AWARENESS OF THE TURKISH CONSTRUCTION INDUSTRY TOWARDS INDUSTRY 4.0 TECHNOLOGIES AND CONCEPTS

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ABSTRACT

AWARENESS OF THE TURKISH CONSTRUCTION INDUSTRY TOWARDS INDUSTRY 4.0 TECHNOLOGIES AND CONCEPTS

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The Architecture, Engineering and Construction (AEC) industry is a well-known latecomer to the effectiveness proposed by embracing of Industry 4.0 technologies; while other sectors embrace digitization and Information Communication Technologies (ICT) as an innovative strategy for maintaining economic profit and efficiency. In spite of the potential benefits that proposed by Industry 4.0, this revolution was not able to gain enough attention in the construction industry. Therefore, this study took initial steps to assess the awareness of Turkish construction professionals towards the implementation of a full digitalization to the construction value chain using Industry 4.0 technologies, moreover, a strategic roadmap for implementing Industry 4.0 technologies and concepts in the construction industry which is consist of five phases is proposed. In order to gather data from Turkish construction industry experts, a questionnaire was prepared and distributed among them.

According to the survey responded by Turkish construction professionals, although awareness on Industry 4.0 average is low, there are some technologies like Building Information Modeling (BIM), Simulation Models/Tools, and Mobile Computing that the majority of respondents' area aware of them. Moreover, consultants'' awareness towards the smart factory cluster technologies is exceptionally high, while these technologies are neglected in the publications and practice. Turkish construction industry professional’s area aware that embracing these technologies can have a significant impact on improving decision making quality, and sustainability.

Keywords: Industry 4.0, Construction 4.0, Digitization, Digital Construction Industry, Digital Transformation Roadmap

ÖZ

TÜRK İNŞAAT SEKTÖRÜNÜN ENDÜSTRİ 4.0 TEKNOLOJİLERİ VE KAVRAMLARINA YÖNELİK BİLİNCİ

Ebrahimi, Shima
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Eylül 2019, 103 sayfa

Mimarlık, Mühendislik ve İnşaat (AEC) endüstrisi, Endüstri 4.0 teknolojilerinin benimsenmesiyle önerilen etkililiğin bilinen bir geçiştir; Diğer sektörler ise ekonomik kar ve verimliliği korumak için sayısallaştırma ve Bilgi İletişim Teknolojilerini (BİT) yenilikçi bir strateji olarak benimsemektedir. Endüstri 4.0 tarafından önerilen potansiyel faydalara rağmen, bu kavram inşaat sektöründe yeterince dikkat kazanmamıştır. Bu nedenle, bu çalışma, Türk inşaat uzmanlarının, Endüstri 4.0 teknolojilerini kullanarak inşaat 4.0 değer zincirine tam dijitalleşmenin uygulanmasına yönelik farkındalıklarını değerlendirmek için ilk adımları atmış, ayrıca Endüstri 4.0 teknolojilerini ve kavramlarını inşaat endüstrisinde uygulamak için stratejik bir yol haritası oluşturmuştur. Beş aşamadan oluşması önerilmiştir.

Türk inşaat profesyonelleri arasında dağıtılan verilerin çeşitli uzmanlık alanlarından elde edilmesi için bir anket kullanılmıştır. Türk inşaat uzmanlarının yanıtladığı ankete göre, Endüstri 4.0 ortalaması ile ilgili farkındalık düşük olmakla birlikte, katılımcıların çoğunluğunun kendilerinin farkında olduğu Bina Bilgi Modellemesi (BIM), Simülasyon Modelleri / Araçları ve Mobil Hesaplama gibi bazı teknolojiler var. Ayrıca, danışmanların akıllı fabrika kümesi teknolojilerine yönelik farkındalığı son derece yüksektir, ancak bu teknolojiler yayınlarda ve uygulamalarda ihmal edilir.

Türk inşaat endüstrisi uzmanı, bu teknolojilerin benimsenmesinin karar verme kalitesini ve sürdürülebilirliği artırmada önemli bir etkisi olabileceğinin bilincindedir

Anahtar Kelimeler: Endüstri 4.0, İnşaat 4.0, Sayısallaştırma, Dijital İnşaat Endüstrisi, Yol Haritasi

To my beloved family and love of my life, for their enduring faith in me

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LIST OF ABBREVIATIONS

ABBREVIATIONS

AEC	Architecture, Engineering and Construction
AI	Artificial Intelligence
DIHK	Association of German Chambers of Commerce and Industry
AR	Augmented Reality
Auto-ID	Auto Identification
BAP	Battery Assisted Passive
BIM	Building Information Modeling
CIFE	Center for Integrates Facility Engineering
CPPSs	Cyber Physical Production systems
CPS	Cyber Physical System
E2E	End to End
ERP	Enterprise Resource Planning
ACATECH	German National Academy of Science and Engineering
GHG	Global Greenhouse Gas
GDP	Gross Domestic Product
HCI	Human Computer Interaction
IIoT	Industrial Internet of Things
ICT	Information Communication Technology
IaaS	Infrastructure-as-a-Service
IoS	Internet of Systems
IoT	Internet of Things
MES	Manufacturing Execution System
M&A	Mergers and Acquisitions
MR	Mixed Reality
OCR	Optical Character Recognition
PaaS	Platform-as-a-Service
PLM	Product Lifecycle Management
RFID	Radio Frequency Identification
R&D	Research and Development
S&Ms	Small and Medium Sized Companies
SaaS	Software-as-a-service
TPS	Toyota Production system
VR	Virtual Reality

CHAPTER 1

INTRODUCTION

1.1. Problem Statement

Industry 4.0, the fourth industrial revolution, was born in 2011 when the German government published a digital technology-intensive roadmap for manufacturing environment of Germany till 2020. This trend was an initiative approach towards digitization, automation, and implementation of “smart factory” in the manufacturing process of industries. As part of the efforts to obtain or retain global leadership in manufacturing, the government of several countries are providing funds for companies and academicians. The term Industry 4.0 includes a range of technologies to developing a digital value chain and enabling a digital and automated manufacturing environment. This transformation results in a high-quality product and reduce the amount of the time to market.

The construction industry has a significant contribution to the GDP of each country. The daily increase in the world's urban population (200,000 people daily) is affecting this sector. Simultaneous with population increase and economic growth, the demand for transportation, social infrastructures, and inexpensive houses has never been higher than this. Such difficulties guaranteed that the construction industry prerequisites to reconsider and reshape its value chain. However, as always, it is reluctant to embrace this digital industrial revolution because of some internal and external features of it. For instance, tight collaboration between project participants is of the most crucial challenges for projects. This industry is comprised of many small and medium-sized companies (S&Ms) which make the investments for research and development (R&D) in modern concepts and technologies hard.

1.2. Research Questions and Aim of the Research

Given these conditions as well as the increasing challenges of construction firms to maintain their global competitiveness, the following research questions arise:

- Question 1: Which technologies in the construction industry are presently linked to the Industry 4.0 concept?
- Question 2: In the construction industry, what is the present state of the art of Industry 4.0 related technologies?
- Question 3: How is the awareness rate of Turkish construction industry about industry 4.0 related technologies?
- Question 4: How is the utilization rate of industry 4.0 related technologies in today's construction industry? Which technologies have been adopted? Also, if it is not utilized now, what they think about its utilization time?
- Question 5: What is the benefit and impact rate of Industry 4.0 technologies in the determined areas (time and cost-saving, decision making, quality and sustainability, safety, and collaboration)?

According to these questions, this research aims primarily at offering a wide-ranging overview of the technology in the construction industry that is currently studied and implemented Industry 4.0. Assess the Turkey's construction industry awareness towards industry 4.0 related technologies and propose a strategic roadmap for implementation of these concepts and technologies in the construction value chain

1.3. Thesis Structure

Chapter 1 covers the current literatures about Industry 4.0 and digital transformation. The rest of this study is designed as follows. In chapter 2, the multilayered concept of Industry 4.0 has been covered, then construction industry importance in the national economy of each country has been discussed, finally through publications, we try to show that implementation of Industry 4.0 technologies and creation of a digital value chain is essential for the construction industry. In chapter 3, by reviewing publications, a list of technologies that are associated with Industry 4.0 are presented and defined. In chapter 4 the methods used to conduct this study and the questionnaire's design is clarified. Chapter 5 covers the results gathered by Turkish construction experts and explain their attitude and awareness toward these technologies. Further a basic roadmap has been proposed to guide sector players to implement these new concepts and preserve their competitiveness in the national and international market. In the final chapter, a summary of this study and a conclusion of results is presented.

Embracing of the Industry 4.0 technologies and concepts can assist the construction industry to maintain its productivity and competitiveness among all other manufacturing, nonetheless, their technology-intensive approach did not gain enough attention in the Turkish construction industry, yet. According to some publications, the overall awareness of Turkish construction industry is higher than South Africa, but still it is not satisfactory for an industry that has one of the most significant shares in Turkey’s GDP.

CHAPTER 2

LITERATURE REVIEW

For the first time, in 2011, Kagermann published industry 4.0 concepts and in follow of that German National Academy of Science and Engineering (ACATECH) published industry 4.0 platform in 2013 [Aarts, 2014]. Industry 4.0 is an initiative strategy that takes action in "High-Tech Strategy 2020 Action Plan" of Germany. It facilitates German's government road to solidify its leadership in manufacturing industries.

Industry 4.0 caused a transformation in manufacturing environments. This transition tries to make business models and companies' structures more digital and change the way we produce products or providing services. Interconnectivity, automation, machine learning, and real-time data are the most important aspects that Industry 4.0 focused intensely on them to assist in the implementation of digitization in each stage of the supply chain.

2.1. Evolution of Manufacturing from Industry 1.0 to 4.0

To understand the fourth industrial revolution (Industry 4.0) more clearly, it is necessary to understand the evolution of industrial revolutions since the 1800s till now. There is an interesting point about Industry 4.0. In industry 4.0 manufacturers have the opportunity of guiding this digital transition and evolve it in a shape that they want, while all the benefits of previous industrial revolutions came about after the fact (Gilchrist, 2016). In the following paragraphs, all industrial revolutions will be reviewed.

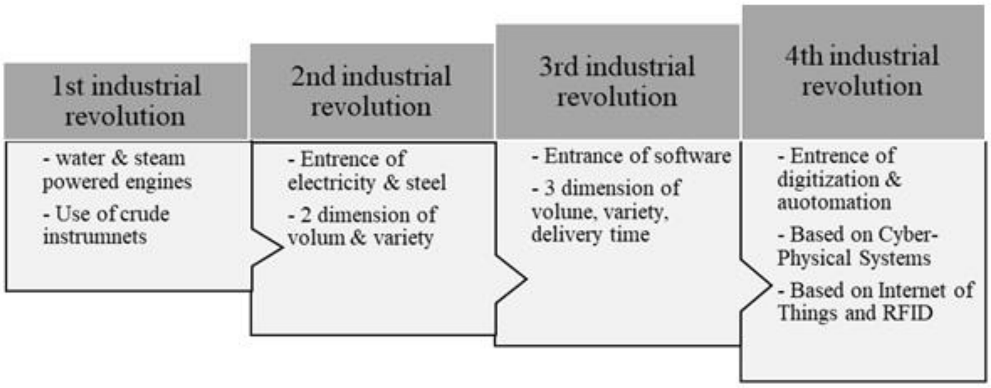

Figure 2.1. Industry 1.0 to Industry 4.0

2.1.1. First Industrial Revolution, Industry 1.0

In the late 1700s and early 1800s, the first industrial revolution took place. Water and steam-powered engines have been invented and transformed manufacturing from concentrating just on manual labor to a more optimized form of labor performance with the help of machine tool. (E. Crandall, 2017; Yin et al, 2018, Epicore, 2018).

2.1.2. Second Industrial Revolution, Industry 2.0

The second industrial revolution was happened by the entrance of electricity and steel to the manufacturing environment in the late 19s century and the early part of the 20th century. The second industrial revolution was intensively focused on two dimensions of volume and variety of products. This revolution boosted the efficiency percentage of labor and machinery. Frederick Taylor's "The Principle of Scientific Management" was the first publication on modern management theory, which was a turning point of Industry 2.0. Then, Henry Ford and Taiichi Ohno were extended Taylor's theory by their inventions and ideas. Ford executed the concept of the mass-production assembly line and cope with the shortage of supply in product volumes. Moreover, Ohno establish the Toyota Production System (TPS), which is the pioneer to lean, then concentrate on customer interests in diversity of products (E.Crandall, 2018; Yin et al., 2018).

2.1.3. Third Industrial Revolution, Industry 3.0

The third industrial revolution (industry 3.0) has been started in the late 1950s and comes till today. This revolution was about transforming from analog to digital machineries which came true by implementing technological innovations into the procedure and supply chain. During this transformation, manufacturers began to emphasize more on digital technology and automation software and less on analog and mechanical technologies. In comparing with industry 2.0, Industry 3.0 three dimensions of volume, variety, and delivery time, also in this revolution request for products increased tremendously (Yin et al., 2018). Richard E. Crandall in APICS magazine defined Industry 3.0 "By invention and manufacture of electronic devices such as integrated circuit chips and transistors in the last decade of the 1900s, it was feasible to automate individual machines to complement or replace operators fully. In the same era, software systems were developed to build on electronic hardware. Company resource planning instruments have supplemented integrated systems such as planning material specifications to allow people to plan, schedule, and monitor product flow through a plant. Integrated systems such as material planning have been substituted with company-level scheduling instruments that allowed people to plan, schedule, and track product flow through the factory. Cost reduction pressure encouraged many companies to transfer component and assembly activities to low-cost nations. Geographical dispersion has led to the emergence of the concept of supply chain management." (E. Crandall, 2017).

2.1.4. Fourth Industrial Revolution, Industry 4.0

A fourth industrial revolution, called Industry 4.0, has appeared in recent decades. This multi-faceted term was evolved by the German federal government to support its high-tech approach and includes many interdisciplinary ideas with no apparent difference (Lasi et al, 2014; Oesterreich & Teuteberg, 2016). Theoretically, establishing a full digital and automate manufacturing environment, also creating a digital value chain are some of the focus center of Industry 4.0 revolution. This transformation wants to create an environment which anything and anyone in it can have an effective communication and collaboration (Schmidt et al., 2015).

Industry 4.0 provides a more extensive, interconnected, and integrated production strategy. It links physical to digital, enabling stronger cooperation and communication across divisions, suppliers, product, and employees. It enables the company's managers to monitor and comprehend each part of their operations precisely and to use real-time data to increase productivity, enhance procedures, and drive development (Epicore, 2018).

Industry 4.0 also mentioned as Industrial Internet of Things (IIoT), Smart Manufacturing, Smart Production, Internet of Things (IoT) and Internet of Systems (IoS) (Oesterreich & Teuteberg, 2016). All these concepts have the same objectives. Their harmonized combination with big data, machine learning, and digital technologies within the value chain create an integrated environment for companies. Although all companies have different approaches towards their process and management, all of them have a common challenge to face with it, which is their necessity to interconnectivity and access to real-time insights across processes. In other words, Industry 4.0 concerns renewing and growing the whole system, not just the implementation of new technologies to enhance business efficiency.

Although Industry 4.0 create critical changes in the way business are done and propose advantageous to systems such as growth in quality of product and efficiency of value chain, this revolution was not able to take adequate attention among academicians and market players. More attention is required, particularly in scholarly research, for analyzing the contents thereof and its thorough description as well as for clarifying likely future trends (Oesterreich & Teuteberg, 2016; Piccarozzi et al, 2018).

Some academic papers have been published and gave some definitions about this concept. For example, Pan et al. in 2015 state that Industry 4.0 provides a manufacturing environment that industrial components can communicate with each other's (Pan et al., 2015). Schmidt et al. (2015) described the inclusion of smart products in digital and physical procedures as Industry 4.0. Digital and physical procedures communicate continually and lead to major changes in geographical and organizational boundaries (Schmidt et al., 2015).

