In this study, indoor air temperature, relative humidity, air velocity, and globe temperature were measured and recorded via the probes connected to TESTO Thermo-Anemometer Model435-2. The probes were positioned at 1.1 m. height from the ground level and in the center of the indoor environment which is in strict accordance with the prescriptions of ASHRAE Standard 55 (2017) and ISO 7726 (2001). Moreover, the operative temperature, which is used to define the comfort zone in the standards, was calculated to check the compatibility of this parameter with the recommended values in the ISO 7730 (2005). Equation 1, which is given in the ASHRAE Standard 55 (2017), is used to calculate the operative temperatures.

$$T_o = A \times T_a + (1 - A) \times T_r \qquad (1)$$

In the Equation 1, T_o represents operative temperature and A is the weighting factor that is determined based on the air velocity (v_r) and is taken as 0.5 according to the ASHRAE Standard 55 (2017). The CBE Thermal Comfort tool (Hoyt et al., 2017) was used to calculate the PMV values.

Subjective Measurements

Thermal sensation, thermal satisfaction and thermal preference of occupants were obtained via a survey that was developed by the authors. Thermal sensation was assessed on the Fanger's seven-point scale, which correspond to Thermal Sensation Vote (TSV). The responses were utilized to calculate the AMV, which is the weighted average of the TSVs (Yao et al., 2010). The AMV values were evaluated against the PMV values to investigate the relationship between predicted and actual thermal sensation of occupants. Regarding thermal satisfaction and thermal preference, occupants voted among 7 options presented in Table 2. The votes of thermal preference were used to obtain occupants' preferred temperatures.

Table 1. Scales used to evaluate qualitative data.

Scale	Thermal sensation	Thermal satisfaction	Thermal preference
3	Hot	Very satisfied	Much warmer
2	Warm	Satisfied	Warmer
1	Slightly warm	Slightly satisfied	Slightly warmer
0	Neutral	Cannot decide	No change
-1	Slightly cool	Slightly dissatisfied	Slightly cooler
-2	Cool	Dissatisfied	Cooler
-3	Cold	Very dissatisfied	Much cooler

A total of 109 responses were collected. Table 3 presents the gender and age group distribution of participants.

Table 2. Distribution of gender and age groups of participants.

Subjects		#	%
Total		**109**	
Gender	Male	98	90
	Female	11	10
Age	18-24	79	73
	25-34	30	27

The checklist of clothing in the ISO 7730 (2005) was used to obtain the clothing insulation (clo) values, which were determined according to the garments that are most likely to be worn. Subsequently, the clo values were determined as 0.57 clo both for females and males. The metabolic rate of occupants was determined based on the occupants' activity levels, which are defined in the ISO 7730 (2005). The metabolic rate of occupants was determined as 1.2 met, which corresponds to office sedentary activities.

Findings and Discussion

Analyses of Objective Measurements

Descriptive statistics of indoor environmental parameters in each test per classroom as well as the reference values recommended by ISO 7730 (2005) and ASHRAE Standard 55 (2017) are presented in Table 4.

Table 3. Descriptive statistics of indoor environmental conditions.

			Indoor air temp. (°C)		**Mean radiant temp. (°C)**		**Relative humidity (%)**		**Air velocity (m/s)**		**Operative temp. (°C)**	
Classrooms	**C1**	Test 1	29.69	0.58	29.39	0.52	35.96	1.97	0.11	0.12	29.54	0.55
		Test 2	27.77	0.44	27.52	0.32	39.21	3.04	0.04	0.04	29.74	0.38
	C2	Test 3	27.38	0.43	27.21	0.36	40.38	2.66	0.01	0.02	27.3	0.39
		Test 4	29.87	0.68	29.62	0.58	43.06	2.51	0.07	0.07	27.65	0.63
Reference values	**ASHRAE Standard 55 (2017)**		22.2-26.7		-		30-60		-		24.5-27.8	
	ISO 7730 (2005)		-		-		30-70		<0.19		23-26	

The average indoor air temperatures of classrooms were above the recommended values, and, thus, they did not comply with the reference values recommended for the cooling season provided by the ASHRAE guidelines. Regarding the relative humidity, all average relative humidity levels obtained from the classrooms were within the recommended ranges provided by ISO 7730 (2005). In addition, all average air velocity values were lower than the maximum value recommended by ISO 7730 (2005).

Regarding the average values of operative temperatures, the ISO 7730 (2005) and ASHRAE Standard 55 (2017) recommend 24.5°C±1.5°C and 24.5°C-27.8°C for the cooling season, respectively. It should be noted that the range recommended by the ISO 7730 (2005) depends on the Category B ($-0.5 < PMV < +0.5$; $PPD < 10\%$) whereas the range recommended by the ASHRAE Standard 55 (2017) for typical indoor environments is calculated via graphic comfort zone method which takes into account the occupants' activity levels and clothing insulations. The results show that all average operative temperatures were higher than the range recommended by the ISO 7730 (2005) whereas only the average operative temperatures obtained for classroom 1 was higher than the range recommended by ASHRAE Standard 55 (2017).

Analyses of Subjective Measurements

The fact that buildings are operated according to the thermal comfort standards, it is expected that most of the occupants' thermal sensation is neutral. However, only 23% of occupants stated that they felt neutral whereas totaly 65% of the occupants stated that they felt slightly warm, warm, and hot. This result might be due to the fact that the average operative temperature in the classrooms were 28.56°C, which is above the recommended values by ASHRAE Standard 55 (2017) and ISO 7730 (2005). It should be noted that the occupants did not have manual control over the cooling systems in the classrooms. Furthermore, it was observed that the occupants opened neither the doors nor the windows to change the thermal environment.

The crosstab summary of thermal sensation votes and thermal satisfaction votes in Figure 3. It can be seen that half of the occupants voted slightly satisfied in slightly cool sensation. Moreover, in cool sensation, 20%, 40% and 30% of occupants voted slightly satisfied, satisfied and very satisfied, respectively. In addition, in cold sensation all of occupants voted very satisfied. These results indicated that the occupants in the classrooms are more satisfied in cool environments compared to neutral environments.

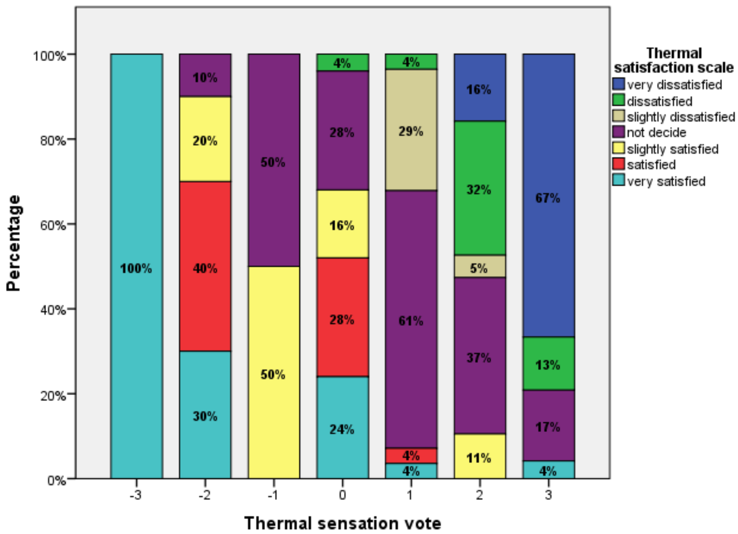

Figure 1: The crosstab summary of thermal sensation vote and thermal satisfaction vote.

The crosstab summary of thermal sensation votes and thermal preference votes are presented in Figure 4. It can be seen that 24% and 4% of the occupants preferred slightly cooler and cooler environment in neutral sensation, respectively. In addition, 70% of the occupants in cool sensation and 100% of occupants in cold sensation preferred "no change" in the environment. Moreover, 20% of the occupants in cool sensation preferred cooler environments. These results indicated that the occupants in the classrooms preferred cool environments. Other studies conducted in classrooms also indicate that students prefer cooler environments and are more sensitive to warm conditions (De Dear et al., 2015; Hwang et al., 2009; Liang et al., 2012; Trebilock & Figueroa 2014; Zomorodian et al., 2016).

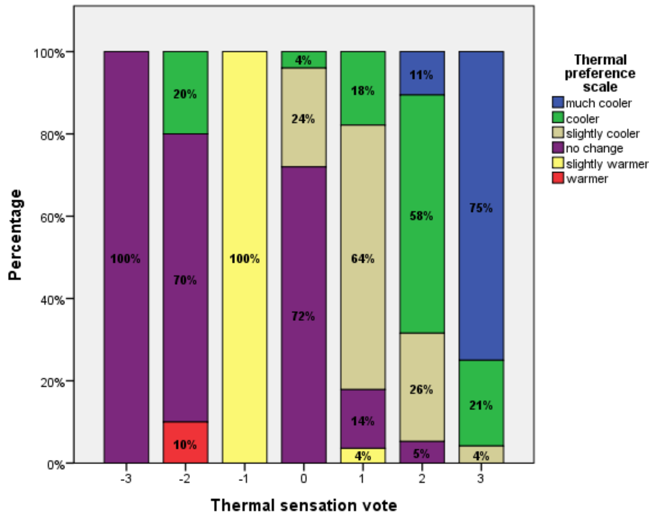

Figure 2: The crosstab summary of thermal sensation vote and thermal preference vote.

Comparison of PMV and AMV Values

The comparison of PMV and AMV values are shown in Table 5. In all tests conducted in the classrooms, the thermal comfort was found as "slightly warm" according to the PMV model. On the other hand, the AMV values in two tests conflict with the PMV model and the occupants indicated that they feel "warm" and "neutral" in tests 1 and 4, respectively. It should be noted that the average operative temperature of the classroom was 29.54°C and 27.3°C in tests 1 and 4, respectively.

Table 4. Comparison of PMV and AMV values.

		PMV		AMV	
C1	Test 1	1.33	slightly warm	1.72	warm
	Test 2	1.41	slightly warm	1.19	slightly warm
C2	Test 3	0.73	slightly warm	1.26	slightly warm
	Test 4	0.85	slightly warm	-0.35	neutral

Zhou (2008) and Cao et al. (2011) indicated that, if the indoor temperature is below or beyond the comfort zone suggested by the standards, the PMV prediction will deviate from real thermal sensation of occupants, even in an air-conditioned room. The findings of this study are also in agreement with the literature. The results obtained from Test 2 shows that average operative temperature (29.74°C) was higher than the values recommended by the ASHRAE Standard 55 (2017) and ISO 7730 (2005) and the PMV model underestimated the thermal sensation of occupants.

Neutral and Preferred Temperature

In this study, the neutral temperature is calculated by using the Griffith's method (Nicol & Roaf, 2012). This method is widely used in the field studies and is especially useful when the volume of data may not provide a reliable regression to predict the neutral temperature and the variation of temperature during the fieldwork is small, as shown in Table 4. Therefore, the neutral temperature was calculated via the following equation:

$$T_n = T_i + (0 - TS)/G$$

where T_n is the Griffith's neutral temperature, T_i is the indoor operative temperature, TS is the thermal sensation vote and G is the Griffith's slope. In the literature, three different constant G values including 0.25, 0.33, and 0.50 were investigated by Humphreys et al. (2013) and Tanabe et al. (2013). In this study, the constant G value was selected as 0.50 by taking into account the results from different studies (García et al., 2019; Leyten et al., 2013; Mustapa et al., 2016; Shahzad & Rijal, 2019). Subsequently, the equation means that in case the TSV of the respondent was not neutral, a change of 2°C is considered for every scale.

The neutral and preferred temperatures calculated via this method are shown in Table 6. It is seen that the average neutral temperature in classrooms is 26.61°C whereas the preferred temperature is 26.24°C. This indicates that the occupants preferred lower temperatures compared to neutral temperatures calculated based on thermal sensation votes.

Table 5. Neutral and preferred temperatures.

		Observed Temperature (°C)	**Neutral temperature (°C)**	**Preferred temperature (°C)**
C1	Test 1	29.69	26.25	26.06
	Test 2	27.77	25.4	25.4
C2	Test 3	27.38	24.86	24.86
	Test 4	29.87	30.57	29.09

Figure 3 demonstrates the relationships between preferred temperatures and neutral temperatures. In the figure, the regression line is highlighted in pink for whereas the solid black diagonal line represents the equality of the preferred and neutral temperatures. As can be seen, the regression line does not match the diagonal line. This result indicates that the neutral temperature is different from the preferred temperature. The following equation is obtained:

$$T_p = 0.6268 \times T_n + 9.563 \quad (R^2 = 0.66, p < 0.000) \qquad (1)$$

where T_p presents preferred temperature (°C); R^2 presents coefficient of determination; *p* presents significance level of regression coefficient. This regression equation is used to predict the preferred temperature by using the neutral temperature. For instance, when the neutral temperature is 26°C, the preferred temperature of the occupants is 25.8°C. This result suggests that when the neutral temperature is high, a lower temperature is preferred compared to the predicted one calculated based on thermal neutrality. On the other hand, when the neutral temperature is 22°C, the preferred temperature of the occupants is 23.4°C. This result suggests that when the neutral temperature is low, a higher room temperature is preferred, as compared to the assumption according to thermal neutrality. These figures also provide the indoor air temperatures that neutral and preferred temperatures are equal. The result show that the neutral and preferred temperatures are theoretically equal at 25.62°C.