In 2016, Glichrist published different definitions for Industry 4.0 in his book, some of them are:

- "Industry 4.0 is the fourth industrial revolution. It is best known as the new stage of organization and control throughout the value chain of the product life cycle and increasingly focused on individualized customer demands. The process starts with the concept of the item, order, spreads to the operation stages, until the product reaches the end customer, and concludes with recycling and encompasses all service delivery. The foundation for industry 4.0 is the real-time accessibility of all appropriate data by linking all items and people in the value chain. It is also important that information can be used to obtain the optimum value added at any moment. The connectivity between individuals, machinery, elements and anything in the process generate real-time optimized value-added links in and between companies. These can be enhanced to meet diverse requirements such as expenses, accessibility, and resource consumption."
- Industry 4.0 structure depends on:
    - "The digitization and integration of the horizontal and vertical value-chains.
    - The digitization of products and services
    - The introduction of innovated business models."

Kovacs and Sebastian in 2017 stated that the core of the idea for Industry 4.0 is the implementation of network-connecting intelligent systems that carry out a selfregulatory output: people, devices, machinery, and products will interact with each other.

Barreto et al. (2017) state that Industry 4.0 is responsible for the creation and implementation of creative Information Communication Technology (ICT) within the sector. Its overarching objective is to enhance smart product and process networking in all areas of the value chain so that organizational procedures are used more effectively to produce goods and services that promote client satisfaction by providing them with distinctive products and services. These industry-related changes are seen as a holistic paradigm, now dubbed the Fourth Industrial Revolution.

Zhou et al. (2015) stated that the principal concepts of Industry 4.0 are the inclusion of ICTs and industrial technologies. It is primarily based on constructing a Cyber-Physical System (CPS) to build a smart and digital factory on encouraging manufacturing to become digital, information-led, individualized, and sustainable. Industry 4.0 aims to create an extremely versatile manufacturing system of customized and digital products and services with real-time relations during the manufacturing cycle between individuals, products, and devices.

In order to achieve Industry 4.0, Germany has created a strategic strategy to realize Industry 4.0. This scheme can be summarized in the following primary points: (Zhou et al., 2015).

- **Creating a network** such as Cyber-Physical Systems (CPS). A network should link all physical objects to the internet and include five tasks of computation, communication, accuracy monitoring, coordination, and independence. This system will integrate the physical world with the digital world. Moreover, the network, which is the central basis of Industry 4.0, enables smart manufacturing and product.
- **Researching on two critical topics** of “smart factory” and “intelligent manufacturing.” The foundation of these topics is the mixture of smart devices and ICT. Smart factory concentrates on smart production systems, procedures,

and application networked scattered production equipment. Intelligent manufacturing focuses on generating an extremely flexible, customized, and networked industrial chain. To obtain these characteristics, intelligent manufacturing works on things-to-things communication, human-computer communication, 3D printing, inventory management and other innovative techniques that can be implemented to the whole manufacturing system to generate an extremely efficient, customized and networked value chain.

- **Comprehension of three integrations:** horizontal integration, vertical integration, and end-to-end integration are the three integrations. They will be discussed precisely in the coming chapters.
- **Realization of eight planning goals** which create the foundation of reaching Industry 4.0. The particular content of these goals is:
    - System standardization and the construction of a reference project
    - Efficient management models need to be established due to the advent of a broad and complicated value chain
    - Establishment of an integrated and trustworthy industrial infrastructure. Industry 4.0 imposes rigid principles on the communication network. This networks need to be secure, extensive, and high-quality.
    - Personal and environmental safety should be assured (from equipment and product itself) while avoiding item misuse or unlawful access to manufacturing equipment.
    - Organizing and designing job with the content, procedures, and environmental modifications, making higher requirements on production management, green manufacturing, automation, and leadership.
- Staff training and enduring professional improvement are vital to creating life-long training and ongoing professional improvement programs to help the employees handle new job and skill requirements.

- Creating a legislative framework is necessary. Inventions introduce new issues, such as corporate data, accountability, private information, and trade limitations. Standards, model contracts, and other suitable controls are required.
- Enhancing resource efficiency can be obtained by consumption of new materials, procedures, techniques, and other actions can enhance effectiveness in the use of resources and reduce and equalize the use of pollution-related environmental resources.

2.1.4.1. Four Main Characteristics of Industry 4.0

Presentation of Internet of Things or Systems to the procedure and the integration of Cyber-Physical System within the manufacturing procedure should be synchronized in order to create a smart and digital manufacturing process and product. Industry 4.0 approach is to transform centralized production to decentralized production, also transform conventional products to individualized products to engage the customer with the pleasure of product design and production.

Industry 4.0 proponents named four primary features and specific features:

Vertical integration of smart production systems: Vertical networking is based on the use of Cyber-Physical Production Systems (CPPSs) to build reconfigurable factories and flexible manufacturing environment, which lets to act quickly and correctly to any changes in demand levels, stock levels, machine defects, and unanticipated delay. Because of this, integration and networking of smart factories, smart products, and smart value chains are necessary.

Tjahjono and his team members in 2017 state that vertical integration of smart products in manufacturing processes enable the autonomous organization of production management and maintenance management too (Tjahjono et al, 2017).

Horizontal integration through value chain networks: The connection between business partners and clients is the main thing to think of when talking about horizontal integration. Horizontal integration means the integration of new business models across countries and even continents, thus it can play a crucial role in making a global network (Gilchrist, 2016). The integration of Cyber-Physical Systems and IT systems within the process and flow of data between different parties such as employer, contractor, designer, producer, and subcontractor empower closer relationship with value chain partners across company borders (Oesterreich & Teuteberg, 2016). As well as vertical integration, horizontal integration creates a flexible manufacturing environment, enabling the company to respond faster to any changes.

End-to-end engineering across the entire value chain: With the implementation of innovative improvements in the design, development and manufacturing processes and also by using advanced methods of communication and virtualization, companies can enable a significant optimization potential in the process. These technologies provide a tremendous amount of data (Big-Data) that help us to create new products and production systems (Tjahjono et al, 2017). The created communication types by Industry 4.0 associated technologies are human to computer, computer to computer, human to human, or service to service, which enable widespread horizontal, vertical, and end-to-end integration (Zhou et al., 2015). Moreover, this option facilitates highly customized products (Oesterreich & Teuteberg, 2016). All entities involved in the process have access to real-time information and controls on the shop-floor level, through End-to-End (E2E) Engineering. In other words, which process in which factory or company will be done will be less important (Brettel et al, 2014).

Acceleration of manufacturing through exponential technologies: The implementation of innovative technologies such as exponential technologies on manufacturing is the fourth main characteristic of Industry 4.0. The exponential technologies play as a catalyst for the manufacturing process which enables companies to reduce costs, increase flexibility, customize products and also provide the necessary field for individualized solutions (Tjahjono et al., 2017)

Besides these key aspects, Industry 4.0 requires other essential factors to be highly cognitive and autonomous. Some of these factors are the Internet of Things and Services, Artificial Intelligence (AI), Big Data, and Cloud computing. (Oesterreich & Teuteberg, 2016; Tjahjono et al., 2017)

2.2. Construction Industry Importance in the Economy

Contrary to common opinion, the construction industry has a vital role in the economy of countries; its impact can be demonstrated by the number of investments in construction projects and their share of the nation's GDP. According to the EPoC publication (2016), with a total of EUR 1.37 billion investment in 2014, the EU is one of the most prominent actors in the construction industry. Almost 54% of this investment is owned by the four major sectors in the EU: Germany, France, the United Kingdom, and Spain which their share ranges from 8.1% to 11.8% of total GDP (Deloitte, 2017; Oesterreich & Teuteberg, 2016). It is anticipated that in the coming years the sector will expand considerably to almost $15 trillion revenue by 2025. With combination of $10 trillion annual profits and $3.6 trillion add value, the construction industry contributes to 6% of worldwide GDP. Precisely, in developing countries and in developed countries, respectively it represents 8% and 5% of total GDP. (Gerbert, 2016)

The construction industry role in the national economy of each country has been highlighted by several researchers. Khan in 2008, addressed that the construction industry regarded as one of the vital player of financial growth, development and economic growth.

The construction industry is also a major source of employment to millions of unskilled, semi-skilled, and skilled workforce. In 1989, Park asserted that the construction industry generates one of the highest multiplier effects through its extensive backward and forward linkages with other sectors of the economy. In 1990, Ofori noted the significance of construction industry in the domestic economy and allocated it to strong economic ties. Construction is considered as an extremely important contributor to the development process of nations (Field & Ofori, 1988). The World Bank (1984) indicated that the construction industry's significance derives from its powerful links with other industries economic (Oladinrin et al, 2012).

Although the construction industry has a significant impact on the economy of countries -especially in developing countries- funding projects are extremely low for research and development (R&D) in the construction industry. According to an EU R&D Scoreboard publication in 2015, in the construction industry R&D investments in one of the lowest in compare with other manufacturing (less than 1% of net sales) (Eastman et al, 2008; Hernández et al., 2015), while this figure for the auto and aerospace sectors is 3.5 to 4.5 percent (Agarwal et al, 2016). This scoreboard comprises 2500 companies which investing the most considerable sum of R&D in the world and also 1000 companies based in EU with the highest R&D investments. Another fact is the weak labor productivity of the construction industry. In 2007, The Center for Integrates Facility Engineering (CIFE) at Stanford University had developed a graph which is illustrated poor labor productivity of the construction industry from 1964 to 2004. During these 40 year-long periods, non-farm industry productivity doubled (including construction). In the meantime, labor productivity approximately is 10% below what was in 1964 in the construction industry (Eastman et al., 2008).

According to the evidence discussed in previous paragraphs, it becomes evident that there are fundamental inconsistencies in construction industry structure that should be taken under consideration. (Oesterreich & Teuteberg, 2016).

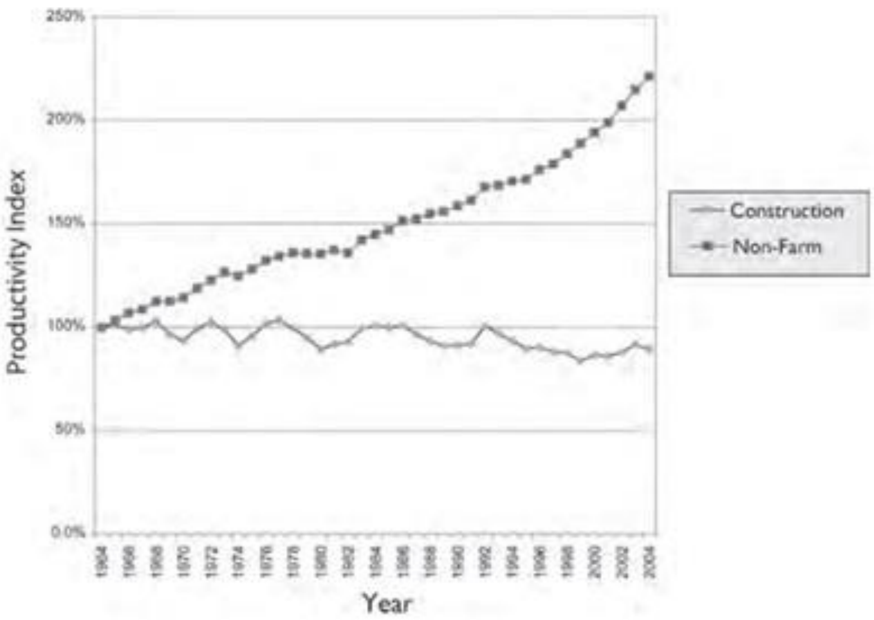

Figure 2.2. Indexes of labor productivity for construction and non-farm industries, 1964-2004.

2.3. Motivation of Digitization for the Construction Industry

Digitization is a must for construction industry, there is no substitute for digitization, and ACE industry needs to adopt it. The Denmark government used "digital construction" term for the first time in 2007, to state low productivity of sector (Arayici & Aouad, 2011).

The construction industry is the biggest worldwide consumer of materials: 3 billion tons of raw material and 50% of global steel manufacture. In addition, in the United States it is responsible for 40% of solid waste drives from demolition and construction. Also, 25% to 40% of global carbon dioxide belongs to buildings (Gerbert, 2016).

According to Akamu et al. (2013) statement, approximately, 30% of construction budgets are wasted due to inefficiencies, errors, delays, and weak communications among participants and stakeholders. Design errors, design modification and updates, ineffective real-time communication with construction site along with lack of sufficient collaboration among participants resulted in delay and cost overrun. Access to real-time model updates can assist project managers in making educated choices. Barreto et al. (2017) were introduced two main logistic problems of the construction industry: the elevated need for transparency (supply chain visibility) and quality control (right materials, at the right moment, in the location, proper quantities and at the exact price).

Updating the as-built model with on-site modifications is essential for project life-cycle management. However, they still updated as-built model manually after construction. Therefore, it is susceptible to mistakes due to inappropriate modifications record. Virtual models (such as BIM) provide a significant advantage in assisting documentation of as-built data, the collaboration among project participants, and visualization of construction progress, but they are mainly restricted to the pre-construction stage. By amplifying virtual models' advantages to the construction, operation, and maintenance stage of a project lifecycle, much more advantage can be extracted. In other words, virtual and physical models integration can enhance data and knowledge management from design to construction and operation (Akanmu et al., 2013; Motamedi & Hammad, 2009; Shen et al., 2010; Chin et al, 2005). These problems persuade the construction industry to adopt the concept and technologies of Industry 4.0. As stated in the Association of German Chambers of Commerce and Industry (DIHK) study, 93% of companies approve that digitization will affect each part of their process.

For understanding the necessity of digitization for the construction industry, it would be better to understand what digitization is. According to the Oxford dictionary, the conversion of text, pictures, or sound into a digital form that can be processed by a computer is digitization. In an article published by I-Scoop website, digitization has been defined as follows "digitization is creating a digital format of analog or physical things such as paper documents, images, sounds and more. In other words, it implies that a non-digital thing is converted or represented into a digital format (bits and bytes), which then used for many feasible purposes by a computing system" (De

Clerck, 2018). A significant advantage of digital data compared to analog or physical data is its efficiency in storing, accessing, transferring, and analyzing data (Techopedia, 2019).

As discussed previously, the first transformation in production was occurred by steam and water power (Industry 1.0), then by the entrance of electricity (Industry 2.0), then by the implementation of technological innovations (Industry 3.0), and more recently by digitization (industry 4.0) which lead us to a complete digital ecosystem. Digitization is about companies coming across integrated systems at every step in the value chain, and it will permeate to every part of companies. This ecosystem is about the full implementation of ICT based tools and practices such as, Cyber-Physical Systems, Big Data, Internet of Things, Cloud Computing and others. Information and communication technologies are not just simple tools to boost companies' performance a little bit; they are here to basically change the way business is done and also enabling new business models (See Figure 2.3). With another statement, businesses are developing toward the complete digital ecosystem (Berger, 2016; Schrauf & Berttram, 2016).

Automation, connectivity, digital data, and digital access are the four essential keys for digital transformation of the European construction industry based on Berger (2016) research. In this research a survey and in-depth interview was done with 40 companies (wide range size) in Germany, Switzerland, and Austria's construction industry (Berger, 2016).