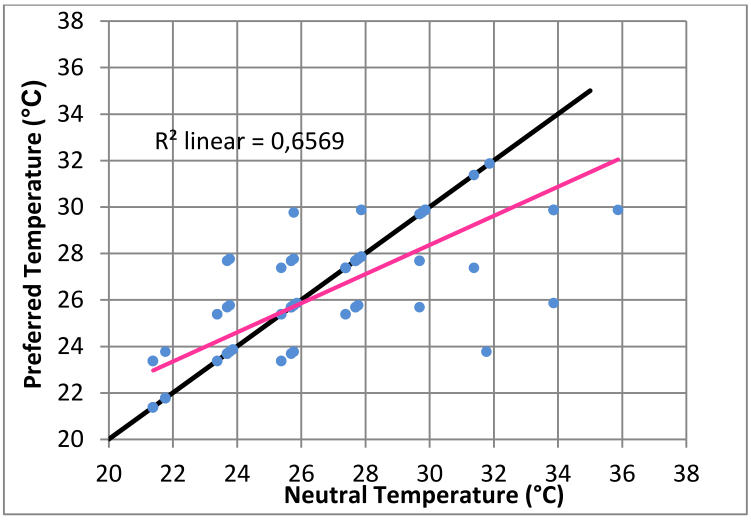

Figure 3: The relationship between preferred temperature and neutral temperature.

Zomorodian et al. (2016) indicate that the preferred temperatures were not exactly the same with the neutral thermal sensation of students. The neutral temperatures were reported 1.5–4°C lower than the preferred temperatures. The neutral and preferred temperatures that were calculated in this study also shows that preferred temperatures of occupants in classrooms were lower than neutral temperatures in the cooling season.

Conclusion

In this study, a total of 4 test campaigns, which consist of monitoring of indoor environmental conditions and surveys, were conducted in classrooms during cooling season to assess the thermal sensation and preference of occupants. In addition, the difference between the PMV and AMV values as well as neutral and preferred temperatures were analyzed. The main findings are summarized as follows:

- The average indoor air temperatures of classrooms were above the recommended values, and, thus, they did not comply with the reference values recommended for the cooling season provided by the ASHRAE guidelines
- All average relative humidity levels obtained from the classrooms were within the recommended ranges provided by ISO 7730 (2005) whereas all average air velocity values were lower than the maximum value recommended by ISO 7730 (2005).
- All average operative temperatures were higher than the range recommended by the ISO 7730 (2005).
- Occupants were more satisfied in cool environments compared to neutral environments, and, thus, their preferences were "cool environments" in the cooling season.

- It was observed that the thermal sensations found according to the PMV model and the AMV values had discrepancy in 50% of the tests.
- The preferred temperatures in classrooms in the cooling season were lower than the neutral temperatures which were calculated based on the thermal sensation votes of the occupants.
- The neutral and preferred temperatures of occupants are theoretically equal at 25.62°C.

The results show that there is a discrepancy between neutral and preferred temperatures in air-conditioned university building classrooms located in the Mediterranean climate type. Therefore, the preferred temperature can be used as one of the indices to evaluate occupants' preferences for thermal environment and a set point for heating and cooling systems. The limitations of this study are that it was carried out in an educational building and only during the cooling season. Future studies can focus on conducting this strategy for longer durations in other similar type of buildings in different seasons.

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Matlab Script for Fuzzy AHP Analysis

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Abstract

Decision-makers face many challenging issues during their careers. To improve the accuracy of decisions they made, Multi-criteria Decision Making (MCDM) plays an important role. One of the widely used MCDM methods is the Analytical hierarchy process (AHP). There are many reasons (advantages) behind the popularity of the AHP. For instance, AHP is the only MCDM method that can measure the consistency of the judgments of the experts. However, pairwise comparison is performed on a 1-9 scale in AHP methods, which in turn may cause that decision-makers can not reflect their judgments very effectively. To eliminate this drawback and to further strengthen the AHP tool, the fuzzy AHP method was introduced. Currently, various computer programs, which can perform MCDM methods, were developed such as Expert Choice and Super decision. However, any software has not been developed for the fuzzy AHP method. This reduces the exploitation of the benefits of the fuzzy AHP method by the professionals since they usually have little time for learning new methods. Thus, this study aims to develop a script in the Matlab environment that can perform fuzzy AHP analysis. The computational accuracy of the tool was tested by using the data of Işık and Aladağ (2017). *The results showed that the tool is reliable to use in the decision-making process.*

Keywords: *Fuzzy AHP tool, Matlab environment, MCDM, decision making*

Introduction and Theoretical Background

Decision-makers have to make many decisions in their professional lives. These decision-making processes usually include various sets of alternatives and the criteria for choosing one alternative over other alternatives. Here, the biggest challenge for decision-makers is deciding in the presence of the conflicting criteria. The term conflicting criteria are described as the criteria which are inversely proportional to each other. Cost and quality, for example, are the conflicting criteria. It is unlikely to have the highest quality of an alternative at the cheapest price. Thus, a decision-maker has to find the optimum alternative which best fits his/her needs. To overcome these issues and make correct decisions, Multi-criteria decision making (MCDM) has long been the focus of the decision-makers (Velasquez & Hester, 2013).

MCDM is not a method alone. By contrast, MCDM is a term used to describe the nature of decision making. Many MCDM methods exist in literature to aid decision-makers such as the Analytical hierarchy process (AHP), and Technique for Order Preference by Similarity to

Ideal Solution (TOPSIS). These methods have been applied to the integrated manufacturing systems (Putrus, 1990), evaluations of technology investment (Boucher & McStravic, 1991), water, and agriculture management (Ozelkan & Duckstein, 1996; Raju & Pillai, 1999).

The (AHP) was developed by Saaty (1980) and became one of the most popular multi-criteria decision-making methods (Kahraman et al., 2003; Rao, 2007). The method decomposes a decision-making problem into a system of hierarchies of objectives, attributes (or criteria), and alternatives. Mechanism of the AHP includes decompositions, pairwise comparisons, and priority vector generation and synthesis. The main reason behind the popularity of AHP is its ability to handle intangibles presented in any decision-making process. Computational easiness is also another advantage of the AHP. Owing to its comprehensible mathematical calculations, the AHP became widely known among the decision-makers who usually have little time to learn new methods (Javanbarg et al., 2012). Other advantages of AHP are listed as follows: (1) AHP can measure the consistency in the pairwise comparison of the experts. In this respect, AHP is unprecedented. (2) Its hierarchical structure allows decision-makers to visualize the critical aspects of a problem and ease the decision-making process; (3) the AHP can be integrated with the other operation research techniques to deal with more difficult problems; (4) Both qualitative and quantitative data can be analyzed using AHP (Durán & Aguilo, 2008; Triantaphyllou & Lin, 1996). However, on the other hand, AHP is not capable of using linguistic variables so that the experts have difficulties in reflecting their opinions on a 1-9 scale (Javanbarg et al., 2012). Although the use of the discrete scale of 1-9 for pairwise comparison helps to simplify the mathematical calculations, it reduces the effectiveness of AHP. Thus, AHP is not recommended to deal with ambiguous problems (Javanbarg et al., 2012).

The decision-making problems with a high level of complexity cannot be picturized quantitatively. However, human brains have a unique feature that can handle these problems by using imprecise knowledge rather than precise. The fuzzy set theory is capable of imitating this unique feature of the human brain. In other words, the fuzzy set theory proposed by Zadeh (1965) adopts a similar mechanism to human reasoning which can generate decisions using approximate and uncertain information. The fuzzy set theory can make a mathematical representation of the uncertainty and vagueness to provide a formalized tool for dealing with the imprecision. In other words, the fuzzy set theory can eliminate the vagueness of human thought. The traditional computing methods, however, cannot provide reliable solutions when certain and precise knowledge is not available. Thus, the fuzzy set theory paved the way for the solution to many engineering problems owing to that knowledge can be expressed more naturally by using fuzzy sets. Fuzzy set theory is not a single method than can be used to solve decision-making problems. Any crisp method or theory could be fuzzified to improve the method's ability to deal with vagueness. Any fuzzified methodology is stronger to solve real-world problems since some degree of imprecision and noise exist in almost all real-world problems. Besides, the use of linguistic variables is another benefit of the fuzzy logic application, where linguistic variables such as "large," "medium," are used rather than the number (E.g. Likerts' scale) (Kahraman et al., 2003). For instance, respondents can reflect his/her judgment better in comparison with the numbers. Thus, fuzzy AHP, a fuzzy extension of the AHP, was developed to overcome the abovementioned drawbacks of AHP by Chang (1996). Both AHP and fuzzy AHP methods are used to capture experts' opinion, however, fuzzy AHP handles the impreciseness of the humans' judgments in a more effective way than the conventional AHP (Ayhan, 2013).

Currently, a wide range of computer tools allows users to perform MCDM methods such as Super decision and Expert Choice. However, although its above-mentioned benefits, there has not been any software for fuzzy AHP analysis yet. As a result, decision-makers cannot exploit the benefits of fuzzy AHP methods. Therefore, this paper aims to develop an open-source fuzzy AHP script to ease the application of fuzzy AHP for both professionals and academics. To do this, a set of functions wrapped in a toolbox designed to perform fuzzy AHP analysis is presented. The main benefit of this script is that users can perform the fuzzy AHP analysis without getting drowned in the mathematical background of the method.

In the remaining part of this paper, the mathematical background and the architecture of the script are presented in the next section. In section 3, the validation of the tool is presented while the conclusion is presented in section 4.

Methodology and Software Architecture

In this section, the methodology followed by the script, and the architecture of the software will be presented. The script was designed as a console system, therefore the users should have basic Matlab knowledge. The script has three modules named consistency, fuzzification, and fuzzy AHP. When the code is run, a dialogue box appears on the screen and the user enters which module he or she wants to use. Then, only the specific module stated by the user runs.

Consistency Ratio Module

This module of the script calculates the consistency of the pairwise comparison matrix prepared by the experts. To calculate the consistency, firstly all matrices should be imported as a variable to the workplace of the Matlab. When the consistency module is operated, it is asked from the user to insert the number of the matrices that are desired to check. Then, the name of each matrix (or variable) is entered by the user and the system creates variable "report" and summarizes the consistencies of all matrices.

The methodology proposed by Saaty (1980) was adopted and the steps of the calculation are as follows.

The C.I of a matrix are calculated by using Eqns (1) and (2):

$$C.I. = \frac{\lambda_{max} - n}{n - 1}; \quad (1)$$

$$C.R = \frac{C.I.}{R.I.} \quad (2)$$

Where: λ_{max} is the largest Eigenvalue of the comparison matrix, n is the dimension of the matrix, and R. I. is the random consistency index of the matrix chosen from Table 1.

The codes of the consistency module are given in Table 2.

Table 1. R. I. of random matrices (Xu, 2000).

n	1	2	3	4	5	6	7	
RI	0	0	0.52	0.89	1.12	1.26	1.36	
n	8	9	10	11	12	13	14	15
RI	1.41	1.46	1.49	1.52	1.54	1.56	1.58	1.59

Table 2. The codes of consistency ratio module.

The codes of the module

```
switch func
   case 'c'
%Consistency index
r=inputdlg('Please insert the number of matrices to be checked');
r=cell2mat(r);
r=str2num(r);
RItable=[0 0 0.58 0.9 1.12 1.24 1.32 1.41 1.45 1.49 1.52 1.54 1.56 1.58 1.59];
for x=1:r
   variable=inputdlg('Please insert the name of the variable');
   variable=string(variable);
[~, a]=size(evalin('base',variable));
eigenmax=max(eig(evalin('base',variable)));
CI=(eigenmax-a)/(a-1);
RI=RItable(1,a);
CR=CI/RI;
Report(x,1)=CR;
end
warndlg('Check variable "Report"')
```

Fuzzification Module

Fuzzification is the first step of the fuzzy AHP analysis. The respondents prepare the pairwise comparison matrices by using linguistic variables. Then, linguistic variables have to be converted to the 1-6 scale and the new matrix should be inserted into the script. The script re-arranges the matrix by using fuzzy numbers. In other words, the script fuzzifies the matrix. As a final step, the script saves the new matrix under the specific name entered by the user. It should be noted that each matrix should be inserted into the system individually. The system completes the fuzzification process by using the triangular fuzzy scale shown in Table 3.

Table 3. Triangle fuzzy scale (derived from Chang (1996))

Preferences expressed	Numeric	Triangle	Triangle fuzzy
Just Equal	1	(1, 1, 1)	(1, 1, 1)
Equally Important	2	(1/2, 1, 3/2)	(2/3, 1, 2)
Weakly Important	3	(1, 3/2, 2)	(1/2, 2/3, 1)
Strongly More	4	(3/2, 2, 5/2)	(2/5, 1/2, 2/3)
Very Strongly More	5	(2, 5/2, 3)	(1/3, 2/5, ½)
Absolutely More	6	(5/2, 3, 7/2)	(2/7, 1/3, 2/5)

The codes of the fuzzification module are shown in Table 4.

Table 4. The codes of the fuzzification module

The first section of the code

```
 case 'f'
warndlg('Name of the variable should be "Decisionmaker"')
[~, r]=size(Decisionmaker);
fuzz=[1 1 1];
for x=1:r
   z=1;
   for y=1:r
     if Decisionmaker(x,y)==1
        fuzz(x,z)=1;
        z=z+1;
        fuzz(x,z)=1;
        z=z+1;
        fuzz(x,z)=1;
        z=z+1;
     elseif Decisionmaker(x,y)==2
        fuzz(x,z)=0.5;
        z=z+1;
        fuzz(x,z)=1;
        z=z+1;
        fuzz(x,z)=1.5;
        z=z+1;
     elseif Decisionmaker(x,y)==3
        fuzz(x,z)=1;
        z=z+1;
        fuzz(x,z)=1.5;
        z=z+1;
        fuzz(x,z)=2;
        z=z+1;
     elseif Decisionmaker(x,y)==4
        fuzz(x,z)=1.5;
        z=z+1;
        fuzz(x,z)=2;
        z=z+1;
        fuzz(x,z)=2.5;
        z=z+1;
     elseif Decisionmaker(x,y)==5
        fuzz(x,z)=2;
        z=z+1;
        fuzz(x,z)=2.5;
        z=z+1;
        fuzz(x,z)=3;
        z=z+1;
     elseif Decisionmaker(x,y)==6
        fuzz(x,z)=2.5;
        z=z+1;
        fuzz(x,z)=3;
        z=z+1;
        fuzz(x,z)=3.5;
        z=z+1;
```

The second section of the code

```
     elseif Decisionmaker(x,y)==0.5
        fuzz(x,z)=0.66;
        z=z+1;
        fuzz(x,z)=1;
        z=z+1;
        fuzz(x,z)=2;
        z=z+1;
        elseif Decisionmaker(x,y)==1/3
        fuzz(x,z)=0.5;
        z=z+1;
        fuzz(x,z)=0.66;
        z=z+1;
        fuzz(x,z)=1;
        z=z+1;
        elseif Decisionmaker(x,y)==1/4
        fuzz(x,z)=0.4;
        z=z+1;
        fuzz(x,z)=0.5;
        z=z+1;
        fuzz(x,z)=0.66;
        z=z+1;
        elseif Decisionmaker(x,y)==1/5
        fuzz(x,z)=0.33;
        z=z+1;
        fuzz(x,z)=0.4;
        z=z+1;
        fuzz(x,z)=0.5;
        z=z+1;
        elseif Decisionmaker(x,y)==1/6
        fuzz(x,z)=0.285;
        z=z+1;
        fuzz(x,z)=0.33;
        z=z+1;
        fuzz(x,z)=0.4;
        z=z+1;
     end
   end
end
name=inputdlg('Insert the ID of the decisionmaker that you
want to save','s');
name=string(name);
save(name,'fuzz');
```

Fuzzy AHP Module

This is the last module of the system. To operate this module, firstly all fuzzified matrices of the decision-makers should be imported to the workspace. However, this module requires a specific naming convention for the analysis. For instance, the matrix of the first decision-maker should be named DM1 and the others should be named DM2, DM3 …., and DMX respectively. The system aggregates all of the matrices by using the geometric mean (Rao, 2007). Then, the fuzzy AHP analysis starts.

Chang's extent analysis method was followed in the development of this script. This method was used to find the weights of each criterion. Chang's (1996) extent analysis provides a general method of using crisp mathematical concepts to address fuzzy quantities. The codes of the system are given in Table 5.

Table 5. The codes of the fuzzy AHP module

The Codes of the module

```
%Aggregationofdecisionmatrix
%load all the variables
   case 'fa'
num=inputdlg('Insert the number of respondents');
num=cell2mat(num);
num=str2num(num);
%Enter the name of each variable below.
Decisionmatrix=(DM1.*DM2.*DM3.*DM4.*DM5.*DM6.*DM7.*DM8.*DM9.*DM10.*DM11.*DM12.*DM13.*DM14.*DM15).^(1/num);

%Calculation OF S_value
[r, c]=size(Decisionmatrix);
y=1;
totaltotal_l=(1);
totaltotal_m=(1);
totaltotal_u=(1);
total_l=(1);
total_m=(1);
total_u=(1);
for x=1:r
total_l(1,x)=sum(Decisionmatrix(:,y));
y=y+3;
end
totaltotal_l=sum(total_l);
total_Mg_l=(1);
y=2;
for x=1:r
total_m(1,x)=sum(Decisionmatrix(:,y));
y=y+3;
end
totaltotal_m=sum(total_m);
y=3;
for x=1:r
total_u(1,x)=sum(Decisionmatrix(:,y));
y=y+3;
end
totaltotal_u=sum(total_u);
%total_Mg Values
for z=1:r
   y=1;
   total_Mg_l(z,1)=0;
   for x=1:r
  total_Mg_l(z,1)=total_Mg_l(z,1)+Decisionmatrix(z,y);
  y=y+3;
   end
end
total_Mg_m=(1);
for z=1:r
   y=2;
   total_Mg_m(z,1)=0;
   for x=1:r
  total_Mg_m(z,1)=total_Mg_m(z,1)+Decisionmatrix(z,y);
  y=y+3;
   end
end
total_Mg_u=(1);
for z=1:r
   y=3;
   total_Mg_u(z,1)=0;
   for x=1:r
  total_Mg_u(z,1)=total_Mg_u(z,1)+Decisionmatrix(z,y);
  y=y+3;
   end
```

The Codes of the module

```
end
%Synthetic Values
total_Mg=[total_Mg_l total_Mg_m total_Mg_u];
Svalues=[total_Mg_l/totaltotal_u total_Mg_m/totaltotal_m total_Mg_u/totaltotal_l];
d=(1);
for y=1:r
   for x=1:r
      if Svalues(y,2) >= Svalues(x,2)
         d(y,x)=1;
      else
         d(y,x)=(Svalues(x,1)-Svalues(y,3))/((Svalues(y,2)-Svalues(y,3))-(Svalues(x,2)-Svalues(x,1)));
      end
   end
end
Weights=(1);
for x=1:r
   Weights(x,1)=min(d(x,:));
end
Sumall=sum(Weights);
Normalized=Weights/Sumall;
warndlg('Check variable "Normalized"')
end
```

Validation of The Tool

The computational accuracy of the tool is tested by using the data given in Işık and Aladağ (2017). It should be noted that results of Işık and Aladağ (2017) is based on excel sheet developed by the authors. In their study, the authors provided the aggregated decision matrix of the data set. Thus, this aggregated decision matrix was inserted into the tool, and the tool expected to provide the same results as the Işık and Aladağ (2017). Table 6 includes both the results of the Işık and Aladağ (2017) and the output of the script. Table 6 reveals that the accuracy of the script is impressive.

Table 6. Comparison between the result of both Işık and Aladağ (2017) and the script

	A_1	A_2	A_3	A_4	A_5	A_6
Results of Işık and Aladağ (2017)	0.043	0.155	0.077	0.275	0.265	0.185
Results of the script	0.0429	0.1547	0.0768	0.02746	0.02655	0.1855

Limitations of The Tool

Every study has its limitations such as bias, variance, timing, or even problems originated from the research process. This study is not an exception. Thus, the potential limitations of this study are listed as follows:

1- User intervention is required to operate the system. Thus, the user has to know basic Matlab knowledge. Therefore, the user interface might be developed to improve user-friendliness.

2- Matlab is not open-source software. Thus, the user has to pay the exact amount of license fee. To prevent this, the script could be re-coded in open-source programming languages such as Phyton.

Conclusions

In this research, it is attempted to develop a Matlab script that can perform fuzzy AHP analysis. The system has three modules. These modules are the consistency module, fuzzification module, and fuzzy AHP module, respectively. The consistency module works with the principles established by Saaty (1980). The user should insert all matrices whose consistency will be checked. When the module is operated, the system asks the number of the matrices to be checked. Then, the user inserts the name of each matrix via a dialogue box. The consistencies of each matrix are presented in the variable named "Report". The second module is the fuzzification module. In practice, the expert's judgments are collected through a questionnaire. If the fuzzy theory is adopted, the respondents fill the pairwise comparison matrix by using the linguistic variables. However, linguistic variables later should be re-arranged with the triangular fuzzy numbers. The fuzzification module performs this convention. In other words, the output of the fuzzification module is the fuzzified decision matrix. The third and the last module of the tool is the fuzzy AHP module. This module performs the fuzzy AHP analysis and calculates the normalized weights of each criterion and the sub-criteria and the alternatives. The output of this module is validated by comparing the results of an article with the results of the script. The validation results showed that the computational accuracy of the tool is at the desired level.

This study provides significant contributions to the engineering practice since professionals and academics who want to exploit the unprecedented benefits of the fuzzy AHP can use this tool and perform the fuzzy AHP analysis without dealing with the mathematical background of the method.

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Lean Construction Scheduling

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Abstract

Lean is a philosophy that should be applied systematically and integrally to all the processes in an organization to attain best performance. Lean construction is the application of lean concepts, tools and techniques to design and construction. The tools used for project management on construction sites mainly focus on planning. As the construction progresses, construction schedules require changes due to unpredicted events and uncertainty both in duration and variation. The difference between actual and planned time, quantity or rate is caused by variability and uncertainty in construction projects. Lean construction scheduling focuses on improving plan reliability by generating constraint free tasks and short term plans to address the problem of 'separation of execution from planning'. This paper presents a review of studies on lean construction scheduling.

Keywords: *construction schedule, last planner, lean construction.*

Introduction

Lean methodology was created in manufacturing industry, in Japan, for the purpose of improving production performance. Lean production system used less human effort, less time in product development while generating higher quality, less inventory, and higher variety of products. In lean methodology, system is viewed as a whole and focus is on improving relations between parts rather than individual areas (Womack et al., 1990).

Lean is a philosophy that should be applied systematically and integrally to all the processes in an organization to attain best performance. Lean is also viewed by many as a goal, as a constant change process and as a set of tools and techniques. Its implementation changes the way an organization operates, welcoming change and striving for continuous improvement in processes, products or services, more than just simply eliminating waste which is any process that does not add value to the customer (Stern, 2017; Liker, 2004).

Although lean methodology was created in manufacturing industry, these principles were also adapted to other industries. Construction industry, criticized for being wasteful, unsafe and inefficient, is project oriented and focuses on meeting budget, schedule, quality and safety goals (Mehany, 2015; Tezel & Nielsen, 2013). Lean construction goes beyond these goals to improve the overall process by adding value to the customer and reducing waste and risk (Mehany, 2015).

Koskela challenged the construction industry in 1992 by studying the adoptability of a manufacturing concept to construction and project delivery (Cesarotti et al., 2019). Core principles underlying the philosophy are: eliminating waste and variability, defining value from clients' perspective, defining the value adding and non-value adding activities, making the value adding steps flow uninterruptedly, making what the client pulls quickly and when it is needed, and continuously improving for pursuing perfection (Tezel et al., 2020).

Collaboration is critical in lean approach. Strategies like Last Planner depend on commitments from all project team partners for reliability and improvement. Exchanging and analyzing data is critical to collaboration. Teams discuss their understanding of the work and how their work is related to the others'. As project proceeds the plan is reviewed regularly so any new available information or added design is implemented in the plan and the tasks that no longer add value are eliminated (Dave et al., 2013). Main features required from a lean scheduling system are flow, integration between planning levels and value generation (Dave et al., 2015).

In the following sections lean construction scheduling will be explained in detail as concept, compared to traditional methods, implementation, challenges and benefits, and social aspect.

Lean Construction Scheduling

The tools used for project management on construction sites mainly focus on planning (Gurevich & Sacks, 2014). Construction work is generally planned by specifying activities, their durations, their assigned resources and forming dependency relationships between these activities. When executed, these activities are expected to start at the earliest time possible with the assumption that all resources assigned to them will be available. However, as the construction progresses, construction schedules require changes due to unpredicted events and uncertainty both in duration and variation. Therefore, rather than using the traditional push driven approach in construction scheduling, a pull driven approach that aims to produce products in an optimum time, optimum cost and optimum quality improves the performance of construction process (Tommelein, 1998).

Concept

As the time between planning and implementation increases, so does the variance of actual schedule and budget. Planning activities to be executed more than 3 months into the future is useless because of uncertainties and variations (Winch & Kelsey, 2005). The difference between actual and planned time, quantity or rate is caused by variability and uncertainty in construction projects (Sacks & Harel, 2006). Lean construction scheduling focuses on improving plan reliability by generating constraint free tasks and short term plans to address the problem of 'separation of execution from planning' (Dawood & Sriprasert, 2006). Main purpose is delivering value while waste is eliminated. (Mossman, 2009).

Lean Construction Scheduling vs. Traditional Methods

Construction scheduling is generally done by computer tools that use critical path method. However, these schedules are not adequate for production planning and control since they do not consider the availability of a resource. Therefore, field workers prepare their own work plans which usually consist of work to be done, people, equipment and material assignments (Tommelein, 1998).

A general criticism of traditional construction planning is that the practice focuses on management of contracts and costs instead of production processes (Dawood & Sriprasert, 2006). Traditional method is found to be ineffective for production level planning and control and communicating with the site team about planning activities (El-Sabek & McCabe, 2018).