1800 Industry 1.0	1900 Industry 2.0	1970s Industry 3.0	Today 2015+ Industry 4.0	2030+ Digital ecosystems
The invention of mechanical production powered by water and steam started the first industrial revolution	Mass production, with machines powered by electricity and combustion engines	Electronics, IT, and industrial robotics for advanced automation of production processes	Digital Supplay Chain	Flexible and integrated value chain networks
			Smart Manufacturing	virtualized process
	Introduction of assembly line	Electronics and IT (such as computers) and the internet constitute the begining of the information age	Digital poducts, services, and business models	virtualized customer interface
			Data analytics and action as a core competency	Industry collaboration as a key value driver

Figure 2.3. The supply chain at the center of the digital enterprise

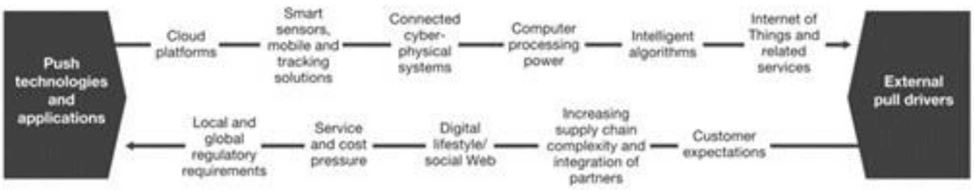

Figure 2.4. digital supply chain would be effected from push and pull technologies

Digital Workplace	**Digital Engineering and manufactruing**	**Digital supplay chain**	**Digital products, services, and business models**	**Digital customer and channel management**
Digital applications				
E-finance	Vertical integration	Integrated planning and execution	Digitaly enhanced products	B2B2C customer interaction
Digital HR	Big data process optimization	Logistic visibility	Intelligent and connected products and solutions	Digital customer experience
Internal knowledge sharing	Predictive maintennce	Procurment 4.0	Automated and data-based services	Omnichannel sales integration
	Condition monitoring	Smart warehousing	Digital bussiness models	Omnichannel marketing
	Augmented Reality	Efficient spare parts management		Point-of-sale-driven replenishment
	Integrated digital engineering	Autonomous and B2C logistics		Microdeliveries
	Digital factory	Prespective supply chain analytics		Customer lifetime value management

Figure 2.5. The long road to industry 4.0, the digitization of every aspect of business (Schrauf & Berttram, 2016)

At the center of all these practices and activities stand the digital supply chain, which is a fundamental key to the production procedure of every company. Digital value chain brings together all relevant players and parties —The suppliers, the production process, distributors of products, and the customer — to extends all corporate functions of the company from vertical integration to horizontal dimension. For this purpose, it utilizes a network of sensors and embedded tags which supervised via a central control system, and managed by a comprehensive data analysis engine (see Figure 2.5 and Table 2.7) (Schrauf & Berttram, 2016). Leading the transformation towards the smart supply chain is a mixture of two strands. From one side, ICT based technologies such as big data analytics, Internet of Things/Systems, and the cloud are entering the market. On the other hand, employees, consumers, and business partners are force companies to develop trustworthy and responsive supply chains to meet their comprehensive and exact expectations (see figure 2.6).

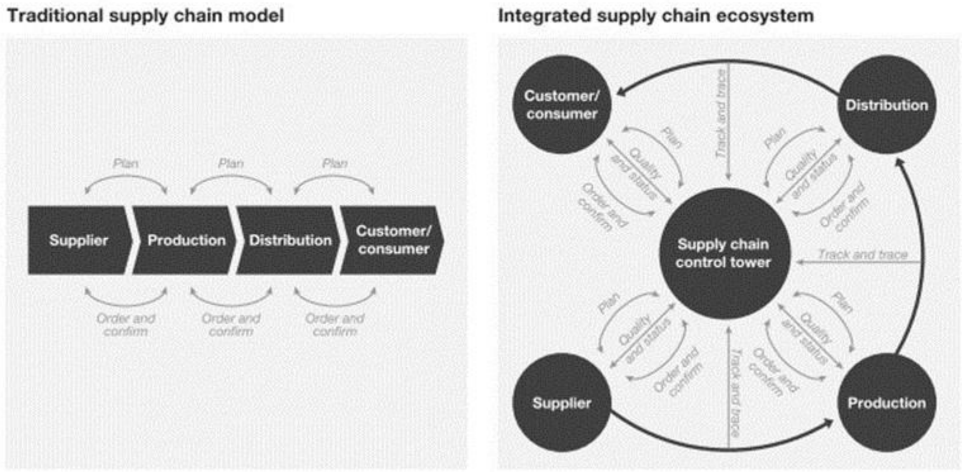

Figure 2.6. The digitally enabled supply ecosystem vs. traditional linear supply chain (Schrauf & Berttram, 2016)

Digitally Enabled Supply Ecosystem	Traditional Linear Supply Chain
Transparency	
Limited view of supply chain	A complete view of Supply chain
Communication	
Information delayed as it moves through each organization	The information available to all supply chain members simultaneously
Collaboration	
Limited visibility to the entire chain, hindering meaningful collaboration	The natural development of collaboration depth to capture intrinsic supply chain value
Flexibility	
End customer demand distorted as information flows along the material path	End customer demand changes are rapidly assessed
Responsiveness	
Different planning cycles resulting in delays and unsynchronized responses across multiple tiers real-time	Real-time response on planning and execution level (across all tiers to demand changes)

Figure 2.7. Traditional vs. digital supply chain, 2016)

CHAPTER 3

INDUSTRY 4.0 RELATED TECHNOLOGIES IN THE CONSTRUCTION INDUSTRY

In first literature review, a list of technologies and concepts that are essential for the implementation of Industry 4.0 in the construction industry are prepared. Cyber-Physical Systems, Radio Frequency Identification/Embedded tags, Internet of Things, Internet of Systems, and Big Data are some of the main pillars of embracing this industrial revolution in the construction industry. Oesterreich and Teuteberg categorized these concepts in three categories of Smart Factory, Simulation and Modeling, and Digitization and Virtualization (Figure 3.1). Each of these categories is consist of related technologies and concepts. In this chapter, these three clusters and their associated technologies state of the art will be reviewed.

3.1. Cluster 1, Smart Construction Site

In order to enable the construction process to be automated and smart, the first cluster technologies which propose a broad variety of technologies will be essential. The technologies associated with this cluster are tailored to one of the critical features of Industry 4.0, end-to-end engineering (E2E). First cluster is consist of technologies such as Cyber-Physical Systems, Internet of Things/Systems, and Radio-Frequency Identification are some of the exciting approaches to the creation of Smart Construction Site. These internet-based platforms and sensors enable the construction site participants to track and monitor the site. These technologies are presented in Figure 3.1 and Figure 4.2 and their description are described in the coming paragraphs.

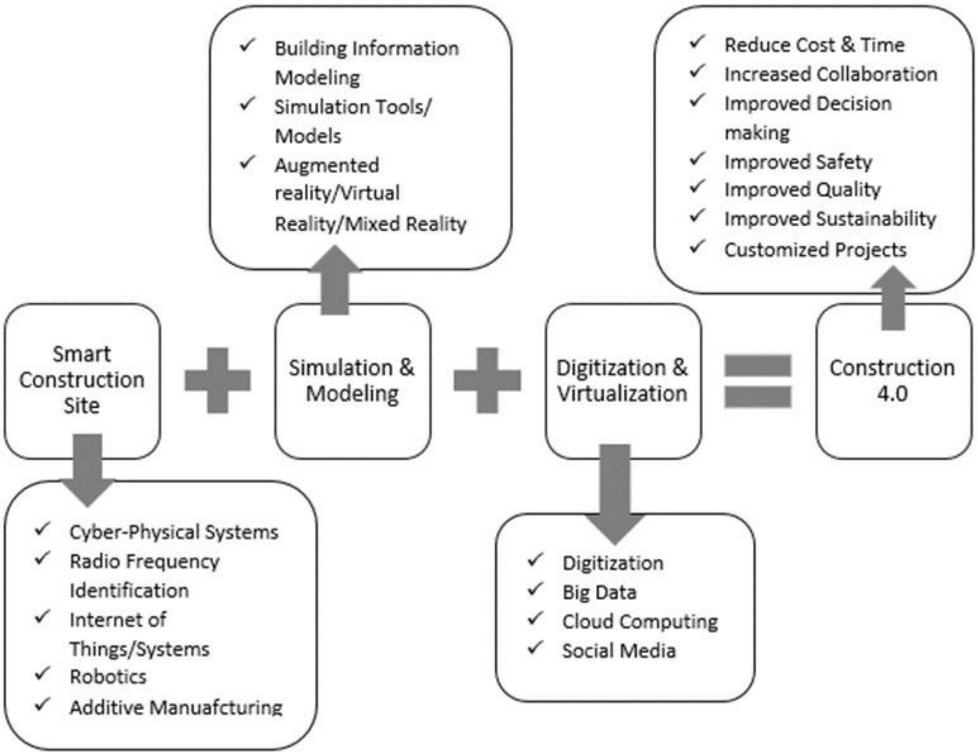

Figure 3.1. A Conceptual Framework for Construction 4.0

3.1.1. Cyber-Physical Systems

Shortly, all physical objects and structures will be equipped with computational and communication capabilities. Beside this mobilizing, applications and codes will be created to take full advantage of these competences through space and time, also, by harnessing these capabilities, a vast social and economic benefit will emerge. Cyber-physical systems is a kind of systems which make a channel between cyber-world and the physical world. These physical and engineered systems (cyber-physical systems) have a computing and communication core to supervise, synchronize, control, and integrate all operations that are done by cyber-physical systems (CPS). It is interact with the physical world, and mostly it operates reliably, securely, efficiently, and most important in real-time (Rajkumar et al, 2010). There are various definitions for cyber-physical systems. For instance, in 2016, Esterle and Grosu introduce CPS as a distributed, time-sensitive, multipurpose, and networked integrated system that requires strong integration of computing, communication and control techniques to attain efficiency, durability, and scalability in managing physical applications. Then in 2018 Ding et al. describe CPS as “large-scale, geographically distributed heterogeneous, and life-critical systems in which embedded devices such as sensors and actuators are networked to sense, monitor, track, and control the physical environment.”

Beghi et al. mention that CPS relates to new and original combinations of hardware and software that create intelligent and self-acting devices which enable effective end-to-end workflows and novel forms of user-machine interaction. Akanmu et al. point out that Cyber-physical system is close integration and coordination of virtual models and physical construction. Cyber-physical systems bring a transition to the physical world via the cyber world. The cyber-world gather data’s by use of sensors and make an atmosphere to transfer this information. This strategy will empower developments in progress tracking, construction process control, as-built documentation, and sustainable building methods.

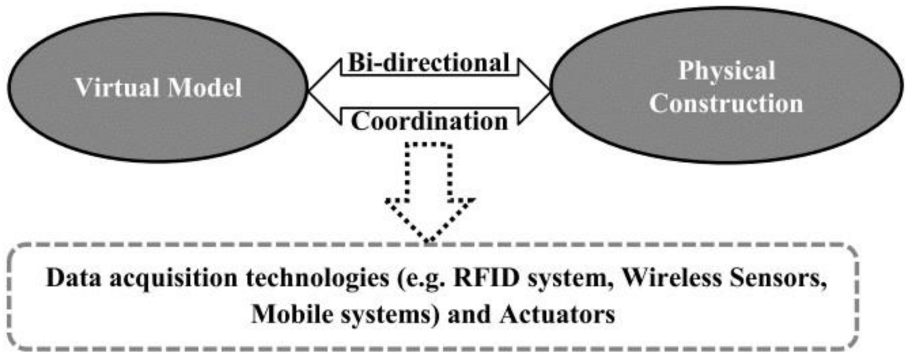

Figure 3.2. Bi-directional coordination between Virtual models and the Physical construction (Akanmu et al., 2013)

The internet and CPS have the same effect on communication. The Internet revolutionized how humans interrelate with each other because it changed where and how the information access. Likewise, CPS will transform how human cooperate and control the physical world. CPS has entered into many layers of various industries. It is notable in medical devices and systems, aerospace industry, defense industry, smart highways, robotics, process control, smart factories, and smart spaces (smart building and environment).

Several latest trends drive CPS ' promise: the explosion of cheap, high-capacity, low-power, and small size computing devices and sensors; a revolution in wireless communication; unlimited internet bandwidth; ongoing enhancements in alternative energy resources and their capacity. On the other hand, cyber-physical systems vendors in industries such as healthcare, aerospace, construction, process control, and smart factories are highlighting the need for CPS technologies. They recognize that the technology to construct highly-specific security-critical CPS in a correct, cost-effective, flexible, scheduled manner does not exist (Rajkumar et al., 2010).

3.1.2. Radio Frequency Identification (RFID)

Philips proposed the smart environment idea, and it brought up in literature for the first time in 1999 (Aarts, 2004). In a smart environment, various technological devices such as sensors, readers, and computers are imperceptible and inconspicuous to users and communicating with them is effortless and straightforward. A typical example is a room with automatic lights, where lights lit if brightness is below a certain amount, and if there are people inside the room. This definition leads to the creation of new research topics related to the automation of human-human and human-machine interactions. Traditional interacting devices are substitute with wireless sensors, touch-sensitive screens, and others. Which requires less interaction with the user. (Valero et al., 2015)

Nowadays, the necessity of automatic identification of elements and the collection of related data is felt in many industrial, scientific, service, and social spheres. Without the need for human intervention to enter information. In response to this need, many technologies have been designed and implemented. An Auto Identification (Auto-ID) term is used to identify a set of technologies which used to identify objects, humans, and even animals by the help of machines. The goal of most automatic identification systems is to increase efficiency, reduce data entry errors, and release employees' time to perform more important and sensitive tasks. So far, various technologies have been designed and developed for automated identification. Bar codes, smart cards, voice recognition, some biometric technologies, Optical Character Recognition (OCR) and Radio Frequency Identification (RFID) are examples in this area.

According to Calis et al. research, in 2011, Radio Frequency Identification (RFID) is a technology that is based on data exchange via electromagnetic signals. Li and Gerber, in 2011, define RFID systems as a technology which has two components, a reader and a tag. When the tag is near or within the codec range, the magnetic field generated by the code reader activates the tag. The integration of chip and antenna is called RFID Tags or RFID transmitter. The tag store identification information (ID) of objects, and it is attached to an object. The chip, with the help of the embedded antenna, transmits the identification information of objects to the reader. The reader transforms the radio waves to digital data to makes it functional for computers to store and analyze data. This set of technology is used for detecting and monitoring objects and people automatically.

Tags can be differentiated by their energy source as passive, active, or semi-passive.

- **Passive tags** will be activated when they are within the codec range of the reader. Their source of power is provided by the electromagnetic energy that the reader emits. Hence, they have an unlimited lifespan. For the same reason, they have short read-write ranges and smaller data ranges. Because of their simplicity, flexibility, and durability in severe environments, passive tags have been entered into various industries.

- **Active tags** power is provided by an internal battery that not only considerably increases the read-write range but also allows for extra built-in memory and local sensing and processing capabilities. This local power results in a shorter lifetime (5-10 years) and more expensive tags. (Ergen et al. 2007c)
- **Semi-passive tags:** Battery-assisted passive (BAP) tags or semi-passive tags use internal batteries to run the chip's circuitry, but they are only communicating and transferring information when they are in the reader's codec range.

In the following table, state of the art for each types of tags are summarized.

	Passive tags	Semipassive tags	Active Tags
Power Source	RF from readers	Internal batteries	Internal batteries
Availability of tag power	Only when within readers' read range	Continous after activated by readers	Continuous
Typical radio frequency	125–135 kHz, 400–960 MHz	400–960 MHz, 2.45–5.8 GHz	400–960 MHz, 2.45–5.8 GHz
Read range	Up to 10 m	Up to 100 m	Over 100 m
Data storage capacity	512 byte to 4KB, normally not extended	Extendable and can vary greatly Extendable	Extendable and can vary greatly
Data Transfer Rate	Up to 1 KB=s	Up to 16 KB=s	Up to 128 KB=s
Lifetime	Unlimited	Over 6 years	Up to 10 years
On-Board data retention	Unlimited	Up to 10 Years	Same as lifetime
Cost	$0.1 to $1, UHF label tags in large quantities are cheap	$20 to $60	$30 to $100

Figure 3.3. Compression of Different Tag Types

RFID is a successful wireless non-contact device that most commonly used. Radio frequency identification technologies are used in various applications, including aviation, construction, facility management, health, retailing, and security, due to its capacity to recognize and track items (Valero et al., 2015).

Radio frequency identification (RFID) has included in the construction industry since the 1990s. It can be implemented in all main stages of the lifecycle of a structure: planning and design, construction and commission, operation and maintenance. Monitoring and tracking the components of a production chain is a process that is usually done using RFID technologies (Valero et al., 2015). In robots construction, the RFID device integration into the manufacturing process enables data to be accessible for the following tasks (Yagi et al, 2005).

3.1.3. Internet of Things and Internet of System (IoT/IoS)

The term “Internet of Things” was invented by Kevin Ashton in a presentation at Procter & Gamble (P&G) in 1999 (Ashton, 2009; BIM engineering U.S., 2018). Internet of Things or the Internet of Services (IoT and IoS) is another key concept in Industry 4.0 that provides the impetus for the development of virtual networks to support smart factory environments. Internet of Things creates value. Oesterreich in 2016 state that from the technical perspective, IoT is the combination of sensors (RFID), cloud applications, ERP (Enterprise Resource Planning) integration, and business intelligence technology. Martac et al. in 2016 defined Internet of Things (IoT) as a network of physical objects which incorporating with electronics, software, and sensors that enable users to acquire precise and in-time data through data exchange services between producers, users, and another connected device. In other words, the IoT allows things and objects to interact with each other through sensors and also cooperate with their neighboring ‘smart’ components, to reach common goals (Hermann et al, 2016). In 2013, Kagermann claimed that the integration of the Internet of Things (IoT) and the Internet of Services (IoS) in the manufacturing process had originated the fourth industrial revolution. As stated in Mckinsey&Company report, using IoT technologies on construction sites, mines, oil and gas extraction sites result in optimizing operations, monitoring the health of machinery, improving health and safety issues. Therefore, the implementation of IoT technologies on worksites can save $160 billion to $930 billion annually (Manyika et al., 2015). Regardless of all benefits, the construction industry did not adopt this technology.