One of the weaknesses of traditional methods is the assumption that prerequisites of each work package will be available at the time the work is scheduled to start (Sacks et al., 2007). However, for a reliable work plan, constraints should be considered and removed before starting any task, most common of them being design, materials, prerequisite work, space, equipment, labor, plan and contract constraints (González et al., 2010).

Traditional systems view the project as a combination of activities where as lean systems view the entire project as a temporary production system. Waste, variability and collaboration are the three features that separate lean from traditional systems (Ghosh & Burghart, 2019). Lean construction scheduling methods are used for improving production control as they support faster response and reduced uncertainty and constraints (Olivieri et al., 2019).

Methods Developed

Many professionals start practicing lean construction by implementing Last Planner system (Alves & Tsao, 2007). Last Planner, which is the most well-known planning and control system in lean construction tools, attempts to resolve unseen constraints and eliminate uncertainties to improve work plan reliability by employing pull flow (Chua & Shen, 2005; Sacks & Harel, 2006).

The Last Planner System of Production Control, established by Glenn Ballard and Greg Howell, is a pull system where materials or information is allowed into a production process only if the process is capable of doing that work as opposed to a push system where inputs are pushed into the process based on a target completion or delivery date. Last planner system is based on 4 fundamental concepts: should, can, will, did. Should sets the goals, can solves constraints, will stands for what is scheduled and did stands for what is executed (Ballard, 2000; Zegarra & Alarcon, 2017). This system is a pull technique that eliminates overproduction waste. It is a creative process so it is a form rather than a formula. Process starts from the first principle every time and is done collaboratively, involving the workers in the work planning since they are the ones that create value for the customer (Mossman, 2009).

Last Planner starts with a master plan which is the long term initial project plan that identifies overall execution strategy for the project. Based on targets from the master plan, a more detailed and manageable phase schedule is formed. Then the master plan or phase schedule is detailed to create medium term look ahead plan that pulls the resources into planning process.

Look ahead plan shows the work to be done in a time frame such as six weeks. Look ahead plan is more than just task breakdown, it involves making work ready and if not implemented correctly, affects the end result. After that short term work plan is generated for scheduling of the work that will be done on-site, activities are only committed to the work plan if they can be performed, based on the evaluation of specific field conditions (Gonzalez et al., 2008; Song & Liang, 2011; Hamzeh et al., 2015; Gonzalez et al., 2015). Plan reliability is measured by a lean construction metric called percent plan complete which is calculated as completed weekly scheduled tasks divided by total weekly scheduled tasks (Mitropoulos & Nichita, 2010).

Effective implementation of the Last Planner improves production performance and reliability while the workflow variability is decreased. It assist in collaborative planning and improves teamwork and proves to be dynamic method that provides forward information for control (Alsehaimi et al., 2014). Implementation results in increased productivity, shortened durations and cost savings (Russell et al., 2015).

Workplan is a method developed by Choo et al. that adopts Last Planner and leads users through stages of establishing a quality weekly work plan that represents an element of a more detailed master schedule. Work packages have constraints that should be satisfied for them to be carried out. The constraints of a work package consist of contract constraints, engineering constraints, material constraints, labor and equipment constraints and prerequisite work and site conditions. Work package is released for construction after all the constraints are satisfied. Workplan guides users through the steps of the planning process that helps the users to work more accurately(Choo et al., 1999).

Chua et al. developed Integrated Production Scheduler, a constraint based planning tool that also handles resource and information constraints in addition to the process constraints. This model is said to simplify collecting data and reduce inconsistencies in work plans (Chua et al., 2003).

Sriprasert and Dawood (2003) developed multi-constraint modelling which is a collaborative, multi-constraint considering construction planning methodology that effectively handles uncertainty.

Choo et al. (2004) developed DePlan which is an integrated approach in design management that has the operational approach of Last Planner. DePlan consists of design planning, scheduling and control.

Dawood and Sriprasert (2006) proposed LEWIS- Lean Enterprise Web-based Information System, a ‘multi-constraint scheduling’ method, rooted in the Last Planner, concerning four major types of construction constraints which are physical, contract, resource and information. They developed a multi constraint genetic algorithm application in MS Project and obtained a near optimum constraint-free schedule.

Björnfot and Jongeling (2007) proposed the application of line-of-balance scheduling in combination with 4D CAD model as a method to improve work flow management. Line-of-balance technique is resource oriented as opposed to critical path model which is activity oriented. In line-of-balance method, project is broken down in physical sections and location is considered as a dimension for simpler planning of continuous resource use. 4D CAD models link activities with 3D CAD models and allows project parties to visualize and simulate work before it is executed on site. Implementation of the model helps uncover potential problems.

Sacks et al. (2010) proposed a Building Information Modelling enabled system based on Last Planner, called KanBIM to support production planning and control on construction sites. It is a software system that provides 3D visualization of process status which increases reliability and decreases variability while enabling real time feedback. Use of KanBIM eliminated substantial amount of waste and improved workflow resulting in improved productivity (Gurevich & Sacks, 2014).

Construction Owners Association of Alberta developed Workface Planning which has become a contractual requirement on most of the industrial construction projects in Alberta, Canada. Main aim of Workface Planning is to deliver all necessary resources to the right places and people at the right time to avoid cost overruns and delays and to keep onsite supervision team away from time consuming tasks to help them focus on supervising their crews. Workface Planners help superintendents to divide works into more manageable installation work packages, sequence and integrate these packages into the project schedule, align resources and remove constraints for executing these work packages and provide support in executing and controlling the installation work packages. At the end of the projects, lessons learned are documented to enable continuous improvement (Fayek & Peng, 2013).

Kim and Kim (2014) presented a computerized integrated project management system whose foundation is a scheduling system that adopts lean construction principles. Material management is linked to a detailed production plan and the system which follows the Last Planner, integrates manpower/equipment management and safety/environment/quality information. Implementation of the system increased productivity and accurate schedule planning ability while reducing demand variability, material inventories and supplier lead time.

Heravi and Rashid (2018) developed a lean construction plan based on waste elimination. Appropriate lean construction techniques were used to reduce specified non-value added processes and Last Planner method was improved using critical chain method as a component of the developed plan. The performance of the studied project was shown to improve 19% by implementation of the developed lean construction plan.

Implementation

Implementation of a lean construction scheduling system is a very challenging and complex process because it does not just depend on the method itself but also how the implementation is organized (Mäki et al., 2020). Last Planner, although really effective implementing tool, requires significant support for project teams by dedicated facilitators over the long term which is difficult to maintain.

A key step in implementation is constraint analysis on planned activities. Work plans are susceptible to uncertainties caused by unresolved constraints which could be anything that hinders performance (Chua & Shen, 2005). Construction constraints can be grouped as: physical constraints, contract constraints, resource constraints and information constraints

(Sriprasert & Dawood, 2003). Hamzeh et al. (2012) propose that for proper implementation of look ahead planning, tasks should be broken down into level of processes and then level of operations, constraints should be identified and removed for making tasks ready for execution and operations should be designed through first run studies. Successful implementation depends on top management commitment and training of staff and workers (Salem et al., 2005).

Challenges and Benefits

Lean construction scheduling is a collaborative process so it involves many parties so low understanding of the concept, language issues and weak communication are some of the barriers of implementation. Implementation challenges include lack of training, lack of management commitment, resistance to change, contractual issues and partial or late implementation (Lindhard & Wandahl, 2015).

According to Sacks et al. (2007) lean construction scheduling is better at meeting needs of the customers than traditional approach since pull flow eliminates rework, work in progress is reduced and dependence between work teams are removed. Benefits associated with implementation of lean construction include reduction in waste, schedule, cost, risk, and workflow variability, improvement of efficiency, quality, processes, inventory control, project delivery method, health and safety, supplier relationship and stakeholder cooperation, increase in labor productivity and performance and employee satisfaction, generation of better customer value, reliability and profitability (Babalola et al., 2019; Forbes & Ahmed, 2011; Sarhan et al., 2017).

Human Factor and Social Aspects

Lean construction scheduling is a collaborative process so social interaction is required. Human is an important factor and system works on mutual commitments. Slivon et al. (2010) list commitments as a category of participants in the construction process. Commitments are composed of design and specifications, agreements, decisions, instructions and external conditions-socially constructed reality and as the teams work to fulfill these commitments they build trust with each other. With the trust, reliability and chances of success increases.

Priven and Sacks (2015) studied twelve residential projects to measure the impact of the Last Planner and found that implementation of the system strengthens social networks and communication. It results in establishment of social network connection in different groups where no or little connection would have been established without it.

Viana et al. (2017) propose that the main reason for success of the Last Planner is the way it manages commitments. Mutual understanding is important in successful management. Ghosh et al. (2019) studied social interaction patterns of participants of two construction projects, one implementing the traditional system (A) and the other one implementing the Last Planner (B). Participants of project B had a higher shared understanding about the project, were more cooperative, had higher level of trust in each other and had higher involvement in decision making. Exchange of commitment was seen to be an important component of project B.

Conclusion

Lean construction scheduling methods are used for improving production control as they support faster response and reduced uncertainty and constraints. Last Planner is the most well-known and powerful planning and control system among all lean construction tools. Many other lean construction schedules that are developed follow the Last Planner. Lean construction scheduling is a collaborative process so social interaction and human is an important factor and system works on mutual commitments. As participants work to fulfill these commitments they build trust with each other. With the trust, reliability and chances of success increases.

Success of lean construction schedules comes from two way communication and the way the commitments are managed. Implementation of a lean construction scheduling system is a very complex process because it does not just depend on the method itself but also how the implementation is organized (Mäki et al., 2020). There is not a formula for adopting a lean scheduling technique and every project is unique. Therefore there are many researches about implementation, supporting tools and metrics to measure the reliability and performance of the system adopted. Applying lean construction scheduling results in cost savings, increased work quality, reduced project time and less inventory and rework (Khanh & Kim, 2016).

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Development of Renewable Energy Projects in Highway Rights-of-Way: The Turkish Experience

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Abstract

Renewable energy projects are of critical importance for Turkey in terms of reducing dependence on foreign energy and constitute one of the most important elements of sustainable development. The main purpose of this research was to complete the basic scientific work required for the selection, development, and implementation of the most suitable renewable energy projects that will provide high added value in the highway rights-of-way (ROW) in Turkey. In this paper, national and international renewable energy project practices in the highway ROW are analyzed and examined. Analyzing renewable energy projects introduced in this paper integrate all of the research findings from the literature review, survey of Departments of Transportation, face-to-face interviews, and case studies of select projects leading to the development of the Renewable Energy Project Feasibility Analysis Tool. This tool, aimed for the use of the decision makers in highway agencies, provides a list of technical, financial, and environmental criteria that play an important role in choosing and implementing new renewable energy projects in highway ROW. Finally, this paper provides examples of suitable locations for renewable energy projects in the highway ROW in Turkey determined using the Renewable Energy Project Feasibility Analysis Tool developed in this research.

Keywords: *Rights-of-way, Renewable energy***,** *Feasibility Analysis Tool.*

Introduction

There is an increasing energy requirement in the world and meeting this need with non-renewable energy sources causes serious environmental problems; furthermore, these non-renewable energy sources are not sustainable at all and will become unable to meet the need in the near future (Petroleum 2019). Obtaining energy from sustainable resources such as sun and wind through renewable energy projects is also of critical importance for Turkey in terms of reducing dependence on foreign energy, and constitutes one of the most important elements of the nation’s sustainable development. Building on this background statement, the main purpose of this research is to complete the basic scientific work required for the selection, development, and implementation of the most suitable renewable energy projects that will provide high added value in the highway rights-of-way (ROW) in Turkey.

Benefits that could be realized from implementing renewable energy projects in highway ROWs include (i) adding value to empty, unutilized pieces of land in the highway system, (ii) providing additional revenues and cost savings to highway agencies, (iii) ensuring energy security by diversifying energy production, (iv) accelerating the transition to renewable energy as a country, and (v) increasing public interest in renewable energy.

Renewable energy projects for highway ROW are not applicable under all geographic and financial conditions. The primary objective of this research was to develop a Renewable Energy Project Feasibility Analysis Tool for decision makers in highway agencies and to determine example opportunity zones in Turkey where renewable energy projects could be applied to extract added value from highway ROW. The development of the proposed analysis tool included analysis of financial and technical criteria for different renewable energy project types in the highway ROW including solar energy, wind energy, and biomass energy. To achieve this objective, the research was conducted in three phases. Phase-1 established the state-of-practice of renewable energy project in highway ROW through data collection by using literature review, interview survey, and case studies of select projects. In Phase 2, the proposed renewable energy project feasibility analysis tool was developed for solar photovoltaic (PV), wind energy, and biomass energy, separately. Finally, using the developed feasibility analysis tools, a few opportunity zones for application of renewable energy projects in highway ROWs of Turkey were determined in Phase 3.

Phase 1: Analysis and Examination of Renewable Energy Project Practices in the Rights of Way

The goal of Phase-1 was to compile all the relevant data on the application of renewable energy projects in the highway ROWs. To achieve this goal, a comprehensive literature review was conducted. Later, a questionnaire survey was conducted to gather information about projects that are not in the literature yet or are in the beginning stage. Besides, information on select, successful projects was collected through case studies. The following sections provide brief information on the results of the literature review, questionnaire survey, and case studies.

Literature Review

The literature review was conducted by reviewing published consultancy reports, documented research and and other publications found through the Internet and in academic journals. Below are the most important findings of the literature review
.

- The United States, Germany and Switzerland are leading the development of renewable energy projects in highway ROWs.
- Solar energy is the most widely used renewable energy type in highway ROWs. Solar energy is followed by wind energy.
- Although the number of projects has steadily increased in the last 10 years, the energy produced by such projects is still very limited. For example, the electrical energy obtained through the use of renewable energy sources is at most 10-15% of the total energy need of highways in most countries.
- In the United States, especially Oregon, Ohio, Massachusetts are the leaders in the use of renewable energy in the highway ROWs. The type of energy used in these states is mostly solar energy. Solar energy is generally produced by panels installed in empty spaces on the side of the highway or the roofs of the DOT (Department of Transportation) buildings on the roadside. Small-scale wind turbines installed in the

highway ROW to generate wind energy and planting in the highway ROW to produce biofuels are other examples of producing renewable energy in the highway ROWs in the United States (Ponder et al. 2011; Proudfoot et al. 2015; Tuz 2010).

- In Europe, especially in Germany and Switzerland, the use of renewable energy in the highway ROW is achieved by solar energy panels mounted on the sound barriers (Bayraktar et al. 2013; Poe et al. 2017).
- In Turkey, the use of renewable energy projects in highway ROWs is very limited as only two fully implemented examples were identified including one in Izmir and one in Hatay-Kisikli area.

Questionnaire Survey

Pilot projects that are in their initial stages or have not yet been announced to the public for any reason are common, especially in rapidly developing areas such as the use of renewable energy. For this reason, in order not to skip any renewable energy projects implemented in highway ROW, a questionnaire was developed for national and international transport organizations. The questionnaire form consisted of two parts: *A) "Contact Information" and B) "Your Institution's Experiences Regarding Renewable Energy Projects Implemented in highway ROW."* In the contact information section, information such as name, title/profession, institution, telephone number, and e-mail address were requested from the participant. In the second part of the questionnaire, "*Your Institution's Experiences Regarding Renewable Energy Projects Implemented in highway ROW,"* the following three questions were directed to the participants about the alternative use of renewable energy projects in the highway ROW.

1. Has your agency implemented any value extraction strategy/alternative use of the highway rights-of-way to generate revenue or offset expenditures?
2. Is your agency currently exploring/considering the implementation of any value extraction strategy/alternative use of the highway rights-of-way to generate revenue or offset expenditures?
3. Has your agency explored/considered the implementation of any value extraction strategy/alternative use of the highway rights-of-way in the past, but decided not to proceed?

A total of 14 answers, 7 (seven) international, and 7 (seven) national, were collected for the survey. 6 (six) of the answers in the international part of the questionnaire came from the United States, and one was from Germany. Within the scope of the national survey study, face-to-face interviews were also conducted with employees in different units in the General Directorate of Highways (Ankara), the 1st Regional Directorate of Highways (Istanbul), and 2nd Regional Directorate of Highways (Izmir). To summarize the findings of the survey study, international answers mainly highlighted use of solar energy and wind energy in parallel with the findings of the literature review. Also, the light-emitting diode (LED) technology and electric vehicle charging station applications in highway ROW were stated as value extraction projects related to the subject of renewable energy.

In the national questionnaire survey, a total of 5 out of 7 that participated in the survey indicated "No" in their response to the first question. A person who answered "Yes" indicated solar-powered flashers as an example of renewable energy applications. The same person reported the biggest problem of Turkey was to be faced with incidents of theft in some areas. The other person who answered "Yes" mentioned about the 1 MW Highways Çesme Solar Photovoltaic (PV) Technology project, which was implemented in Cesme in 2017 by the 2nd Regional

Directorate of Highways. In the second question, only one person answered "Yes". This person stated that they have started to work on a lighting system based on wind or solar energy to illuminate the Korutepe and Gultepe highway tunnels located within the borders of Kocaeli with renewable energy sources. The most important result of the national questionnaire survey is that there is a very limited number of projects (in service or in the planning stage) to generate renewable energy in highway ROWs.

Case Studies

The purpose of the case studies was to collect additional detailed qualitative and quantitative data on the high-priority project types identified through literature review. The collected data were combined with the information collected through literature review and survey of transport agencies to develop the proposed renewable energy feasibility analysis tools. In execution of the case of studies, each project was analyzed with respect to **(i)** technical issues (size, location, positioning, security, etc.), **(ii)** economic issues (revenues, costs, financing model, incentives, etc.), and **(iii)** social issues (stakeholders, environmental effects, etc.). Also, other motivations and lessons learned were collected and analyzed.

The following projects were investigated in the case study effort including two national and two international projects: Oregon DOT, United States – *Project name: Oregon 1.75 MV Solar Highway Program* (Billitzer 2010)*;* Highways 2nd Regional Directorate, Turkey – *Project name: Cesme 1 MV Solar Photovoltaic (PV)* (Karayollari Genel Mudurlugu 2019); Ohio Department of Transportation, United States – *Project name: Ohio Department of Transportation Northwood Outpost Garage Wind Turbine;* Highways 5th Regional Directorate(Lorand 2013), Turkey – *Project name: Hatay – Kisikli Solar and Wind Hybrid Energy.*

Phase 2: Development of the Renewable Energy Project Feasibility Analysis Tool

In this project, based on the data collected in Phase 1 (including the literature review, the questionnaire survey and the case studies), three *Renewable Energy Project Feasibility Analysis Tools* were developed to assist highway agencies with the application of three renewable energy project types (solar, wind, and biomass) in the highway ROWs. The feasibility analysis tools are expected to assist decision makers in determining which type of projects are suitable for their local resources and will guide in determining where and how renewable energy projects could be implemented by providing the important points to take into account in the decision-making process. The tools provide a list of technical, financial, and environmental criteria that play an important role in choosing and implementing new renewable energy projects in highway ROW. In this paper, the technical criteria section of the tool developed for solar energy projects is presented below. (Zhu et al. 2012; Chen et al. 2013)

Criteria for Determination and Evaluation of Candidate Sites for Solar Energy Projects in Highway ROWs

Solar Energy Potential
The solar energy potential of the land is found by the amount of solar radiation per unit time (kWh/m^2/day) per a certain surface area. The solar energy potential of the land is one of the most critical issues in land selection.

Climate
Dry climates with less cloud time are more suitable for such solar projects.

Tilt Angle and Direction
In the northern hemisphere, where Turkey is also located, the sun is inclined towards the south and more sun rays come to the south-facing facades.

Surroundings
Buildings, hills, and big trees can produce shade on the surface, thereby reducing PV panels' generation of electricity.

Road Shading & Sun Reflection
Cell shadows on the road can distract drivers. More importantly, these shades will prevent the ice from melting. Similarly, the rays coming from the panels can disturb the drivers, so non-reflective surfaces should be preferred in the panels.

Physical Space
A site must also contain the necessary space for installation. For a solar energy project to be financially sustainable in the highway ROW, at least 20.000 m^2 area is required.

Network Connection
The electricity distribution station should be close to the land because the transportation cost increases with every kilometer. Besides, network support capacity should be taken into consideration when choosing a location. For example, proximity to urban areas where electricity demand is high should be preferred more than remote areas. Otherwise, the project may be financially unfeasible.

Access and Security
Access to the project area should be available through side roads or existing facilities, not on the highway. Fences or security against theft and looting must be considered.

Regional Energy Planning
Coordination with energy distribution companies is required for the project land. Project distribution companies may not accept your project proposal if there is no energy requirement in the area where you will implement the project.
Environmental Features
Pre-screening should also try to exclude areas with significant environmental resources, such as wetlands, or locations with endangered species.

Water resources
Pre-screening should also take into consideration the risk related to flooding and landslides.

Future Use
Lands that can be used for other purposes in the future (such as parking areas, road widening, or building new facilities) should be avoided.

Archaeological, Historical and Cultural Aspects
In some previous projects, the projects planned were postponed or the construction period was extended due to the existing historical artifacts. It will be beneficial to investigate the existence of any cultural structure with archeology experts during the site selection process.

Phase 3: Determination of Opportunity Zones for Renewable Energy Projects

The purpose of this phase was to determine example opportunity zones and suitable candidate sites in highway ROWs in Turkey for execution of solar energy, wind energy, and biomass energy projects based on the criteria offered in the *"Renewable Energy Project Feasibility Analysis Tools."* Within the scope of the study, the locations offered by various local highway agencies were examined carefully and 3 opportunity zones for the solar energy projects, 3 opportunity zones for the wind energy projects, and 2 opportunity zones for the biomass energy projects were selected. Below, the sites that were chosen for solar energy projects are presented.

Opportunity Zones for Solar Energy

1. There are approximately 20.000 m^2 of land located at the cloverleaf junction at the Ulukisla exit district of the Tarsus-Ankara highway (Figures-1 and 2).

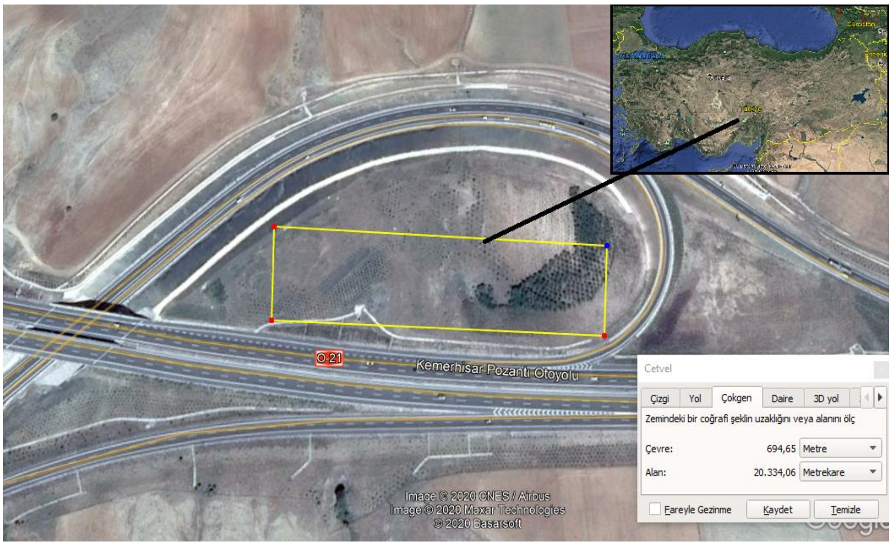

Figure-1: Ulukisla land bird's eye view

Figure-2: Ulukisla land south view

2. The land in Sahin Tepesi locality near the Cesmeli exit, at the end of the Adana-Erdemli Highway (Figures-3 and 4)

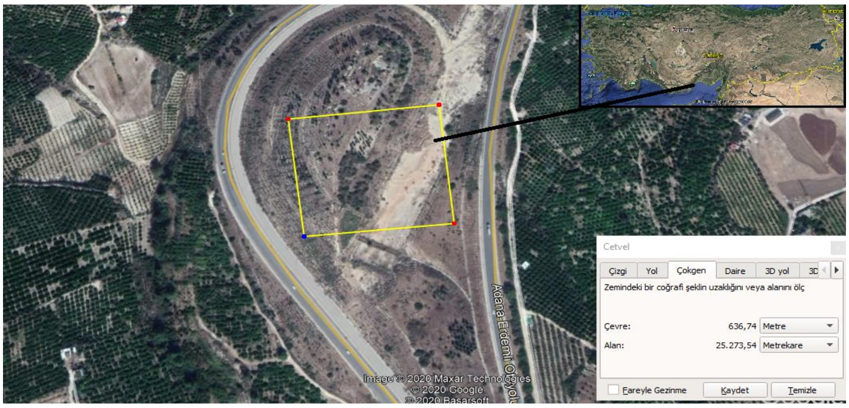

Figure-3: Sahin Tepesi area, bird's eye view of the land

Figure-4: Sahin Tepesi area land east view

3. The land in the around of the Free Zone Port exit of the Adana-Erdemli motorway where the Highways Maintenance Operation Directorate and the Highways Public Housing are located (Figures-5 and 6).

Figure-5: Port area land bird's eye view

Figure-6: Port area land south view

Conclusions

This paper presented an overview of the research in which national and international renewable energy project practices in the highway ROWs were analyzed and summarized. First, a comprehensive literature review was completed followed by a questionnaire survey conducted to gather information about projects that are not in the literature or are in the beginning stage. Also, information on select, successful projects was collected through case studies. Based on the data collected through the literature review, questionnaire survey and the case studies three *Renewable Energy Project Feasibility Analysis Tools* were developed to assist highway agencies with the application of three renewable energy project types (solar, wind, and biomass) in the highway ROWs. Finally, example opportunity zones and suitable candidate sites in highway ROWs in Turkey for execution of solar energy, wind energy, and biomass energy projects based on the criteria offered in the *"Renewable Energy Project Feasibility Analysis Tools."*

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Determination and Ranking of Obstacles in BIM implementation with Relative Importance Index

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Abstract

BIM technology has become a cornerstone of project management in construction industry. Notwithstanding the fruitful features improving project management process, construction industry still encounters stark obstacles during its implementation. What is more controversial is that there is no overarching considerable research with respect to obstacles occurring during BIM executions although there is extensive literature concerning BIM. Therefore, this study aims to detect the significance of the problems during the course of BIM implementation. Hence, both an in-depth literature review and an expert panel were conducted to detect the current problems faced during the course of BIM implementation, and then the importance of each problem was detected via surveying with the experts experienced in BIM. Afterwards, the significance of each of these problems was detected via Relative Importance Index (RII). It is highly believed that this study will contribute to the improvement of BIM process by guiding the researchers.