Some examples of IoT implementation in the construction industry is the integrated sensors on physical objects such as vehicles, robotics, and building components which are capable of connecting to the internet. Machineries (cranes, dozers, loaders) which equipped with sensors will transfer performance data via the internet to engineer to be analyzed. According to received data, engineers can predict the upcoming failures in vehicles and fix them beforehand (Oesterreich & Teuteberg, 2016).

In order to ease data collection in construction projects, several cutting-edge techniques were used. The Internet of Things (IoT) with the presence of RFID tags, is one of the core systems as the central technology that promotes supply-chain management, security management, facility management, and activity tracking (Zhong et al., 2017).

3.1.4. Modularization / Prefabricated Construction

Modularization and prefabricated construction is not a new method in the construction industry. This concept has been used through decades by industry's professionals, but mostly known as a cheap and poor-quality method. Contrary to the past, now this is a vital component of improving productivity in the construction industry. It is also counted as an approach to making construction lean (Bertelsen, 2005). Indeed, the advent of contemporary manufacturing methods, sustainability goals, and Building Information Modeling (BIM) rejuvenate old methods of construction in new format (McGraw Hill Construction, 2011).

In a construction project, inaccurate data collection, inadequate communication, and risk-aversion are widespread due to paper-based manual activities on the construction site. These problems are more highlighted in the traditional prefabricated construction method. In order to get through these problems and gain full advantage of prefabricated construction method, several cutting-edge technologies have been used to simplify supply chain management, safety management, facility management, and activity monitoring. For instance, Building Information Modeling's (BIM's) efficient management of physical and functional digital presentations can be beneficial. Along with BIM, the Internet of Things (IoT) and Radio Frequency Identification (RFID) have been used to promote data collection and analysis in construction projects (Zhong et al., 2017b).

Technically, in literature, modularization is known as prefabricated construction. Modularization or prefabricated construction is the practice of fabricating components of a structure in a factory and transporting the semi-complete or complete components to the construction site. Finally, assemble prefabricated components to the structure. (Oesterreich & Teuteberg, 2016; Tam et al, 2007; J. Hong et al, 2016)

In construction companies, prefabrication has already been commonly embraced as it provides excellent advantages in improving quality and safety while lowering waste and expenses (J. Hong et al., 2016). Many studies have been done on the advantage of modularization in the construction industry. Li et al. in 2014 stated that modularization provides controlled circumstances for poor weather, quality assurance, simplifies project schedule, and decreases material waste compared to standard construction technologies. Likewise, Hong et al. believed that in addition to reducing waste, noise, dust, cost, and labor demand modularization also promote the quality control process and ensuring worker's health and safety on construction site (J. Hong et al., 2016).

3.1.5. Additive Manufacturing

Additive Manufacturing is a rapid prototype technology that can be count as modern technology for Modularization. This field is still in its infancy. According to Lipson and Kurman book, rapid prototype technologies (e.g., 3D printing) could completely revolutionize production methods (Shakor et al, 2019). This technology has been developed since the mid-1990s to enable the automated manufacturing of complex architectural components through robotized deposition without using molds (Bos et al, 2016; Oesterreich & Teuteberg, 2016).

The foremost benefit of rapid prototype technologies is, constructing components based on their digital model (e.g., the CAD data) (Vaezi & Chua, 2011). The 3D printers directly received components specifications from the digital model and print it layer by layer until the elements are formed, without extra labor cost. Lloret et al. in 2015 stated that using 3D printing could decrease the total cost of concrete in construction projects by 35–60% merely by eliminating the need for the framework.

The number of companies exploring 3D printing technology has increased dramatically, and a turning point occurred in 2012. Researchers find out that using quasi-exponential development method is more beneficiary than linear development.

3.1.6. Product Life Cycle Management (PLM)

Product Lifecycle Management (PLM) is a well-known and well-established concept which is considered as a crucial component for a digital value chain. Product Lifecycle Management (PLM) is a concept that flawlessly integrates all the data generated during every phase of a company's product life cycle, from a product’s early conception to its withdrawal, with the aim of simplifying product development and enhancing innovation in the supply chain (Sudarsan et al, 2005; Oesterreich & Teuteberg, 2016).

In 2008, Min et al. define PLM as an innovative management approach, which is created by companies and organizations in order to remain competitive and agile in the market. Sudarsan et al. in 2005, defined PLM as “a strategic business approach for the effective management and use of corporate intellectual capital.” This innovative management system is titled as ‘Information lifecycle management’ and eventually developed as ‘Product Life-cycle Management.’

The construction industry is exceptionally fragmented sector. It has a very complex business process and involved from countless stockholders such as client, architectures, engineers, and contractor which are engaged in different phases of a project from different geographical locations. Hence, there is an obvious need for effective data sharing and exchange system. Product lifecycle management can fill this gap for the sector. It can be useful for managing all data that had been produced through the lifecycle of the project and make it accessible to all stakeholders (Min et al., 2008; Motamedi & Hammad, 2017).

The BIM approach led insights from PLM applications to the product and process of the construction industry (Min et al., 2008). According to Ford et al. publication in 2013, “BIM is the construction industry’s response to Product Lifecycle Management

(PLM)" (Ford et al, 2013). Many studies have been done on PLM applications and many BIM-based system structures have been elaborated to gather data, manage them, and make it accessible to all participants until the retirement of the project.

3.1.7. Human-Computer Interaction (HCI)

In the 1980s, Human-Computer Interaction (HCI) emerged with the emergence of personal computing technology. Since computers were no longer room-sized and costly instruments which constructed solely for specialized environments professionals, it became increasingly essential to make human-computer interaction, which was also simple and effective for less seasoned users. HCI is a multidisciplinary area that consists of Human factor engineering, computer science, and cognitive science (Interaction Design Foundation, 2018). Human-Computer Interaction (HCI) related researches are mostly focusing on how to increase the use of Information and Communication Technologies (ICT) in the construction industry (Oesterreich & Teuteberg, 2016). For example, several studies have been done on developing frameworks to simplify ICT implementation in construction supply chain management. Besides, some investigations are started on how to interact with robots to gain a successful solution on construction sites (Shi et al., 2016).

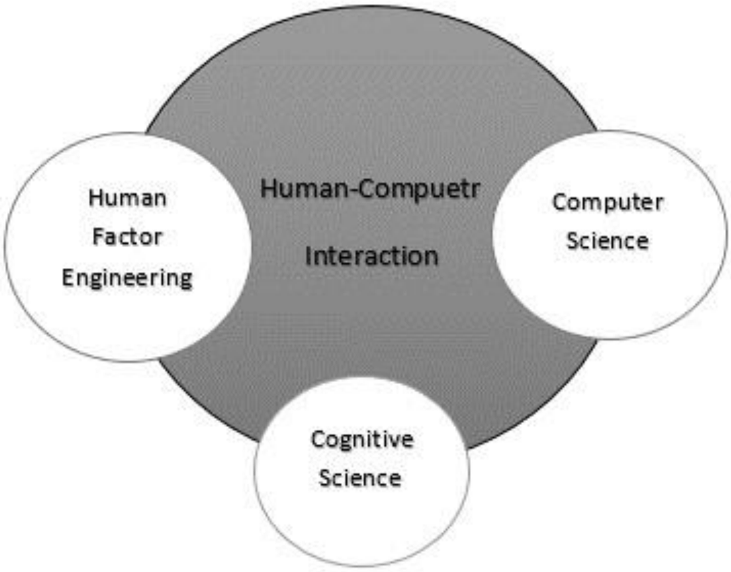

Figure 3.4. The Multidisciplinary Field of HCI (Interaction Design Foundation, 2018)

3.2. Cluster 2, Simulation and Modeling

Simulation and modeling as a critical element for the implementation of Industry 4.0 are discussed in this part. Construction projects inherent is exclusive and complicated; mostly dependent on external variables such as supply variations, unpredictable weather conditions, and worker performance. Therefore, Implementation of second category technologies such as simulation tools and models can be helpful to more effective managing of construction process and enhancing the design of project. Most research in this area proposed a variety of frameworks for project management in general, resource planning, or project planning. Moreover, many studies propose a wide variety of simulation models and tools. (Oesterreich & Teuteberg, 2016).

This category is comprised of Virtual reality, Augmented Reality, Mixed Realuty, Building Inforamtion Modeling, and Simulation Tools/Models, Building Information Modeling, and Augmented Reality/Virtual Reality/Mixed Reality. These technologies will be covered in detail the coming paragraphs.

3.2.1. Simulation Tools / Simulation Models

According to AbouRizk et al. study that had been done in 2011, the concept of using simulation in the construction process was proposed by Teicholz in 1963 in his thesis at Stanford University done. Almost ten years later, Halpin (1973), suggested and implemented the first comprehensive simulation strategy as a tool for managing the construction process and activities (AbouRizk et al, 2011).

In 1993, Oloufa defined simulation as "The method of developing an actual system model and experimenting the model to understand the conduct of the system or to evaluate multiple approaches (Within boundaries enforced by a set of criteria) for the operation of the system." Furthermore, AbouRizk et al. in 2011 defined simulation as a science that model a construction production process and experiment the model's result on the computer

In contrast to mathematical methods, the simulation does not provide an optimum alternative for a system. It can be used in the assessment of a set of predefined options. Almost every issue can be studied using the simulation strategy. Each simulation run becomes an observable and controllable system experiment (AbouRizk et al., 2011)

For simulating construction projects process, the discrete-event method has been introduced as the most comprehensive method, because it represents the behavior of most of the construction projects process correctly and also it is more comfortable to implement. The simulation's behavior is governed by the state of critical entities. The state is a set of variables that are required to define the system's objects at a particular stage in time. Change of State variables in time called event times at designated points. The values of the state variables in a discrete-event simulation do not differ between event times. (Oloufa, 1993; AbouRizk et al., 2011).

3.2.2. Building Information Building (BIM)

The most pervasive and well-known concept of Industry 4.0 is Building Information Modeling (BIM). Under Industry 4.0 concept, Kagermann et al. (2013) are presenting the idea of both the digital value chain and cross-company cooperation as the end-to-end engineering throughout the entire value chain and horizontal integration through value networks. Therefore, BIM can be regarded as one of the core techniques to complement Industry 4.0's primary concept. Since 2012, the amount of BIM publications has increased continuously. It is expected that this process will be constant in the following years, because many countries begin to prioritize the benefits offered by BIM. For example, the German government has recently spoken out of its intention to compel BIM to plan and implement large infrastructure projects since 2020 (Oesterreich & Teuteberg, 2016).

According to Autodesk definition, BIM is an integrated method that significantly increases the knowledge of projects and enables predictable results. This visibility allows all stakeholders to remain coordinated, enhance accuracy, decrease waste, and make informed choices sooner in the process, helping to guarantee the success of the project (Autodesk, 2019). BIM represents a facility's physical and functional features digitally. A BIM is a shared knowledge resource for data that provides a credible foundation for choices during its life-cycle; from early conception to demolition (NIBS, 2013). Indeed, the BIM gives all the project partners the chance to cooperate effectively throughout the entire life cycle by offering appropriate data like cost estimation, planned project, material inventory and technical data on construction components such as geometry and spatial relations (Popov et al, 2010).

3.2.3. Augmented/Virtual/Mixed Reality (AR/VR/MR)

Virtual Reality (VR) and Augmented Reality (AR) are considering as simulation tools and models. Rheingold (1991) defines virtual reality as an experience in which a person is ‘‘Surrounded by a computer-generated three-dimensional depiction that enables the user to travel around and view from various perspectives in the virtual world and capture and reshape it.’’

Masood and Egger in 2019 were introduced Augmented Reality (AR) as a critical component for implementation of Industry 4.0 concept in the industry. Since it enables participants of projects to access digital information and overlap it with the physical world. The annual growth pace of the AR market is anticipated to be 74% between 2018 and 2025. Also, the compound value of market reach to $76 billion in 2025.

Augmented reality is a technology that overlays a computer-generated image with a user's view of real-world (Webster et al, 1996). In the AEC industry, by use of specialized hardware and software, it superimposes 3D digital information (such as Building Information Modeling data) flawlessly into the real-world, In order to provide advantages for architects, engineers, client, and workers in projects. This flourish technology offers significant benefits to the construction industry; therefore, numerous researches had been done, and various applications and frameworks have been suggested. "AR can affect the projects in at least three levels of visualization, information recovery, and collaboration (Dong & Kamat, 2013). By simulating and visualizing, AR enables the viewer to communicate with real and virtual objects and track the construction progress by comparing the project's as-planned and as-built status (Shin & Dunston, 2008)". Park et al. (2013) developed a framework which integrates Augmented Reality (AR) with Building Information Modeling (BIM) to spot construction defects and provide necessary conditions for real-time collaboration and monitoring on-site (Wagner et al, 2017; Oesterreich & Teuteberg, 2016; Golparvar-Fard et al. 2009) established a 4-dimensional AR model has been created to automate project progress tracking, information gathering, handling, and interaction in the project's construction stage. Wang et al. (2007) proposed to use an AR application for heavy construction equipment operator training.

Virtual Reality (VR) is an artificial environment that is generated by computer technology and software. This technology enables users to immerse in a 3D world and have interaction with it. By stimulating more senses, such as vision, hearing, touch, and even smell into this artificial environment, it can create more near-real experiences for users. The accessibility of content and inexpensive computing power are some of the critical limitations for implementation of VR (Bardi, 2019). Virtual Reality for the construction industry considered as the next step for 3D modeling because it consists of a detailed virtual model of the project. The main difference of 3D modeling with Virtual reality is that it places the user directly inside the virtual environment and enable them to walk inside the project (Sharifi, 2018). Although these fields are still in the process of formation, there are some developments and frameworks suggestions, for example, a risk-free virtual environment is developed to prepare space for safety education and training (Sacks et al, 2013). Another example is its advantage in the classroom for teaching. The students can be in touch with the virtual model to witness construction projects sequences in detail and observe the methodologies that have been applied (Sampaio & Martins, 2014).

The last development in reality technologies is Mixed Reality. Mixed Reality (MR) not just overlays the virtual world information with the physical world, it also embeds virtual objects (holographic data from a 3D model) to the real world. Dunston et al. (2017) claimed that Mixed Reality (MR) applications could be beneficial for the efficient communication of prefabrication models, site assembly, planning, and maintenance operations execution. Some companies proposed a few numbers of Mixed Reality (MR) applications, for example, Trimble and Microsoft unveiled the Trimble's Hard Hat as an MR application for the construction industry. This hat is equipped with Microsoft HoloLens, which is an MR product and includes particular components and custom holographic technology processing unit. Integration of Hololens and 3D models enable participants to go over the screen and enter a part virtual and part physical world. In other words, it enables participants to communicate with 3D holograms merged into the physical world. Using more senses like hand movement, eye movement, and voice commands offer participants the chance to discover the 3D model to boost communication, cooperation, and client relationships (Lorek, 2018). Another Mixed Reality (MR) application is "Daqri Smart Hamlet," which is suggested for on-site assistance by showing 3D visual overlaps in the sight field of the user, these hamlets are activating hands-free instruction manuals and remote support in hazardous situations (Leskinen, 2017). MR applications may prove promising for effective communication of designs for prefabrication, site installation, and the planning and execution of maintenance operations.

3.3. Cluster 3, Digitization and Visualization

This category discusses the necessity of digitization technologies in the construction industry. Implementation of the fourth industrial revolution creates a massive amount of digital data that is impossible to be handled by traditional method. Thus, technologies and concepts such as Cloud and Mobile Computing, Big Data, and Social Media are demonstrated as some of few approaches to establish a digital environment and value chain and describe the tendency toward widespread use of ICTs In the coming paragraphs Big Data, Cloud Computing, and Mobile Computing will be described.