Keywords: *BIM Challenges, Relative Importance Index, Construction*

Introduction

The Architectural, Engineering and Construction (AEC) industry has rapidly changed and adapted itself in line with the developments in technology like Building Information Modeling (BIM) (Vass & Gustavsson, 2017). BIM is one of the most powerful tools concerning project management by enhancing knowledge sharing during the life cycle of structure from the initial design to facility management (Jamil & Fathi, 2018). Numerous researchers have contributed to the development of the body of knowledge concerning BIM. Although BIM helps to expedite the process of construction projects via its attributes such as rendering, animation, scheduling and budgeting, BIM also brings challenges for the building process (Bargstädt, 2015; Zibert, Lah, & Samo, 2018). The purpose of this study is to illuminate the difficulties that occurred during the implementation of BIM in construction projects in order to provoke the researchers and practitioners in the way of finding better practice. These aforementioned challenges were detected through an in-depth literature review. In addition to this, an expert panel was conducted with 4 experts experienced in BIM field in construction industry to release further obstacles restraining the utilization of BIM. The expert panel was conducted via WhatsApp video call and took almost one hour. The availability of any additional challenges encountered by the experts during the implementation of BIM was asked during the interviews. Afterwards, the challenges obtained from an in-depth literature review and structured interviews were gathered and listed. Then, surveying was conducted with 10 BIM practitioners to detect the magnitudes of the challenges with 5-Point Likert Scale. The data were analyzed via Relative Importance Index (RII) to detect the significance of each challenge. This study is believed to be unique by shedding light on the priorities of difficulties resulting from the implementation of BIM. This is believed to enable the project stakeholders to prevent any possible defects during the project execution by mocking up the project process before the execution.

BIM Technology

Surging the productivity and efficiency has become the main goal of AEC sector, and the management of information is one of the best ways to accomplish this objective (Monteiro & Poças Martins, 2012). Hence, BIM is a comprehensive tool that has been adopted by many projects in AEC industry in the sense that it is based on a virtual 3D model to manage much of the information concerning building life cycle. Moreover, BIM tools offer novelties concerning 4D (Schedule Management), 5D (Cost Management), 6D (Sustainability) and 7D (Facility Management (FM)). To maintain the quality of BIM usage, there are fruitful standards which are globally accepted. buildingSMART (buildingSMART International, 2020), which is a neutral and an international not-for-profit organization, plays curial roles in this matter by releasing groundbreaking standards, namely ISO19650 standard (Boutle et al., 2019) to manage the information throughout the life cycle of buildings, Industry Foundation Classes (IFC) to enable the information exchange between different BIM software, BIM Collaboration Format (BCF), Model View Definitions (MVD), Information Delivery Manual (IDM) and buildingSMART Data Dictionary (bSDD). Although great efforts have been made in BIM development, practitioners face various difficulties during the course of the applications of BIM (Salah, 2014; Sediqi, 2018; Vass & Gustavsson, 2017; Woo, 2006).

Methodology

In the first phase of the study, challenges of BIM implementations were detected through an in-depth literature review and an expert panel was conducted with 4 experts experienced in BIM domain. The profiles of the respondents are introduced in Table 1 below.

Table 1. Demographic Information of Experts

Expert Number	Experience concerning BIM (Year)	Total Experience (Year)	Project types in which the experts are experienced concerning BIM
Expert#1	4	9	Superstructure
Expert#2	2	19	Superstructure, Infrastructure
Expert#3	6	14	MEP, Superstructure
Expert#4	1	1	Superstructure

After reviewing the existing studies, 16 challenges were detected. In addition to this, these 16 challenges caused by BIM implementation were demonstrated during the expert panel to the experts and additional challenges were discussed. Thus, 2 new challenges were spotted by the experts during the course of the expert panel.

In the second phase of the study, a total of 18 challenges detected were directed to 10 BIM practitioners via surveying in order to define the magnitude of each challenge by using a 5-Point Likert Scale. To clarify, while 1 indicates very low, 5 indicates very high. The data obtained from surveying were analyzed via RII as a technique to define the severity of each challenge. Adopted by many researchers, Relative Importance Index (RII) ranks the importance of factors effectively (Gunduz, 2019; Gündüz, Nielsen, & Özdemir, 2013; Kometa, Olomolaiye, & Harris, 1994; Özdemir, 2010). The computation technique of RII is depicted below.

$$\text{RII} = \frac{\sum_{i=1}^{i=n} W_i}{A*N} \quad (1)$$

In the given formula, W_i points out the value ranging from 1 to 5 given for each obstacle by an expert. A is the highest weight (5), and both N and n represent the total number of attending experts (10). The importance of each challenge falls into the range between 0 and 1 as a result of Formula 1 stated above, and the higher the value is, the more important the challenge is. The methodology is summarized as illustrated in Figure 1 below.

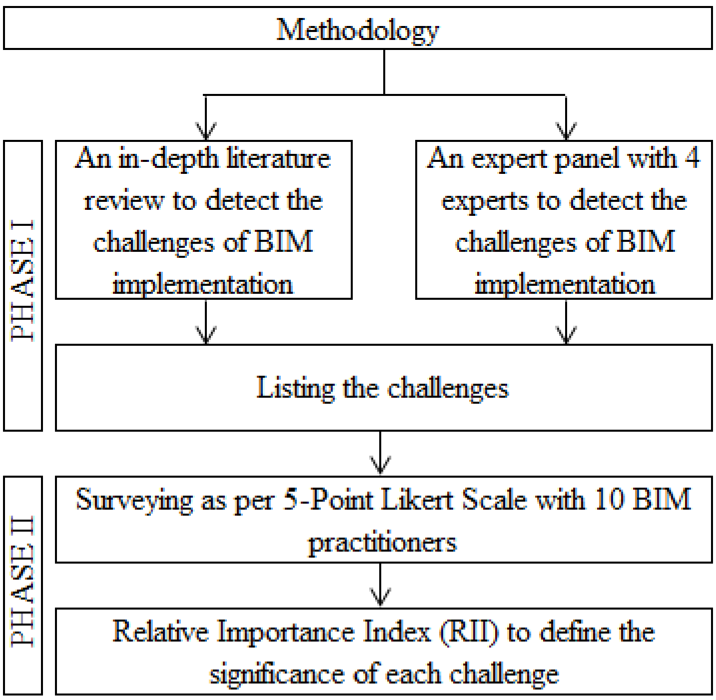

Figure 1: Summary of Methodology.

Findings

Two phases have been implemented to be able to detect the significance of the obstacles restraining the application of BIM. To start with, the challenges of BIM implementation were gathered through an in-depth literature review and the findings are listed in Table 2 below.

Table 2. The main challenges occurring during the implementation of BIM according to the researchers

Reference of Research	(Azhar, Hein, & Sketo, 2008)	(Abbasnejad & Moud, 2013)	(Elmualim & Gilder, 2014)	(DIAZ, 2016)	(Vass & Gustavsson, 2017)	(Zibert et al., 2018)	(Ustinovičius et al., 2018)	(Georgiadou, 2019)
Citation	405	48	161	11	45	0	7	8
Time, cost and adaptation barriers (cultural barriers to change, established mindsets and practices) caused by training the team members			✓	✓	✓			✓
Changing the work practices and organizational structure (Creating new roles)			✓		✓	✓		
Lack of existing users' knowledge and skills concerning BIM				✓				
Disbelief among the project team members about the importance and benefits of BIM				✓				
Financial barriers resulting from BIM software requirements (high performance of hardware, software, upgrading of the available systems, additional employee)			✓	✓		✓	✓	✓
Lack of any stakeholders' BIM Software							✓	
Creating incentives to encourage the other parties (suppliers, contractors, subcontractors, etc.) to use BIM					✓			
Difficulties in detailing the 3D modeling in BIM software						✓		
Lack of functionalities for specific construction fields (e.g. tunneling)						✓		
Developing a mutual BIM procedure (definition, standards, level of responsibility, responsible parties for data entry, etc.)	✓	✓			✓	✓		
Lack of evaluation of the business-value/ benefits concerning BIM implementation			✓		✓			
Controlling the procurement items via BIM					✓			
Difficulties in including the maintenance department to the BIM process					✓			
Poor interoperability capabilities between the software	✓	✓			✓	✓	✓	✓
Legal barriers and cybersecurity	✓							✓
Lack of client demand due to lack of knowledge concerning the benefit of BIM								✓

Scheduling is identified as one of the most important parts of the construction projects (Metkari & Attar, 2015). 3D BIM is a static model and since the construction process requires a dynamic representation due to its nature, 4D has been gaining more momentum (Montaser & Moselhi, 2015; Porkka & Kähkönen, 2007). During the expert panel, there was a joint agreement by the experts that there is a rising trend towards BIM adaptation in construction projects and at the moment the 3D, 4D and 5D BIM tools are operated as asynchronous processes, as is also stated by Butkovic et al. (Butkovic, Heesom, & Oloke, 2019). Expert 1 asserted that "*As is seen in the Enterprise Project Structure (EPS), all tools in BIM software should be synchronized; therefore, when any change occurs in 3D modeling, schedule and cost should change automatically. This will dramatically diminish errors in projects in terms of time, cost, quality and safety.*" It was decided during the expert panel conducted with 4 experts that additional challenges encountered during the implementation of BIM are illustrated as followings;

- Lack of delay analysis
- Lack of automatic synchronization of schedule and cost with 3D BIM software

Having defined the challenges concerning the implementation of BIM in the construction industry, this study also aims to quantify the significance of each challenge to highlight the priority of improvement areas concerning BIM. Significance levels of the foregoing challenges were computed through RII and the outcomes are tabulated in Table 3 below. As is illustrated in Table 3, the scores of the obstacles derived from expert panels, which are rated above 0.56, are by far ahead compared to the other factors detected by the literature review.

Table 3. Ranking the Challenges via RII

Obstacles of BIM Implementation	Very Low (1)	Low (2)	Medium (3)	High (4)	Very High (1)	IRR
Financial barriers resulting from BIM software requirements (high performance of hardware, software, upgrading of the available systems, additional employee)		1		4	5	0.86
Time, cost and adaptation barriers (cultural barriers to change, established mindsets and practices) caused by training the team members		1		4	5	0.86
Lack of client demand due to lack of knowledge concerning the benefit of BIM	1		1	4	4	0.80
Lack of any stakeholders' BIM Software	1		3	2	4	0.76
Developing a mutual BIM procedure (definition, standards, level of responsibility, responsible parties for data entry, etc.)		2	3	2	3	0.72
Lack of evaluation of the business-value/ benefits concerning BIM implementation	1	1	1	5	2	0.72
Poor interoperability capabilities between the software		3	1	4	2	0.70
Creating incentives to encourage the other parties (suppliers, contractors, subcontractors, etc.) to use BIM	1	1	2	4	2	0.70
Difficulties in including the maintenance department to the BIM process	1	2	2	3	2	0.66

Table 3 (Continued). Ranking the Challenges via RII

Obstacles of BIM Implementation	Very Low (1)	Low (2)	Medium (3)	High (4)	Very High (1)	IRR
Lack of automatic synchronization of schedule and cost with 3D BIM software		4	2	1	3	0.66
Disbelief among the project team members about the importance and benefits of BIM	1	2	1	5	1	0.66
Lack of existing users' knowledge and skills concerning BIM		2	4	4		0.64
Changing the work practices and organizational structure (Creating new roles)		5	2	1	2	0.60
Controlling the procurement items via BIM		3	5	2		0.58
Lack of delay analysis	1	4	2	2	1	0.56
Lack of functionalities for specific construction fields (e.g. tunnelling)	1	5	1	1	2	0.56
Legal barriers and cybersecurity	2	5		1	2	0.52
Difficulties in detailing the 3D modeling in BIM software	4	4	2			0.36

Conclusion and Recommendations

In the recent past, many universal breakthroughs concerning BIM development have been made. Meanwhile, the current problems faced during BIM implementations by practitioners have become a driving force encouraging the researchers to develop the better practices. As a consequence of this, identifying the foregoing obstacles as per their significance is assumed to be very crucial to maintain the fragile structure of the construction industry and thus reduce time and cost consumption via BIM. Time and profit, which are the major objectives of the construction projects, require to be controlled and monitored very closely during the course of the projects. Serving as a remedy in this matter, 4D and 5D in BIM help project stakeholders even with insufficient knowledge concerning the construction domain to understand the potential problems and improve the common understanding of schedule and cost via visual communication. Additionally, change is an inevitable part of the construction projects (Ibbs, Ashley, & Asce, 1987), and reflecting the change in design to the other disciplines such as planning and cost is vital to harmonize the disciplines of projects; however, if synchronization is not conducted in real-time but made manually by using importing and exporting tools, harmonization of project disciplines can be disrupted and this results in cost and time overrun. Therefore, it is recommended that, like ERP tools, BIM tools should keep up with the time and synchronize 3D, 4D and 5D together in real-time. Likewise, the difficulties in forensic schedule analysis and the assessment of the Extension of Time (EOT) soar with the complexity of a project (Valavanoglou & Heck, 2020). When 4D and 5D BIM are used efficiently in construction industry, scheduling software will not be needed any longer. In this case, integration of delay analysis with BIM software is compulsory and thus any contribution in this regard is very fruitful for the practical field.