3.3.1. Big Data

Big data is an area that addresses methods of analyzing, systematically extracting information from, or otherwise dealing with data sets that are too big or complicated to be handled by traditional data processing application software.

As technology evolves, the world is flooded by the produced data. According to Digital Universe Study (2012), just 0.5% of 2.8 trillion GB produced data of world was used for analysis (Gantz & Reinsel, 2012). The explosion of data creates significant opportunities for scientist to identify valuable perspectives because approachability of data can improve the existing conditions in different arenas by reinforcing statistical and algorithmic methods. Big Data applications implementation in projects would be beneficial for resource and waste management, clash detection and resolution, facility management, energy management, etc. (Bilal et al., 2016).

Same as other industries, the construction industry is faced with a data eruption, too. Especially with the advent of Industry 4.0 concepts and their implementation in projects, the industry is pushed to adopt Big Data. Big Data applications can assist obtain data from all data generating systems such as BIM models, computers, embedded sensors such as RFID tags, equipment, and staffs then distribute it among all participants (McMalcolm, 2015). Likewise, analysis of weather, traffic, and business activities historical big data can create a construction risk pattern and have a positive impact on construction phase performance (Burger, 2015).

Three V is the three characteristics that define Big Data; construction data has these attributes

1. Volume: a vast amount of design data, planning data, contracts data, and others.
2. Variety: heterogeneous format of data (text, audio, video, graphs) in construction can be observed from software formats such as DWG, DGN, RVT
3. Velocity: the active nature of the construction industry and various source of data enables the stream of data (Bilal et al., 2016).

3.3.2. Cloud Computing

Cloud computing is “Internet computing paradigm, providing access to a shared pool of customized resources (Bughin et al, 2010). The whole concept of Cloud Computing is to outsourcing data storage and calculation to a third-party data center. Thus, several users can access the cloud service without purchasing individual licenses (Bilal et al., 2016). Three service models are offered by cloud computing:

1. Infrastructure-as-a-service (IaaS): In IaaS, the users have access to computing resources (storage, servers, and networking) and companies use individual applications and platforms within the IaaS. It provides flexible, tight control, automated, and scalable environment.
2. Platform-as-a-service (PaaS): In PaaS, users are able to create, handle, and deliver applications in a cloud environment. In addition to data storage and computational resources, users would be the beneficiary of pre-constructed tools because they can create, customize, and test their own apps.

3. Software-as-a-Service (SaaS): SaaS is a computer cloud offering model that provides users access to cloud-based software from a vendor. Users do not install apps on local machines. The apps instead lie on the web-based or an API-accessed remote cloud network. Users can store, evaluate, and cooperate on projects through the implementation. Applications are available from nearly anywhere in the globe via almost any device connected to the Internet. (Barabas, 2019)."

In the construction industry, cloud computing is commonly used as it promotes the integration of tasks in BIM-based applications. For integrating the project's participant's interaction with BIM, Das et al. (2014) offered a cloud-based BIM framework. Rawai et al. (2013) in order to develop a framework for green and sustainable buildings, investigated cloud computing technology and the main ideas of sustainable project management. Hong et al. (2012) by use of Zigbee sensors proposed a system which applied cloud computing for projects energy management. Wong et al. (2014), through a literature review, emphasized legal problems related to cloud-based BIM models. Such as ownership of design, safety and legitimacy of data exchanging, liability, and accountability. Kumar and Cheng (2010) proposed the implementation of cloud computing technology for SMEs design and construction companies. Using cloud-based alternatives, allows all project members have access to data from any communication device via internet, for example through a file-sharing collaboration platform, in order to observe, manage, collaborate, and distribute project-based documents in real-time (Oesterreich & Teuteberg, 2016)

3.3.3. Mobile Computing

High data congestion is a prominent feature of the construction industry, which its success depends on the availability of precise and real-time data (Saidi et al, 2017). The produced data needs to be processed, stored, and distributed among stakeholders to keep them up to date and also enable them for effective decision making (Son et al, 2012).

Despite the significance of data storage and processing, modern approaches to managing data at a construction site are labor-intensive and manual intervention. Delays in obtaining, processing, and accessing data, as well as inconsistent and inaccurate access to data, are the main issues connected with manual entry of data (Son et al., 2012). Due to data that is inaccessible, incorrect, or simply obsolete, construction projects can face substantial delays, overruns in costs, or rework (Saidi et al., 2017).

All these reasons put pressure on the construction industry to digitalize data supply and flow of it. Saidi et al. (2012) claim that taking advantage of Mobile Computing and Handheld Computers provide the stakeholders with precise, reliable, and real-time data where required. The 2015 Construction Technology Report states that 97.6 percent of construction professionals surveyed are using smartphones, and 69.4 percent use a tablet for job purpose (Welsh, 2015).

Son et al. (2012) highlighted several opportunities for Mobile Computing for the construction industry;

- Mobile Computing captures and transmit data flawlessly and eliminate the possible errors aroused from manual methods.
- Create a noteworthy influence to process improvement
- Due to flawless data storage and distribution, Mobile Computing eliminate redundant costs
- Mobile Computing can boost productivity by reducing supporting function time)

CHAPTER 4

METHODOLOGY

In order to answer the study questions raised in the introduction chapter, combined research was designed and accomplished one by one (Figure 4.1). Research questions are:

- Question 1: Which technologies in the construction industry are presently linked to the Industry 4.0 concept?
- Question 2: In the construction industry, what is the present state of the art of Industry 4.0 related technologies?
- Question 3: How is the awareness rate of Turkish construction industry about industry 4.0 related technologies?
- Question 4: How is the utilization rate of industry 4.0 related technologies in today's construction industry? Which technologies have been adopted? Also, if it is not utilized now, what they think about its utilization time?
- Question 5: What is the benefit and impact rate of Industry 4.0 technologies in the determined areas (time and cost-saving, decision making, etc.)?

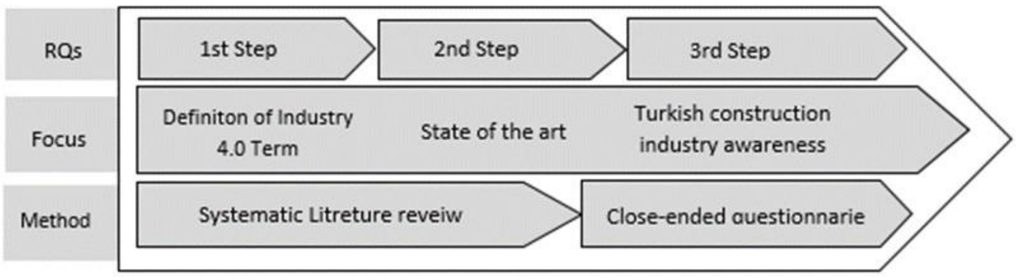

Figure 4.1. Research Design

In order to answer Q1, the first step was to search on different databases such as Google Scholar, ScienceDirect, and Google itself for keywords of “Industry 4.0” and “construction industry.” It becomes apparent that this topic did not gain enough attention between academicians and researchers, still. From 1390 of publications, just 50 of it was relevant to our topic, and most of these 50 publications are not journal or conference papers. The main aim of this systematic literature review and qualitative evaluation of content was to extract a definition for Industry 4.0 term and moreover propose technology and concept list of it. As presented in Table 4.1, Oesterreich and Teuteberg, in 2016 presented a list of Industry 4.0 associated concepts and technologies in the construction industry.

Table 4.1. *List of Industry 4.0 Associated Technologies in the construction Industry*

Cluster	Key technologies and concepts in the context of Industry 4.0
Smart Factory	Cyber-Physical systems
	Embedded systems/RFID
	Internet of Things/Internet of Services
	Automation
	Modularisation/Prefabrication
	Additive Manufacturing
	Product-Lifecycle-Management (PLM)
	Robotics
	Human-Computer Interaction (HCI)
Simulation and modelling	Simulation tools/Simulation models
	Building Information Modelling
	Augmented Reality (AR)/Virtual Reality (VR)/Mixed Reality (MR)
Digitisation and virtualisation	Cloud Computing
	Big Data
	Mobile Computing
	Digitisation
	Social Media

In order to answer Q2, the 2nd literature review must be carried out on the basis of the technology and concept list provided by the 1st literature review. Therefore, our aim at this stage is to explore the state of the art of all technologies regarded as essential technologies for the implementation of Industry 4.0. For searching on databases, mostly the combination of technologies' term with "construction industry" was used. For example, "construction industry and Cyber-Physical Systems," "construction industry and Radio Frequency Identification," "construction industry and Augmented Reality."

Based on the data gathered in the 1st and 2nd literature review, a close-ended questionnaire was designed to provide the essential information for answering research questions 3 to 5.

The achievement of a project depends on the communication and interaction between project members so that this research is based on the perspectives of experts in the construction industry. A quantitative research approach was taken to achieve the study objectives, which include determining the awareness and readiness of construction project participants in Turkey about Industry 4.0 technologies and concepts. This method was used because it could be efficiently studied the link between facts and correlated them with current or previous research by a Non-probabilistic sampling method is used. By designing a close-ended questionnaire, which aimed construction experts, a data collection tool is produced. The designed questions were taken from the first and second literature review, which conducting by revision of various articles, websites, journals, and reports connected to Industry 4.0, Digitization, Construction 4.0, Information and Communication Technologies, and the construction industry in Turkey. As presented in Figure 4.1, the provided list of technologies is summarized to simplify the questionnaire for respondents

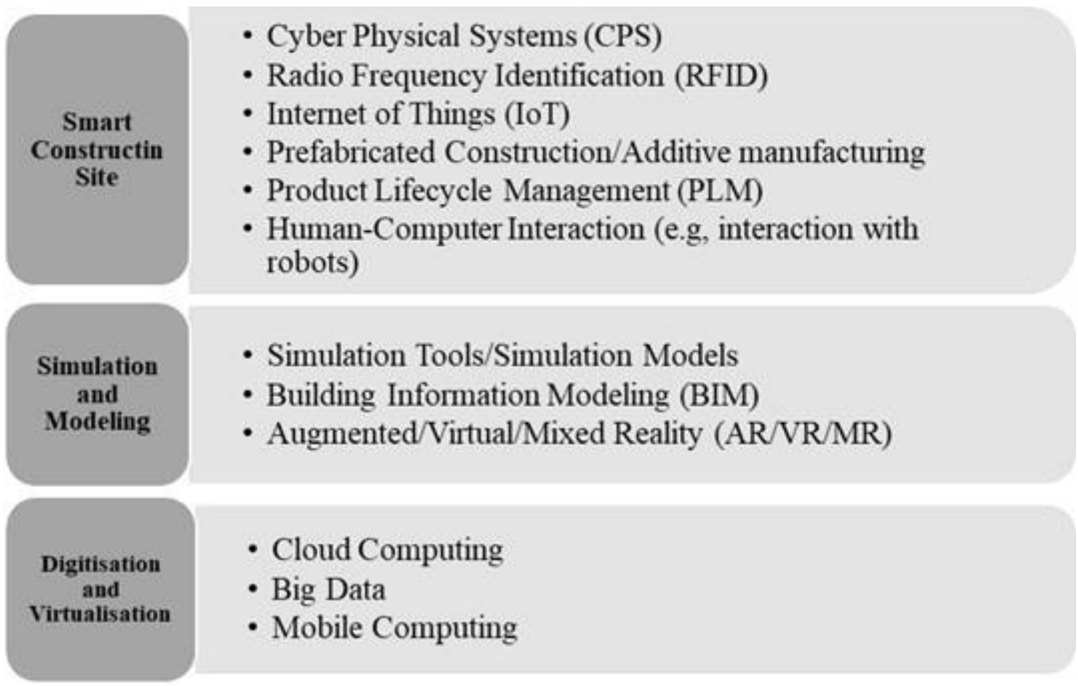

Figure 4.2. List of Technologies That Are Examined in the Questionnaire

The questionnaire is designed in four parts. In the first part the personal information of respondents will be questioning, such as their organization type, company market range (national and international), company size (micro, small, medium, and large), Experience range, and level of expertise in construction-related technologies. These pieces of information enable us to compare the contractor companies' respondents' point of view with the designer companies' respondents.

The second part is covering the respondent's awareness of construction technologies by calculating the mean of rates. In the third part, the respondent's preparedness is examining by asking their idea about technologies utilization rate in the current construction industry and asking their perspective of view about the required time for the implication of Industry 4.0 technologies in the future. The last part is about to scale the determined benefits of technologies from 1 to 5, and finally find out which technology is more beneficiary for the Turkish construction industry.

Nearly seventy-five questionnaires were scattered among construction professionals' participants; a total of 56 were returned, which shows the response rate was 74%, which is sufficient for our study. Therefore, in this study the awareness and readiness of Turkish construction industry towards Industry 4.0 associated technologies and concepts has been assessed. Then a basic strategic roadmap has been propsed.

CHAPTER 5

RESULTS AND DISSCUSSION

In this chapter, the results extracted from the questionnaire will be presented, and the findings will be discussed. To be able to analyze the outputs of the questionnaire in more depth, the background information of the respondents was questioned. For example, their organization type was examined to categorize the respondent's answer according to it and compare the different perspective view of the industry's stakeholders. In the second part, they are going to evaluate their awareness of the concepts and technologies of Industry 4.0 in the construction industry. In the third part, respondents were asked to rate the use of Industry 4.0 technologies and also comment on the required timeframe for implementing these technologies in the industry. In the fourth section, profitability and impact ratings of these technologies to the construction industry were examined.

As will be discussed further in this chapter, our respondents are consist of designer, contractor, academician, and consulting engineers. Diversity of respondents enables this study to perform a partial comparison of their standpoint about Industry 4.0 technologies in the construction industry. Moreover, to see the difference of opinion of companies operating in the "National Market" and "International and National Market," a small comparison was made.

5.1. Respondents' Background Information

As mentioned in the methodology chapter, the first part of the questionnaire examined respondent's background information. In this part, the company's type, the company's market range, the company's size, the respondent's experience range, and the respondent's level of expertise in technologies. Figure 5.1 shows that 41% of 56 respondents are from design companies, 30% of them belong to contractor companies, 16% are academicians and R&D researchers, and finally consultant company proportion is 13%.

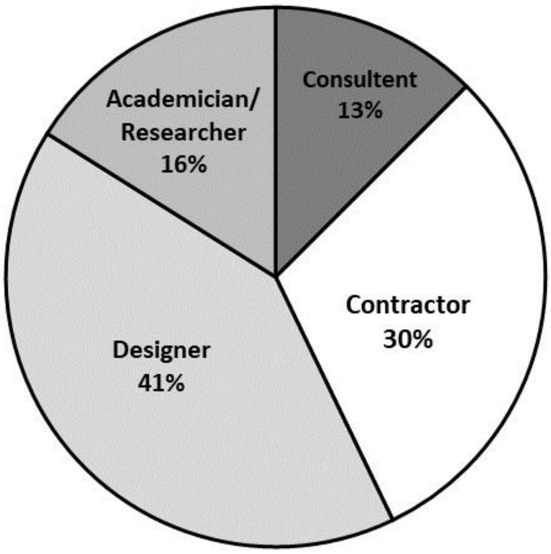

Figure 5.1. Respondent's Company Type

Figure 5.2 shows that 47% of participants are work in the national and international market, 43% is work in the national market, and 9% state that the available choices are not applicable for them. Most probably, these five people are academicians. Future in this chapter these two group of respondents will be compared.

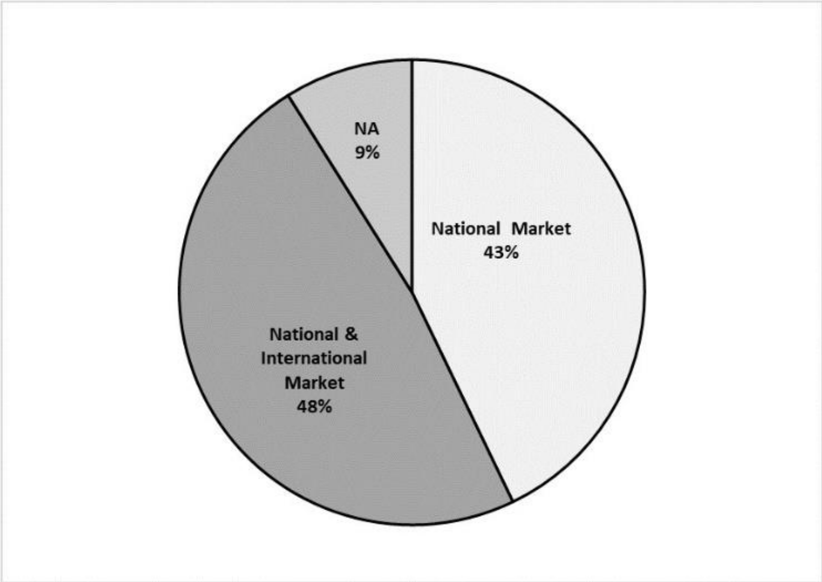

Figure 5.2. Respondent’s Market Range

Figure 5.3 demonstrates the third question answer, which asks the respondents' experience range in the construction industry. Whereas accessing to highly experienced engineers was hard, almost 40% of our participants have more than ten years of experience in the construction industry. The gathered data shows that almost 43% of participants have 0 to 5 years of experience, 21% have 10 to 15 years, 18% have 5 to 10 years, and the same proportion (18%) is valid for people who have more than 15 years’ experience.

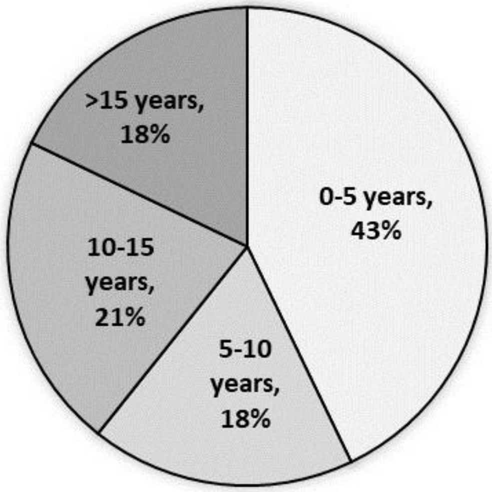

Figure 5.3. Respondent's Experience Range

According to publications companies with more than 250 employees consider as large companies, 50-250 employees considered as medium-sized, 10-50 employee considered as small-sized, and with less than 10 employees it will be categorized as micro-sized companies. In our questionnaire approximately 46% of respondents work in large companies, which has more than 250 employees. 18% work in medium-sized companies, according to published papers, companies with 50-250 employees considered as medium-sized companies. 18% works in small-size companies, small-sized companies have 10-50 employees. 9% works in micro-sized companies, which has less than ten employees. And 9% of participants answered not applicable (NA) choice (See Figure 5.4).

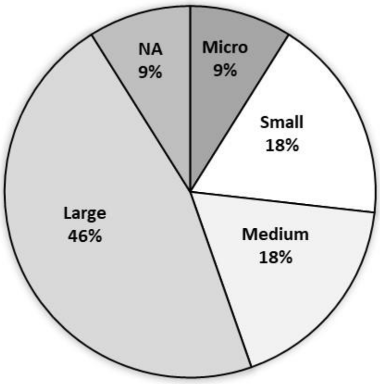

Figure 5.4. Respondent’s Company Size

The last question in the background information section gathered data about participants’ level of expertise in construction-related technologies. More than half of the participants, almost 55%, categorized themselves in the medium-level group. In follow of that, the high-level group with 23%, the low-level group with 13%, the very high-level with 5%, and the very low-level group with 4% ranked from second to fifth, respectively.

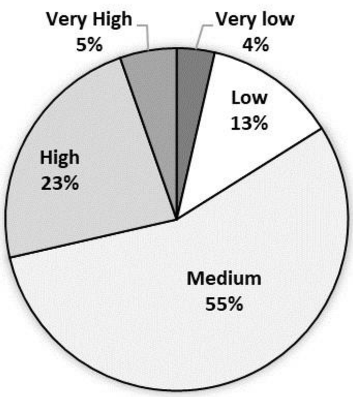

Figure 5.5. Respondent’ level of expertise in construction-related technologies

In Table 5.1, the summary of participants' background information and their company is presented.

Table 5.1. *Summary of Respondents' Background Information*

Summary of Background Information

Category of participents	Percentage	Frequency	Total
Consultent	13%	7	
Contractor	31%	17	
Designer	40%	23	
Academician/Researcher	16%	9	56
National (Domestic Market)	44%	24	
National and International Market	48%	27	
Not applicable	9%	5	56
Micro	9%	5	
Small	18%	10	
Medium	18%	10	
Large	45%	26	
Not Applicable	9%	5	56
0-5 years	44%	24	
5-10 years	18%	10	
10-15 years	20%	12	
>15 years	18%	10	56
Very low	4%	2	
Low	13%	7	
Medium	55%	31	
High	24%	13	
Very High	5%	3	56

5.2. Awareness

5.2.1. Awareness Towards Industry 4.0 Technologies

As discussed in the methodology chapter, for developing a modernized construction industry, three categories of Industry 4.0 related technologies need to be implemented. These categories are the smart factory, simulation tools, and digitization tools which breakdown into respective technologies and asked respondents to clarify their awareness about these technologies. The participant's responses are presented in Table 5.2. In the coming paragraphs, data obtained from other aspects of these technologies will be examined.

Table 5.2. *Respondents' Awareness about Industry 4.0 Related Technologies*

	Yes		Partial		No		
	Percentage	Frequency	Percentage	Frequency	Percentage	Frequency	Total
Cyber-Physical Systems	21%	12	27%	15	52%	29	56
Radio-Frequency Identification	18%	10	29%	16	54%	30	56
Internet of Things	36%	20	27%	15	38%	21	56
Prefabricated Construction/Additive Manufacturing	36%	20	34%	19	30%	17	56
Product Life-cycle Management	21%	12	43%	24	36%	20	56
Human-Computer Interaction	29%	16	38%	21	34%	19	56
Simulation Tools/Simulation Models	54%	30	29%	16	18%	10	56
Building Information Building	77%	43	16%	9	7%	4	56
Augmented/Virtual/Mixed Reality	39%	22	30%	17	30%	17	56
Cloud Computing	38%	21	21%	12	41%	23	56
Big Data	29%	16	27%	15	45%	25	56
Mobile Computing	45%	25	29%	16	27%	15	56
Mean	37%		29%		34%		

As shown in table 5.2, stunningly, on average, 37% of respondents claim to be aware of these technologies, 29% have imperfect information, and 34% have no information. In comparing with the South Africa construction industry awareness, Turkey's construction industry professionals are more mindful of Industry 4.0 technologies and concepts (Osunsanmi, Aigbavboa, & Oke, 2018).

The Turkish Construction industry have shown that with a noticeable difference, with 77% of awareness rate, BIM is the most well-known technology of the Fourth Industrial Revolution. In follow of that, Simulation tools/models, Mobile Computing, and Augmented Reality with 54%, 45%, and 39% took the second, third, and fourth place. These findings are in correspondence with other studies which represent BIM as a pillar technology for transforming the construction industry manufacturing environment. Also, the frequency analysis of the publications confirms that BIM has been taken into consideration by scholars and actors in the construction industry.

To be able to rank the most known technology to the least known one, an approximate awareness mean was calculated. Then the mean of 3 was set as a border, any technology with average higher than 3 will be consider as known technology and with an average less than 3 shows that there is lack of awareness in these areas. The result has been shown in Figure 5.6. In order

As the majority of technologies and concepts obtained low means, the little knowledge of construction industry participants in Industry 4.0 technologies, which are considered as modern and digital intensive technologies, can be seen. The low amount of R&D investment in the construction industry has resulted in a low level of awareness and the benefits provided by Industry 4.0 technologies.

Rank		Mean	
1	Building Information Building	4.04	
2	Simulation Tools/Simulation Models	3.54	
3	Mobile Computing	3.27	
4	Augmented/Virtual/Mixed Reality	3.13	
5	Prefabricated Construction/Additive Manufacturing	3.08	+3
6	Internet of Things	2.97	
7	Cloud Computing	2.95	
8	Human-Computer Interaction	2.92	
9	Product Life-cycle Management	2.79	
10	Big Data	2.76	
11	Cyber-Physical Systems	2.54	
12	Radio-Frequency Identification	2.46	

Figure 5.6. Awareness of Respondents about Industry 4.0 Technologies

As presented in Figure 5.6, Building information modeling, simulation tools, simulation models, mobile computing, Augmented/Virtual/Mixed Reality and prefabricated construction have gained the highest awareness mean among all technologies and concepts, which shows that most technologies from simulation cluster are known in the industry. In addition, it can be concluded that the respondent's consciousness level can be linked to the defined advantage of implementing these technologies elsewhere in the world.

On the other hand, radio frequency identification, cyber-physical systems, big data, product life cycle management, human-computer interaction, cloud computing, and Internet of Things are in the second half of the list indicating low awareness of respondent towards these technologies. While most of these technologies, including cyber-physical systems, Internet of Things, and radio frequency identification, are the main backbones for digitizing the manufacturing environment and the construction value chain.

5.2.2. Various Stockholders' Awareness Towards Industry 4.0 Technologies

The differences in the level of awareness among design companies, contractors, consulting organizations, and academicians/researchers are presented in Table 5.3 and Figure 5.7.

Table 5.3. *Stockholders' Awareness Rate about Industry 4.0 Technologies*

Industry 4.0 Technologies	Designer	Contractor	Consultant	Academician
Cyber-Physical systems	2.61	2.56	4.07	2.83
Radio Frequency Identification	2.35	2.38	3.64	2.83
Internet of Things	3.20	2.91	3.64	3.83
Prefabricated Construction/Additive Manufacturing	3.33	2.38	3.64	3.33
Product Life-cycle Management	2.93	2.47	3.43	3.17
Human-Computer Interaction	3.07	2.91	3.64	3.83
Simulation Tools & Models	3.59	3.35	3.64	3.83
Building Information Building	3.91	3.00	4.29	3.83
Augmented & Virtual Reality	3.00	2.82	3.43	4.00
Cloud Computing	3.39	2.91	4.07	3.50
Big Data	2.87	2.74	3.86	3.67
Mobile Computing	3.39	3.18	4.07	3.67
Awarness Average	3.14	2.80	3.79	3.53

Designers with an average of 3.14 ranked as the third aware group among all others. As depicted in Table 5.3 and Figure 5.7, Building Information Modeling and Simulation Models and Tools are well-known technologies in the design companies, which represents that simulation and modeling cluster of technologies are gained attention. Building Information Modeling consider as a simulation tool, which is the most frequent word in publications and most implemented technology in the construction industry.

Simulation Tools and Simulation Models, Mobile Computing, Building Information Modeling, Internet of Things, Human-computer Interaction, and Augmented/Virtual/Mixed Reality are the most familiar technologies for the contractors. These findings are in accordance with Berger publication in 2016, which represents Mobile Computing as a technology that already took place on the construction site due to its accessibility. Also, as explained in the previous paragraphs, the technologies that already had been adopted in other countries and Turkey, such as BIM, took place in the first place of awareness ranking. As it is evident in Table 5.3, contractors with an average of 2.8 are the least aware group.

In general, the average level of awareness of consultants is higher than the other three groups, with an average of 3.8. No wonder once again BIM achieved the highest level of awareness, but the high average of Cyber-Physical Systems, Cloud Computing, Big Data, Radio Frequency Identification, Internet of Things, and Human-Computer Interaction was impressive. All of these technologies have been neglected as critical technologies for digitization in the construction industry, but they received attention among consultants. This level of awareness can be due to the consultant's knowledge towards the significance of data transfer and analysis and the importance of communication and cooperation between parties.

The last group of respondents belongs to academicians and R&D engineers. With an average of 3.53, they were the second aware group of this study. According to the number of publications about Augmented/Virtual/Mixed Reality, Internet of Things, Human-Computer Interaction, and Simulation Tools, this level of awareness was expected from the academicians and researchers. In order to increase the awareness of the practical part of the industry, academicians' attention is required to some leading technologies of industry 4.0, such as Cyber-Physical Systems and Radio Frequency Identification tags. As discussed in the literature reviews, it is vital to adopt Industry

4.0 technologies in the construction industry and prepare a roadmap for companies in order to gain competitiveness in the global market and maintain its profit margins. In developing countries such as Turkey, the construction industry has a significant contribution to GDP and economic growth of the country; it is critical to raise the awareness and propose frameworks for its implementation into the construction value chain.

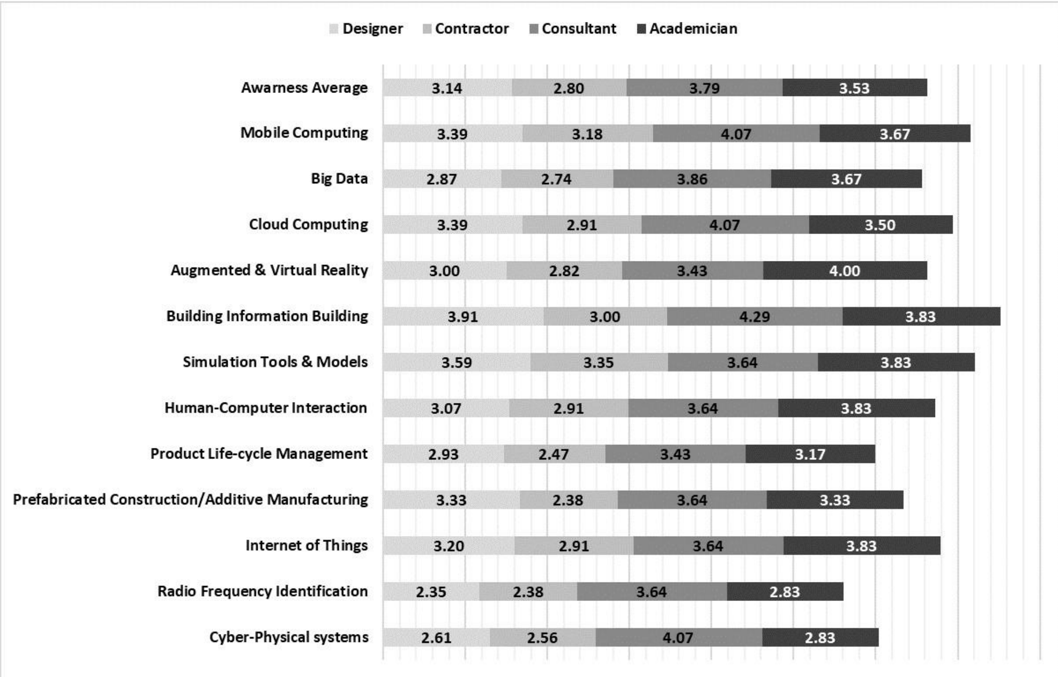

Figure 5.7. Stockholders' Awareness Rate about Industry 4.0 Technologies

5.2.3. International and National Market Player's Awareness Rate Towards Industry 4.0 Technologies

Engineering News-Record publishes a list of top 250 contractors of the world annually. This magazine reported that from 2016 to 2017, a 3.1% boost occurred in contracting revenues (from $468.12 billion to $482.40 billion). This rise comes after three straight years of revenue declines among the Top 250.

In 2012, with 33 companies in the list, Turkey had been ranked second in the list after china with 55 firms. While the number of firms is quite high, the volume of the work undertaken by Turkish contractors was less than 4% in 2012 and 2013, then reached 5.5% till 2016. Although till now the Turkish contractors have managed to preserve its second position in the list after China, its total market share in the global construction market decreased to 4.6%. Moreover, its share in the Asia construction market fell from 4% to 2.1% and surged from 9.7% to 10.4% in the Middle East (Gary J.Tulacz & Peter Reina, 2018)(Engineering News-Record, 2018)(Dem, 2014).

In this study, the number of respondents that work in the national market and the international market is almost equal. As shown in Table 5.1, nearly 48% of respondents' market range is "the international and national market" and 43% is "the national market."

As it is depicted in Figure, the respondents that are working in the international market with a minor difference are more aware of Industry 4.0 technologies than respondents that are active in the national market. Working in international markets empowers the companies to act beyond boundaries and push their limits. Industry 4.0 related technologies had been adopted in U.S.A, UK, Germany, China, and many other European countries, so working international make companies conscious about modern technologies and management methods. Partnerships with local companies that already experienced this transformation and legal obligations to the implementation of technologies make international firms more mindful.