Notwithstanding the widespread use of BIM, many firms especially Small and Medium Enterprises (SME) still don't utilize BIM because of its cost and possible change in the organizational structure. Consequently, the collaborations of the parties adopting the BIM with the parties not adopting BIM may be affected negatively. Therefore, giving the BIM lectures at the universities is believed to diminish the cost of the firms during the transformation process towards BIM. By the same token, Expert#2 contributed to this matter by stating that "*Most of the small enterprises cannot effort BIM software prices and I believe lowering the price by software firms will raise the demand and the profitability of these firms may even increase."* This is to be considered by the BIM software company to increase the BIM applications in the construction industry.

Another crucial barrier to the BIM application is with the procurement process. The traditional procurement process constitutes constant changes resulting from decision-makers, bargaining, changes in specifications and quick amendments to the contracts, etc.; however, synchronization of these changes with BIM can be difficult in real-time. Therefore, the practitioners adopting the traditional construction process should transform to keep up with the developments in ERP and BIM.

There are internationally adopted defacto standards concerning the applications of BIM such as ISO19650, IFC, IDM, MVD, BCF, bSDD, etc.; however, 4D and 5D implementations of BIM are to be well defined in the standards and procedures in order to establish common applications in practice.

4D BIM is simply one of many mediums for the successful executions of projects. What is clear here, however, is that the application of 4D technology on construction projects will only be successful when BIM tool is used proactively at individual projects with its effects fully understood (Kwak, Choi, Park, Seo, & Kang, 2011). Project owners also clearly want to see tangible benefits of BIM implementations. For this reason, researchers have a great role in revealing the benefits of using BIM.

There are a numbers of obstacles that occur in the modeling process depending on the type of BIM software (Gong & Felix Lee, 2011). Although BIM enables the designers to create new objects varying from LOD 100 to LOD 500, it is obvious that practitioners still suffer to create these models efficiently. Therefore, the more BIM technology improves, the more credit practitioner will give away.

On the whole, by illuminating the drawbacks with their significance encountered during the course of the BIM implementations, this study paves the way for future studies focusing on the improvement domains of BIM. Additionally, this study is believed to guide the research forerunners seeking fully integrated and synchronized 4D and 5D BIM.

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A Scientometric Analysis on BIM Enabled Building Energy Management

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Abstract

Nowadays, energy consumption demand of buildings is increasing. In the literature, lots of studies were performed related to energy consumption reduction of the buildings and energy efficiency of the buildings in both design and operation and maintenance stages. Building Information Modeling (BIM) is one of the technologies which facilitates collaborations between different expertise areas. The studies showed BIM is a facilitator tool in energy related studies. Also, there are lots of study about BIM enabled Energy Management (EM). However, the mapping of researches on BIM enabled EM has not been attempted by the researchers. Therefore, this study aims to conduct scientometric analysis of BIM enabled Building EM researches between 2010 and 2020. In the study, Web of Science database was used to conduct scientometric analysis. A total number of 637 publications were found in the area of BIM enabled Building EM. In the scientometric analysis, timeline trends, the co-occurrence of keywords, co-citation analysis, and co-authorship analysis were performed. The study results emphasized that sustainability and lifecycle assessment are the hot topics in the BIM enabled Building EM researches. In the regional context, there is a limited study in Turkey.

Keywords: *BIM, energy management, research visualization, scientometric analysis.*

Introduction

Building Information Modeling (BIM) is an essential data storage, analysis, and visualization tool for the physical and functional characteristics of the facility (NBIMS, 2019). BIM enables more reliable and computable environment for decision-making problems in building lifecycle phases. Besides, it is the only tool which connects information coming from design, construction, operation and maintenance, and disposal phases (Edirisinghe et al., 2017). Therefore, practitioners have started to use BIM in construction projects since mid-2000s. With the increase in adaption of BIM in construction projects, researches on BIM implementation have increased interrelatedly. Some of the researchers focus on technical issues, while others focus on non-technical issues (Zhao, 2017). He et al. (2017) stated that there is a wide spectrum of research topics in relation to BIM. On the other hand, Energy Management (EM) is one of the topics in which BIM is used together. The building environment accounts for nearly 40% of the world energy consumption (Sprau Coulter et al., 2013) and buildings are responsible for 30% of the total greenhouse gases in the world. Also, change in lifestyle and technological developments are exacerbating energy demand (Danish et al., 2019). Therefore, EM is getting a common focus to manage limited existing resources.

In the building lifecycle, energy related measures are taken in both design, operation and maintenance stages. In the design stage, building energy analysis are performed to determine the amount of energy required to heat or cool a building. To perform energy analysis, energy analysts need information about building materials, size, configurations of spaces, and building locations. As a result of the analysis, energy requirements of the buildings and system configuration in buildings are performed (Kim & Anderson, 2012). Within this context, BIM is a facilitator tool since it enables automation of energy modeling, data storage, better presentation of energy-related outputs, and usage of existing libraries (Kamel & Memari, 2019). Also, in the design stage, sustainable design, which includes design optimization, plays an important role in energy consumption of the building. In the sustainable design practices, the feedbacks such as building orientation, the size of building components. from building performance analysis are used in both to improve building design and to meet the demand of sustainable building rating systems' requirements to earn points (Wong & Fan, 2013). Furthermore retrofit for existing buildings which are defined as overlap area of BIM and sustainability researches become prominent in building energy management research areas. In the retrofitting process, BIM is used to help facilitating energy analysis and evaluating retrofitting options. Additionally, the data which is coming from Building Automation Systems (BAS) or Building Energy Management Systems (BEMS) is used to calibrate and to increase accuracy of energy analysis (Gholami et al., 2020; Khaddaj & Srour, 2016). In the operation and maintenance stage, the EM teams manage and maintain energy systems used by end-users. In EM at the operation and maintenance stage, accuracy and flow of information is especially important to save energy and reduce emissions. Within this context, BIM can be used to store energy data on the model. Therefore, BIM provides an opportunity in terms of energy monitoring in FM (Wang et al., 2019). However, BIM enabled building EM is not limited with these research areas. Taken into account of the energy consumption ratio of buildings in the world, EM focused studies are getting more attraction by researchers. Therefore, there is a need more systematic approach for overview of existing literature.

Classification and analysis of the existing studies help to see the state of the art and research direction, and to produce innovative researches. Within this context, scientometric analysis is very helpful to derive research trends (Mayr et al., 2015) which concerns itself with measuring and analyzing scientific literature. In the literature, there are few researches on scientometric analysis on BIM studies. The studies mainly focused on BIM studies (Andriamamonjy et al., 2019; He et al., 2017; Li et al., 2017; Ozturk, 2020; Saka & Chan, 2019; Zhao, 2017). Also, Andriamamonjy et al. (2019) performed scientometric analysis on BIM and BIM-BEPS. Hilal et al. (2019) performed a scientometric analysis on BIM-FM studies.

In the literature, BIM-EM has not been directly investigated. However, energy related keywords were discovered as a result of scientometric analysis on BIM. For example, Liu et al. (2019) stated that BIM implementation in energy and environmental analysis has been recognized by the academic community. Nonetheless, there is a need particular focus on BIM-EM studies, since significant advancements in building monitoring and sensing devices have realized (Menassa et al., 2013). In the scientometric analysis, used keywords play an important role to derive meaning from the analysis. In the conducted studies, EM did not consider attraction from the researchers. Therefore, this study attempts to perform a scientometric analysis of literature relating to BIM-EM. It is believed that the findings from the study can provide better understanding of the new developments and trends in BIM-EM studies.

Method

In the literature, there is a wide of research topics in relation to BIM-EM. Therefore, the analysis and unbiased interpretation of existing studies are very challenging (He et al., 2017). Different analysis (informetric, bibliometric, and scientometric analysis) can be followed to analyze existing studies. While bibliometric analysis helps to share statistical analysis of book, articles, or other publications, scientometric analysis shares advancements in the area of science and technology. Informetric analysis helps to share the quantitative aspects of information. Also, the share results in the informetric analysis does not need to be scientific information (Mayr et al., 2015). In this study, the implementation of scientometric analysis was chosen to share scientific results and advancements. The scientometric analysis helps to interpret and visualize the existing studies. The scientometric analysis is a quantitative method in which scholarly data set are evaluated and structured. In the scientometric analysis, the research questions, methods, publication date, ranking of scientists and institutions, and country are visualized (He et al., 2017). In the scientometric analysis, different tools can be used such as Bibexcel, Paje CiteSpace, Saint, VOSviewer etc. Due to the simplicity and free to use, VOSviewer has been used in this study (Hilal et al., 2019). VOSviewer gives a special attention to graphical representations derived maps and meanings from analysis. With the usage of VOSviewer software, four views can be examined (Cobo et al., 2011);

- Label view: Each element in the analysis is represented by a label and a circle. The size of label and circle emphasize the importance of the elements. According to the customization of zoom level, the most only elements can be shown.
- Density view: The representation working algorithm is remarkably similar label view. However, in this view, the items are represented with a color which depends on the high of the density of item.
- Cluster density view: To obtain this view, the items need to be assigned to clusters. After that, the obtained view is very similar to density view. However, the density of items is evaluated specific to own cluster.
- Scatter view: In this view, items are displayed with a small circle without labels.

Figure 1 shows the research framework followed in the study. Research framework consists of three stages; 1) preliminary search, 2) double-check screening, and 3) detailed analysis.. VOSviewer allows to evaluate bibliographic from Web of Science (WOS), Scopus, Google Scholar, and PubMed (Hilal et al., 2019). While Scopus database was used by only Ozturk (2020) and Saka and Chan (2019), the rest of scientometric analysis studies on BIM used WOS database. Therefore, WOS database was chosen due to its reliability and the availability of most sources in this study (Hilal et al. 2019). The search keywords in WOS were Building Information Modeling" OR "Building Information Modelling" OR "BIM. As a timeframe, data range between 2010 and September 2020 were chosen. After that, the identified researches were filtered according to "Energy" OR "Energy Management" keywords. As a result of filtering, 650 studies found and analyzed.

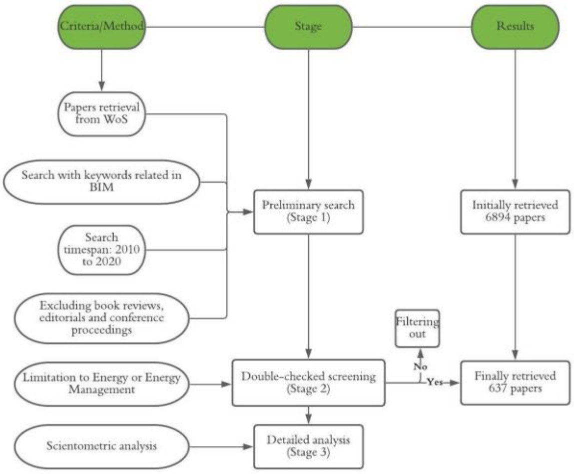

Figure 1. Research framework (adapted from He et al. (2017)).

Results and Discussion

As given in Figure 1, 637 papers were identified and analyzed in the study. In the analysis, timeline trends, the co-occurrence of keywords, co-citation analysis, and co-authorship analysis were conducted. The analyses were performed in the VOSviewer software.

Timeline trends of BIM-EM research

In the study, the researches studies which are between 2010 and September 2020 were considered. Figure 2 shows timeline trends of BIM-EM studies. According to the study results, the highest publication number (124 article) were observed in 2019. Also, the figure shows that there is a steady increase in the number of articles.

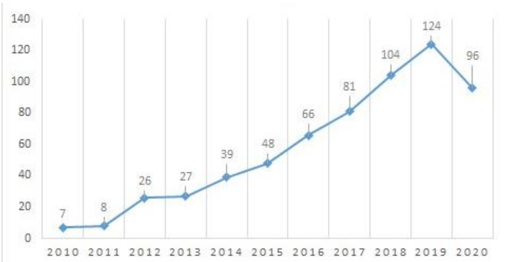

Figure 2. Timeline trends of BIM-EM research

Research areas (Co-occurrence of Keywords Analysis)

Keywords are important to identify the core contents of articles. Identification and investigation of keywords helps to reveal development of research topics over time (Zhao, 2017). The analysis results showed that when the frequency of keyword was set to 1, 1972 keywords were shown in the VOSviewer. Therefore, co-occurrence of keywords analysis is presented with a frequency restriction of 5 keywords to enable more understandable figure (Figure 3). According to the study results, BIM is the most used keywords in the publications.

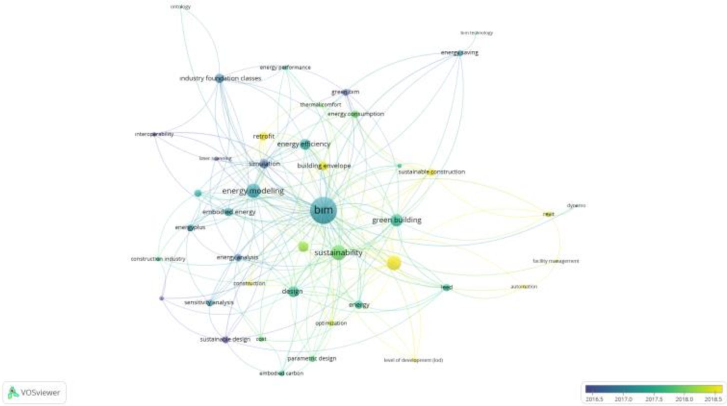

Figure 3. Network of co-occurrence keywords I.