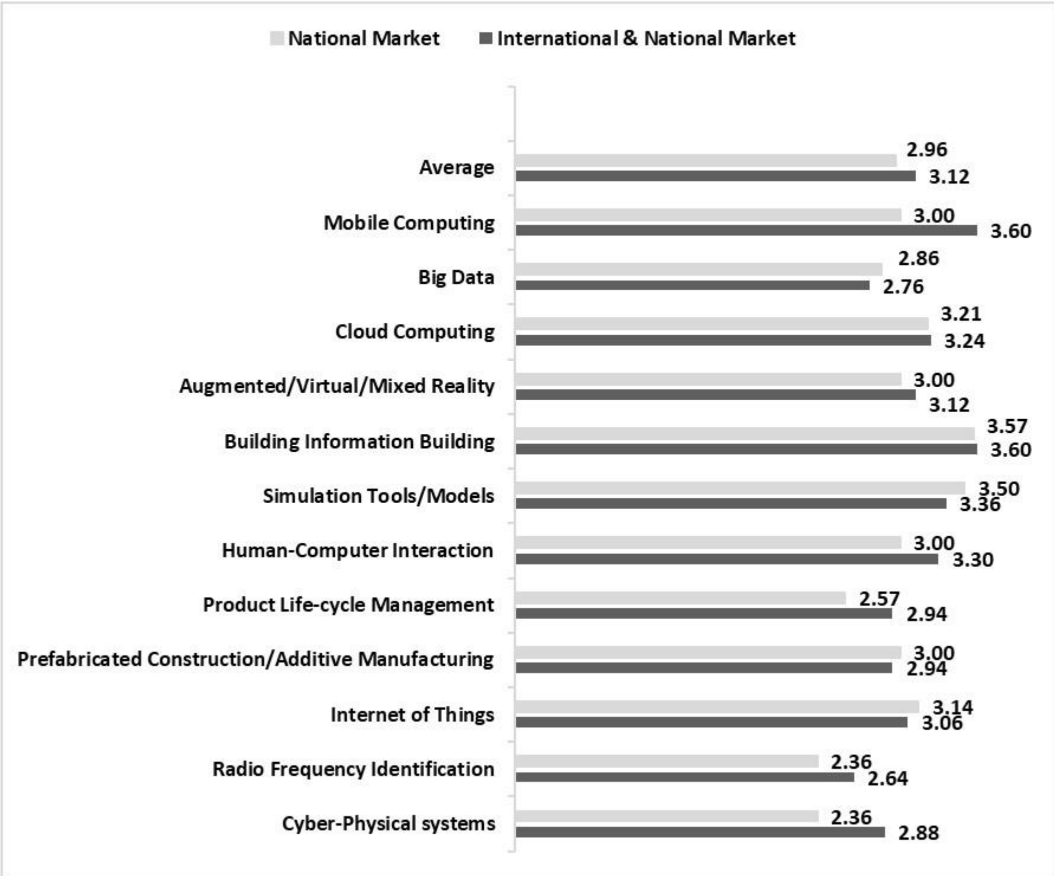

Figure 5.8. International and National Market Player's Awareness Rate

5.3. Level of Utilization

5.3.1. Utilization Rate of Industry 4.0 Technologies in the Construction Industry

Respondents were asked in the third section to rate the level of utilization of each technology in from 1(low) to 5(high), in today's market. In follow of that they propose their idea about these technologies utilization in future with choosing one of already utilized, short term, long term (more than 10 years), and no potential choices.

According to Figure 5.7, as expected, Building Information Modeling and Simulation Tools/Models are the mostly implemented concept in today's construction industry as they obtained an average above 3. In follows of that Prefabricated Construction and

Additive Manufacturing, Mobile Computing, Internet of Things, Cloud Computing, Big Data, Augmented/Virtual/Mixed Reality, Product Life-cycle Management, Human-Computer Interaction, Radiofrequency Identification, and Cyber-Physical Systems are ranked third to twelfth, respectively.

Cyber-Physical Systems, RFID tags, and Internet of things again has the least implementation rate in today's construction industry. While the main pillars for moving the AEC industry towards digitization are these technologies, this absence of awareness and utilization generate from construction industry nature, which consists of many stakeholders, making it a heavily fragmented sector, the low rate of investments in R&D, and lack of researches in the academic environment of the industry.

By holding exhibitions, conferences, and providing training grounds in universities, construction experts will be conscious that embracing Industry 4.0 technologies will facilitate their road towards the digitization and enable them to overcome many problems, such as eliminating a considerable amount of material and time wastes.

Rank		Mean	
1	Building Information Building	3.66	
2	Simulation Tools/Simulation Models	3.13	+3
3	Prefabricated Construction/Additive Manufacturing	2.91	
4	Mobile Computing	2.75	
5	Internet of Things	2.66	
6	Cloud Computing	2.59	
7	Big Data	2.57	
8	Augmented/Virtual/Mixed Reality	2.55	
9	Product Life-cycle Management	2.52	
10	Human-Computer Interaction	2.39	
11	Radio-Frequency Identification	2.20	
12	Cyber-Physical Systems	2.16	

Figure 5.9. Utilization Rate of Industry 4.0 Technologies in Today's Construction Industry

In Table 5.3, the calculated averages for each available option is presented. The short-term gained 38% and sat in the first place, then long-term choice with 37% is in the second place. Already-utilized with 21% and no-potential with 4% ranked third and fourth. According to gathered data, almost 38% of Turkish construction industry professionals believe that Industry 4.0 technologies will be implemented in the short-term (less than 10 years). The same number of professionals believe that these technologies will be accepted in long-term (more than 10 years), and 4% states that these technologies have no place in the construction industry.

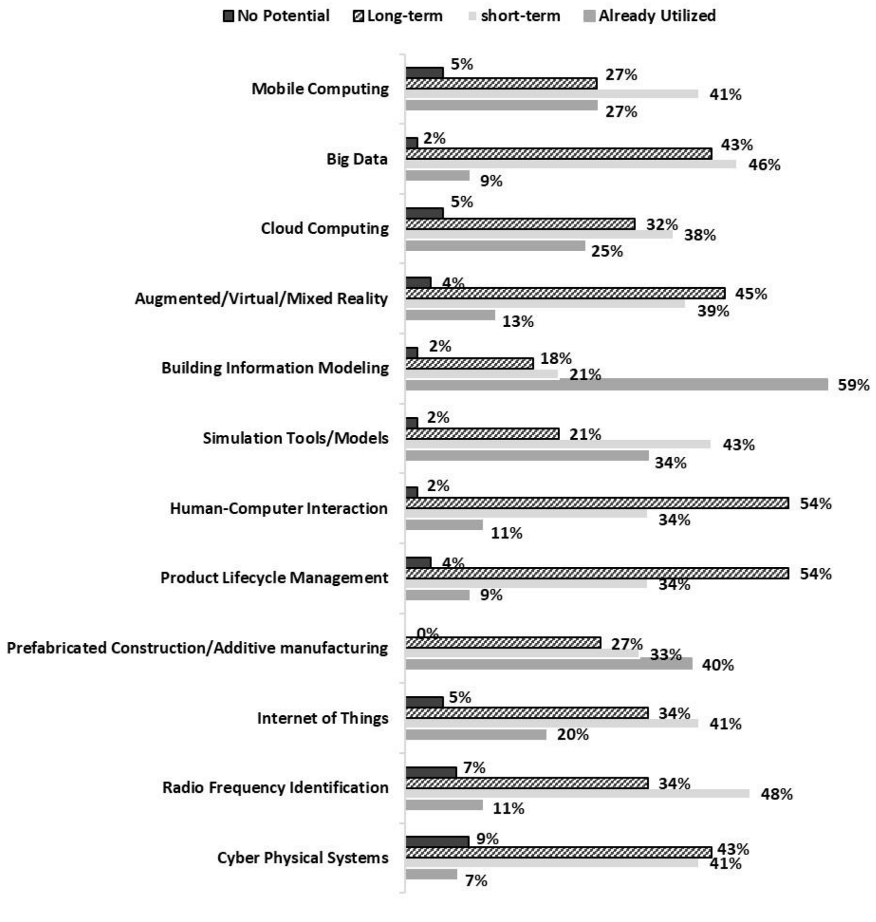

Figure 5.10. Required Time for Implementation of Industry 4.0 Technologies in the Construction Industry

5.3.2. Various Stakeholders' Standpoint about Utilization Rate of Industry 4.0 Technologies in the Construction Industry

However, over the same period, the construction industry has continued to operate as it has for the past 50 years. It still relies heavily on manual labor, mechanical technology and establishes operating and business models. As a result, productivity has stagnated.

Only recently have digital technologies begun to implement into the construction industry, gradually changing how infrastructure, real estate, and other built assets are designed, constructed, operated and maintained. These technologies, including Building Information Modeling (BIM), Prefabricated Construction, Additive Manufacturing (3D printing), Radio Frequency Identification tag, and Human-computer Interaction (automated and robotic equipment) are affecting the entire industry. As seen in the previous paragraphs, the overall average utilization rate of Industry 4.0 technologies in the construction industry is almost 2.7. In order to observe the difference in the stakeholders' point of view, each technology utilization rate calculated based on the type of respondent's organization type. As it is seen in Figure 5.10, there is no significant difference among them; just the contractor group rate the utilization of these technologies in today' construction industry above 3. In follow of that, consultants, academicians, and designers took place. This slight difference in the contractor group may be due to their witnessing the adoption of new technologies stemming from their active role in the practical phase of a construction project.

As represented in Figure 5.10, Building Information Modeling, Simulation Tools/Models, and Prefabricated Construction are the most implemented technologies from all stakeholders' standpoint. These findings are in accordance with Osunsanmi et al. research in 2018 which represent simulation cluster as the most known and implemented technologies in the South Africa construction industry.

Due to the nature of the construction industry which has significant delays in adopting new technologies and the low awareness of cyber-physical systems, Internet of

Things, radio frequency identification tags, cloud computing, and Big Data makes the utilization rate of these technologies in the construction industry is low.

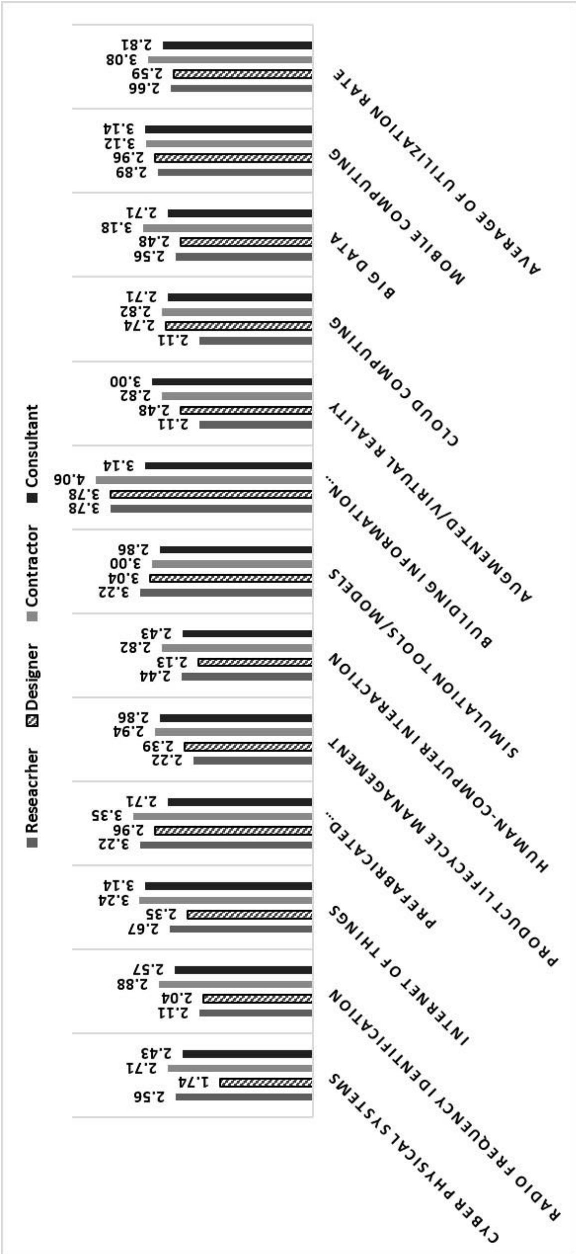

Figure 5.11. Utilization rate of technologies in the construction industry form different parties' point of view

5.4. Benefit and Impact of Industry 4.0 Related Technologies

In the last section, the benefit and impact of industry 4.0 associated technologies have been questioned. Based on the literature review that has been done, provided opportunities by implication of Industry 4.0 associated technologies and concepts in the construction industry, are categorized and summarized as:

- Time and Cost Saving
- Enhancing Quality and Sustainability
- Enhancing Communication and Collaboration
- Enhancing Safety
- Enhancing Decision Making

Respondents rate the advantages outlined above for each technology from 1 to 5.

Time and Cost Savings: Various studies confirmed that timely and budgetary delivery of construction projects is a difficult task. So, the use of innovative digital technologies will simplify the conversion of the traditional construction process, which is a labor-intensive industry, to an automated one. For creating an automatic construction environment taking advantage of innovative digital technologies will be beneficiary. Such as using robotics, automatic workflows, and integrated sensors that enable automatic monitoring of machines, equipment, and materials. Using BIM can assist reduce to maintain the project under budget and estimated time. Use of prefabricated elements or additive manufacturing technology which accelerate the construction time. All these actions result in the reduction of time and cost. (Aghimien et al, 2018; Maskuriy et al, 2019; Sardroud, 2012; McGraw Hill Construction, 2011)

Respondents were asked to rate each technology from 1 to 5 to rank technologies for their importance in saving costs and time. The average is calculated for each technology and ranked based on these averages. Based on the questionnaire data, construction professionals in turkey thinks that Building Information Modeling with a mean of 4.02, has the most effect on delivering a project on time and under budget.

Prefabricated Construction and Additive Manufacturing came in second place with a mean of 3.55. After that, Internet of Things and Mobile Computing obtained the same mean of 3.39.

Rank	Time and Cost Savings	Mean
1	Building Information Building	4.02
2	Prefabricated Construction/Additive Manufacturing	3.55
3	Internet of Things	3.39
4	Mobile Computing	3.39
5	Big Data	3.34
6	Cloud Computing	3.25
7	Simulation Tools/Simulation Models	3.18
8	Human-Computer Interaction	3.09
9	Radio-Frequency Identification	3.04
10	Product Life-cycle Management	2.96
11	Cyber-Physical Systems	2.93
12	Augmented/Virtual/Mixed Reality	2.89
	Overall Average	3.25

Figure 5.12. Impact of Industry 4.0 Technologies on Time and Cost Savings

Enhancing Quality: Simulation tools, simulation models, and BIM-based platforms enables construction professionals to simulate entire construction workflow in the first stage of projects to eliminate errors and improve the quality of the project. Likewise, big data analysis (based on historical data) provides the basis for more effective and informed project managers' decisions that leads to improved project quality. (McMalcolm, 2015)

Enhancing Sustainability: According to IPCC publication in 2007, approximately, the construction industry is using 40% of the total produced energy of the world, which leads to its dominant contribution up to 30% of global greenhouse gas (GHG) emissions, each year. The vast amount of wastes during the construction phase of the project has a share in this 30% too. These statistics ranked construction industry among the seven predominant sectors, which make the most significant participation in worldwide emissions of greenhouse gases. Some alternatives methods have been suggested to address these environmental issues. For example, using BIM to enable sustainable design and construction process and propose a framework to minimize waste in the project. Also, the use of prefabricated concrete elements releases 10% less greenhouse gas in comparing with the cast-in-situ method. (Yin et al, 2019; Dong et al, 2015; Chou & Yeh, 2015, Dong et al., 2015)

Same as other benefit and impact rating method, a mean was calculated for technologies impact on improving the quality and sustainability of projects. Again, Building Information Modeling was ranked first. Then Prefabricated Construction/Additive Manufacturing, Internet of Things, Simulation Tools/Models, Cyber-Physical Systems, Product Life-cycle Management, Cloud Computing, Mobile Computing, Big Data, Radio Frequency Identification, Augmented/Virtual/Mixed Reality, and Human-Computer Interaction was ranked second to twelfth.