According to the analysis results, BIM (336), energy efficiency (47), life cycle assessment (37), sustainability (37), and energy modelling (33) are the most used keywords among 637 papers. Figure 3 also helps to identify research trends in terms of keywords. According to the analysis, "retrofit", "sustainable construction", "automation", "building envelop", "level of development" are research keywords which are frequently used in the recent years. Additionally, keyword of Revit was found as another prominent research keyword. The findings showed that Revit is a more preferred keyword as a BIM software in the published studies. The interoperability feature of Revit can play an important role in this result since Revit can helps to automatically create energy analysis results. Additionally, Revit can host sensor data to enable more efficient FM. Furthermore, Figure 4 shows the network of co-occurrence keywords when the frequency of the keywords is restricted with 14. Therefore, the top 10 keywords were mapped with restriction. The figure indicates that "sustainability" and "life cycle assessments" keywords are prominent keywords in the recent published papers in terms of BIM-EM studies.

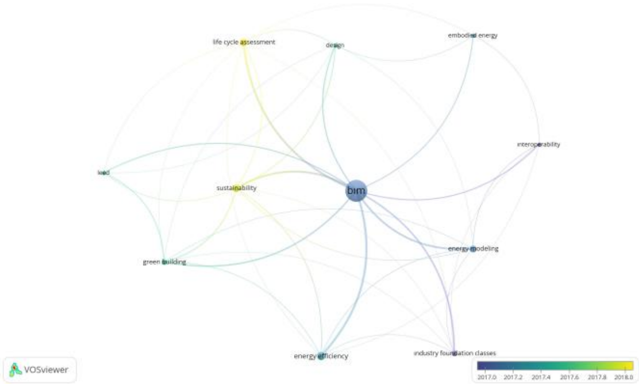

Figure 4. Network of co-occurrence keywords II (Top 10 Keywords).

Co-authorship network

In the co-author analysis, the bibliographic records are analyzed to identify leading researchers, institutions, and countries. Also, closed circuit in the co-authorship network analysis indicated that there is a strong collaboration between the authors who are in circuit. Co-authorship analysis is represented in Figure 5. According to the result of analysis, Wang Xiangyu is the most cited author in the BIM-EM studies with six documents. Moreover, another finding from the results is that Haddad Assed and Hollberg Alexander currently focused on BIM-EM studies. Also, the authors have the most cited new published articles.

Figure 5. Co-authorship analysis.

Furthermore, the studies were classified and then analyzed to find network of countries. The study results showed that BIM enabled EM studies were mostly originated from China (115 published studies) and USA (104 published studies) respectively. This result implies that China and USA have more advancement in BIM-EM studies rather than other countries. In the regional context, a total number of 11 studies were conducted in Turkey which shows that BIM-EM related studies are new topics for Turkish academicians. Additionally, the findings emphasized that there is a need more focus on BIM-EM studies to enable advancement in EM in Turkey (Figure 6).

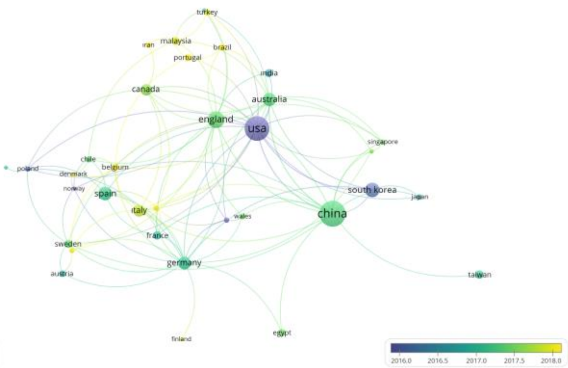

Figure 6. Network of countries.

In the Figure 7, a collaboration links among institutions are depicted. According to analysis result, collaboration between institutions are exceedingly rare. When the organization network is zoomed or restricted with 7 documents to see top 10 organizations, the collaboration between Katholike University Leuven, Swiss Federal Institute of Technology and University Bio are more prominent. Additionally, Shenzhen Universty and Katholike University Leuven are the organizations in which BIM enabled Building EM related studies are currently investigated.

Co-citation analysis

Co-citation analysis is performed to identify proximity of documents. In other words, it is a frequency in which pair of documents is cited by another documents (Zhao, 2017). In the co-citation analysis, journal co-citation analysis and author co-citation analysis were performed with VOSviewer software. Figure 8 shows the top 10 souce journals for BIM-EM researches.

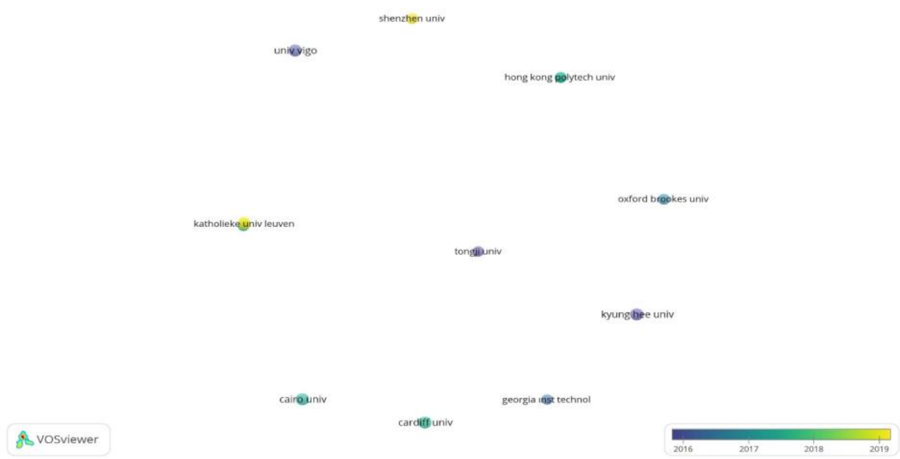

Figure 7. Collaboration network of organizations.

The analysis results showed that "Energy and Buildings" is the most cited journal (1548 citations). The second most cited journal was found as "Automation in Construction" (1522 citations). These journals can be used as primary sources of BIM enabled Building EM studies.

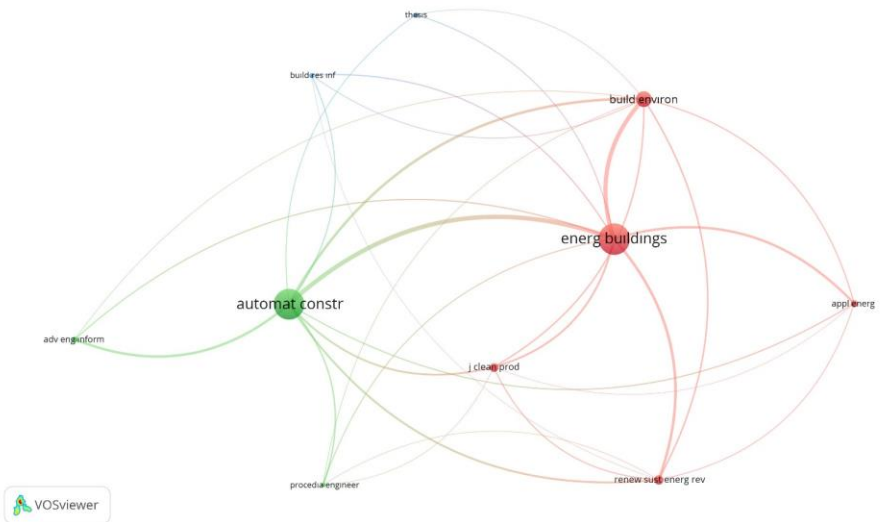

Figure 8. Journal co-citation network.

Author co-citation network is performed to measure relationships among authors which are cited in the same document (Zhao, 2017). The co-citation network analysis is given in Figure 9. The analysis results indicate that Salman Azhar is the most cited author in the BIM enabled EM studies with 156 citations. Charles Eastman is the second most cited author with 155 citations. Also, another interesting finding is that some institutions give a direction to BIM enabled EM studies such as Autodesk (software company), Ashrae (institution which conducts research, standards writing, and education), an U.S. Green Building Council (institution which accredits sustainability feature of buildings).

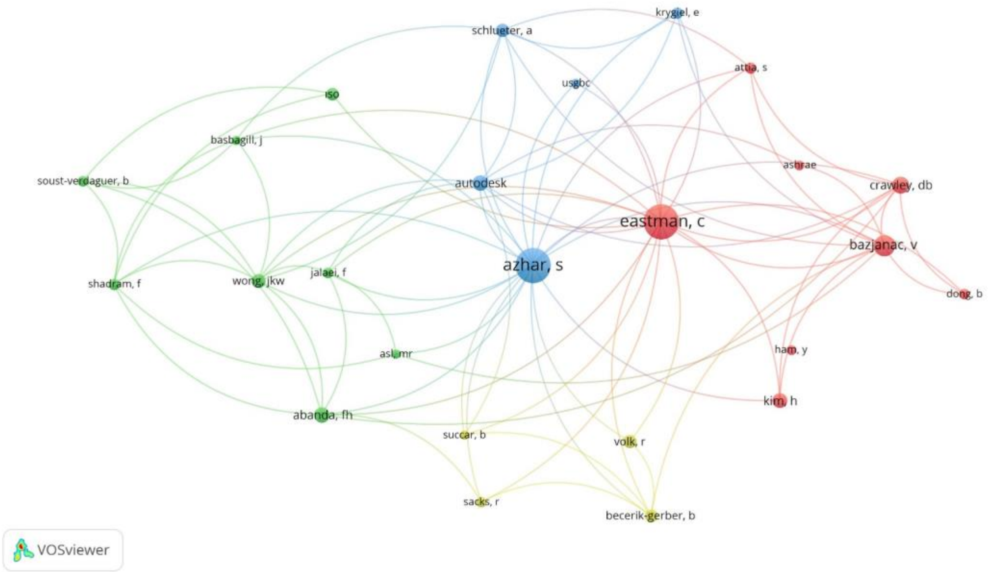

Figure 9. The co-citation network analysis.

Conclusion

Nowadays, built environment has a considerable responsibility in global and local change. Therefore, sustainability practices in AEC industry gain more importance. Within this context, limitation and management of building energy consumption are vital to enable sustainability. In the literature, lots of study have been conducted in the area of EM. In these studies, the usage of BIM comes into prominence since it provides both 3D models to energy simulation software and building geometry and building component information for FM software. However, there is a need systematic literature review of these studies to emerge new directions and innovative solution in the BIM enable building EM. Therefore, this study aims to conduct scintomentric analysis on BIM enabled EM studies.

In this study, WOS database was used to investigate the studies which include keywords of BIM and energy with a timespan from 2010 to 2020. In the analysis, after 6894 BIM-related articles were found, the studies were filtered with energy keywords. As a result of the filtering, 637 articles were analyzed with scientometric analysis by using VOSviewer software. Network of co-occurrence keywords analysis results showed that BIM (336), energy efficiency (47), life cycle assessment (37), sustainability (37), and energy modelling (33) are the most used keywords among the 637 papers. The analysis results also indicated that sustainability and life cycle assessment (LCA) studies are hot topics in the BIM enabled EM studies.

- Sustainability: Todays, sustainability is defined on the three pillars; namely, social, economic, and environmental. Chong et al. (2017) stated that BIM contributes these three essential elements of sustainability positively. However, the study emphasized that there is a need for a new BIM tool for assessing sustainability characteristics of building, and interoperability solutions for data transfer between BIM energy simulation tools. It seems like that the studies on BIM enabled EM are furthered in these areas in the near future.

- Life cycle assessment: LCA method helps to evaluate environmental impact and energy consumption of the building. Within this context, BIM-LCA approaches provides an opportunity to increase operational energy efficiency and reduce in the environmental impact (Najjar et al., 2019). The authors stated that BIM-LCA is intensively used in the energy performance and environmental impact in buildings. However, decision support system in terms of optimization is limited. Additionally, consideration of regional characteristics plays an important role in terms of sustainability. Interoperability issues between BIM and energy simulations are also seen in LCA analysis. Therefore, the studies will be furthered in these areas.

Co-authorship analysis shows that Wang Xiangyu has the most cited authors in the BIM-EM studies and the China has the most published studies (115) on BIM enabled EM studies. Network of organizations analyses shows that the collaboration between Katholike University Leuven, Swiss Federal Institute of Technology and University Bio are more prominent. Journal co-citation network analyzes results shows that “Energy and Buildings” is the most cited journal (1548 citations), and second one is “Automation in Construction” (1522 citations) in BIM enabled Building EM studies. The co-citation network analysis results that Salman Azhar is the most cited author in the BIM enabled EM studies with 156 citations. Finally, all these analyses show that BIM and Energy subjects are important and the need for studies in this area will increase. As a further study, the findings from this study will be used to create a general framework for BIM enabled building EM.

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INDEX

A

B

C

H

I/İ

J

K

L

M

N

O/Ö

P

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