The real-time information is a critical issue for improving the quality of the project and creates a more sustainable environment in construction site, also for the life-cycle of the project. Although concepts and technologies like CPS, RFID, PLM, Big Data, Cloud Computing, Mobile Computing, and HCI are vital resources to produce real-time data and make it accessible to all stakeholders, they did not catch enough attention in the Turkish construction industry (according to their low means). Real-time information is essential for better decision making during the procedure

Rank	Improving Quality & Sustainability	Mean
1	Building Information Building	3.93
2	Prefabricated Construction/Additive Manufacturing	3.61
3	Internet of Things	3.41
4	Simulation Tools/Simulation Models	3.41
5	Cyber-Physical Systems	3.34
6	Product Life-cycle Management	3.18
7	Cloud Computing	3.18
8	Mobile Computing	3.18
9	Big Data	3.16
10	Radio-Frequency Identification	3.05
11	Augmented/Virtual/Mixed Reality	2.96
12	Human-Computer Interaction	2.93
	Overall Average	3.28

Figure 5.13. Impact of Industry 4.0 Technologies on Improving Quality and Sustainability

Enhancing communication and collaboration: The construction industry is made up of different stakeholders, which makes it a scattered sector and makes communication and cooperation between stakeholders difficult. Cyber-physical systems, cloud computing, mobile computing, and BIM-based platforms can impressively enhance communication and collaboration between companies and even beyond the company's border. Another example is the combination of wearable computers or mobile devices with simulation tools like Virtual Reality, Augmented Reality, and Mixed Reality. This combination enables engineers, technical staffs, and labors to have a better vision of each stage and activity; also, it allows the owner to deeply understand the details of design, planning, and construction process in the early stages, the outcome will be a customized project. (Merschbrock & Munkvold, 2015; Groves-Delphos, 2014; Jones, 2016)

The Turkey construction industry professionals rate technologies in terms of their impact on boosting communication and collaboration, as shown in Table. Based on the respondent's knowledge, BIM with an average of 3.89 has the highest impact and PLM, Prefabricated Construction/Additive Manufacturing, and Radio Frequency Identification with almost the same average of 3.04 are the least effective technologies. This ranking was almost one of the few that was in line with researches. However, again, Cyber-Physical Systems and Radio Frequency Identification are not in the position they deserve

Rank	Enhancing Collaboration & Communication	Mean
1	Building Information Building	3.89
2	Cloud Computing	3.59
3	Mobile Computing	3.48
4	Internet of Things	3.45
5	Big Data	3.30
6	Simulation Tools/Simulation Models	3.23
7	Augmented/Virtual/Mixed Reality	3.23
8	Cyber-Physical Systems	3.14
9	Human-Computer Interaction	3.11
10	Radio-Frequency Identification	3.07
11	Prefabricated Construction/Additive Manufacturing	3.04
12	Product Life-cycle Management	3.04
	Overall Average	3.30

Figure 5.14. Impact of Industry 4.0 Technologies on Enhancing Communication and Collaboration

Enhancing safety: Due to the harsh and dangerous environment of the construction industry, safety is a critical issue for construction site staff, contractor, owner, and researchers. Various sources have spoken about the construction industry casualty statistics. In the whole world, the construction industry contribution to fatal work-related injuries is almost 30%, which is 108,000 workers annually. More than 17% of deadly accidents (806 people) occurred in 2012 in the USA was belonged to the construction. In 2011, based on official statistics of the Turkey government, 33.5% of all occupational casualties belongs to the construction industry, which encompasses 6.3% of the labor force. According to OSHA's report, falling and heavy equipment are the leading causes of unsafety on construction site. (Gürcanli & Müngen, 2013; Vahdatikhaki & Hammad, 2015)

By taking advantage of digital technologies, some methods are proposed by researchers. Using embedded sensors for real-time monitoring of workers in hazardous conditions, safety training by use of Virtual Reality or Mixed Reality (Sacks, Perlman, & Barak, 2013), providing a real-time risk map for eliminating accidents (Vahdatikhaki & Hammad, 2015), and wearing Smart Hamlets or Smart Glasses are some of these researches.

As shown in Figure, BIM has the highest impact and Cloud Computing has the least impact on the safety of the construction site. It is evident that respondents are aware of direct and indirect impact of Building Information Modeling, Simulation Tools/Models and Prefabricated Construction. Because these technologies that mostly belong to simulation cluster, have been gained the attention of governments, society, companies, and researchers. However, smart construction site and digitization clusters provided opportunities in governments, economic, social, technological, and environmental issues are neglected. This rating matches with the awareness of respondents too

Rank	Enhancing Safety	Mean
1	Building Information Building	3.68
2	Prefabricated Construction/Additive Manufacturing	3.50
3	Simulation Tools/Simulation Models	3.32
4	Augmented/Virtual/Mixed Reality	3.25
5	Cyber-Physical Systems	3.18
6	Human-Computer Interaction	3.18
7	Product Life-cycle Management	3.13
8	Radio-Frequency Identification	3.09
9	Internet of Things	3.07
10	Mobile Computing	3.05
11	Big Data	3.02
12	Cloud Computing	2.98
	Overall Average	3.20

Figure 5.15. Impact of Industry 4.0 Technologies on Enhancing Safety

Enhancing Decision-Making: Decision-making is a critical activity that is taken daily on the construction site, and it is vital for delivering construction projects on time and under budget. A wrong decision can have significant effects in terms of cost, time, and the relationship between parties, safety, and quality of the project. Accessibility of real-time data is the primary necessity of an educated decision. Most of Industry 4.0 associated technologies, such as Cyber-Physical Systems, Internet of Things, Radio Frequency Identifications (embedded sensors), Big Data, Cloud Computing, Mobile Computing, and Building Information Modeling provide real-time information for projects staffs and enable them to make more knowledgeable decisions.

According to respondents' rating, one more time, Building Information Modeling is the first and in follow of that, Simulation Tools/Models, Big Data, and Cloud computing took the first five-place of ranking. Moreover, with almost equal average, Radio Frequency Identification, Human-Computer Interaction, Cyber-Physical Systems, and Prefabricated Construction were the least effective technologies in enhancing decision making.

Rank	Enhancing decision making	Mean
1	Building Information Building	4.16
2	Simulation Tools/Simulation Models	3.61
3	Cloud Computing	3.46
4	Big Data	3.45
5	Augmented/Virtual/Mixed Reality	3.41
6	Internet of Things	3.30
7	Product Life-cycle Management	3.30
8	Mobile Computing	3.18
9	Radio-Frequency Identification	3.16
10	Cyber-Physical Systems	3.14
11	Prefabricated Construction/Additive Manufacturing	3.04
12	Human-Computer Interaction	2.98
	Overall Average	3.35

Figure 5.16. Impact of Industry 4.0 Technologies on Enhancing Decision Making

5.4.1. Stakeholders' Point of View about Benefit and Impact of Industry 4.0 Technologies

As it is seen in Figure, in order to the ratings, the consultants and researchers accept more that the implementation of industry 4.0 technologies can provide benefits and affect the construction process positively, but the differences are so slight and can be ignored.

The Turkish construction industry experts rated the practical impact of Industry 4.0 in the construction industry as follows;

- Improvements in decision makings; with the mean of 3.41
- Improvements in collaboration and communication; with the mean of 3.34
- Time and cost savings; with the mean of 3.34
- Enhancing quality and sustainability; with the mean of 3.31
- Enhancing safety; with the mean of 3.31here

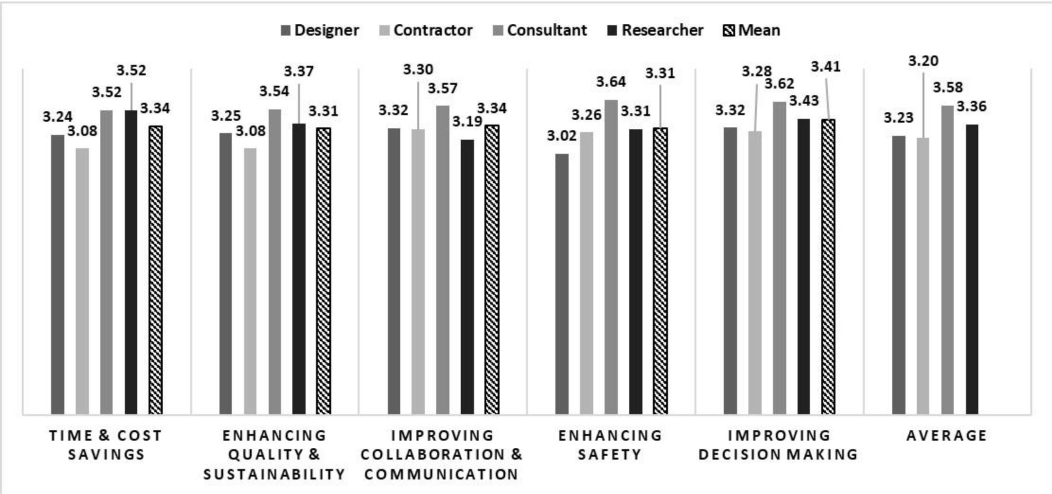

Figure 5.17. Stockholders' Point of View about Benefit and Impact of Industry 4.0 Technologies

CHAPTER 6

STRATEGIC ROADMAP FOR IMPLEMENTING INDUSTRY 4.0 IN CONSTRUCTION COMPANIES

Most leading companies, as early adopters, put Industry 4.0 in the core of their strategic plan to gain national and international competitive advantages. The digital transformation calls for the creative potential of companies, besides entails new business models, strategies, organizational variations in human resources, manufacturing process and managing activities, technologies types, and physical infrastructures (Gilchrist, 2016). In fear of not having every single technical block and development concept in place, this revolutionary transformation can look challenging for construction companies, especially small and medium-sized enterprises, and discourage them from embarking on this path. In order to promote the transition to Industry 4.0, companies should establish a strategic roadmap to take every step and decision more transparent and understandable.

To state the highlighted challenges, a simple roadmap is presented as guidance for the digital transformation of construction companies, which is extracted from current literature and practices. This study and the given basic roadmap, pave the road for companies to determine their particular Industry 4.0 aims and develop a set of actions to reach them. Construction industry players need to envision (company-specific understanding of Industry 4.0 vision), enable (develop a roadmap and identify success factors), and enact for this transformation (Erol, Schumacher, & Sihn, 2016). A comprehensive roadmap should have a specific framework for each phase of strategic management, marketing, human resource, IT maturity, smart manufacturing, and smart supply chain management. But as highlighted in Figure 5.18, this study focused on strategic management, supply chain, smart manufacturing, and IT maturity.

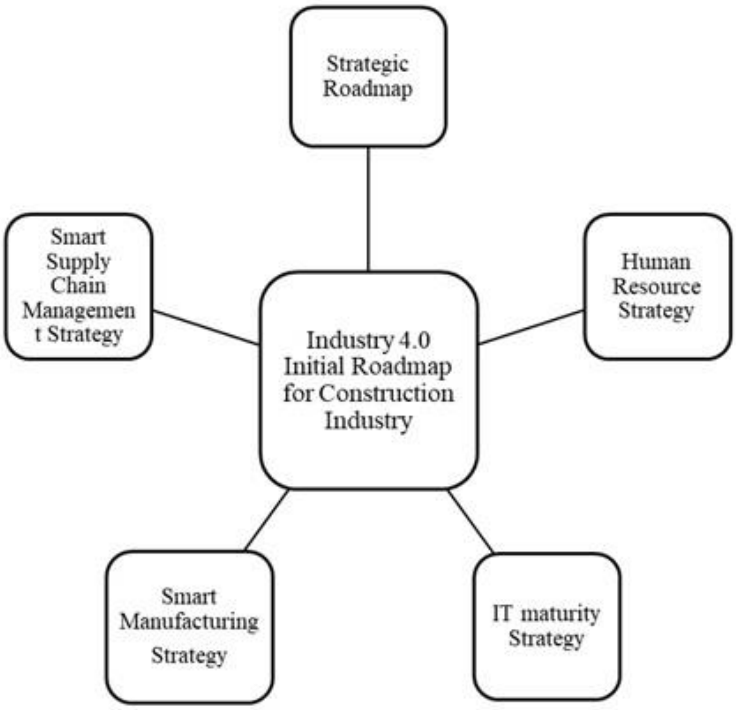

Figure 6.1. Industry 4.0 Initial Roadmap Phases

6.1. Strategic Roadmap for Implementing Industry

Strategic management is the primary phase of Industry 4.0 implementation roadmap. Based on Industry 4.0 definition and proposed advantages, the overall status of a company (where it is, where it should go, and how to reach there) and a time-based (short-term, medium-term, and long-term) strategy will be specified (Schumacher, Erol, & Sihn, 2016). It is vital to assign a team that manages Industry 4.0 implementation and digital transformation of a company and integrate existing infrastructure with new systems and technologies (Ghobakhloo, 2018). Mergers and Acquisitions (M&A) are irrepressible for organizations because all companies are not large enough to manage the horizontal integration of their manufacturing, and also they do not have the prerequisite infrastructure, adequate resources, or IT maturity to adopt Industry 4.0 (Ghobakhloo, 2018). It proves that large companies and SMEs should be conscious of M&A options.

The Industry 4.0 implementation team should develop a transformation process and decode the steps, then describe the features of each stage of transformation and conduct a broad cost and benefit analysis for each stage. Besides, internal and external success factors, functional needs, and preferences required for each phase of industry 4.0 implementation roadmap should be recognized (Kagermann, 2015). Strategic management roadmap is presented in figure 6.2.

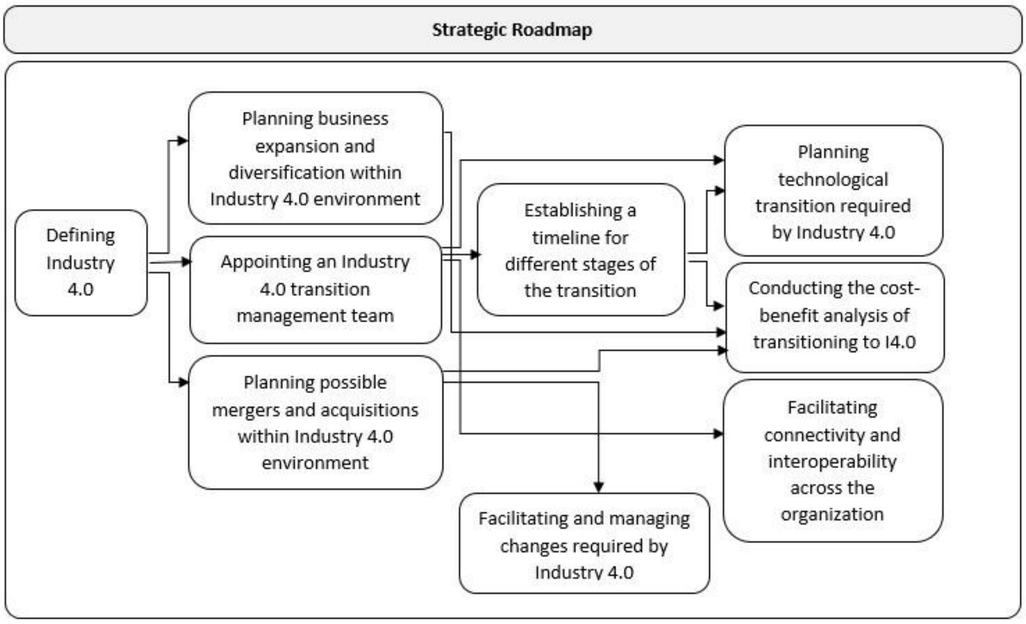

Figure 6.2. Strategic Management Roadmap

6.2. It Maturity Strategies' Roadmap

Industry 4.0 is about usage of information and communication technologies (ICTs) throughout the value chain. Industry 4.0 design blocks (vertical and horizontal integration), type of technologies, such as CPS, RFID tags, IoT, BIM, and VR/AR, proves that ICT technology has a prominent role in Industry 4.0 transition (Leyh et al., 2016). In order to take the first step in ICT maturity, companies need to make a detailed investigation about IT infrastructure such as hardware, software, IoT devises, and trained employees, afterward determine the IT advancement level of their company and what is the required IT level for Industry 4.0 implementation. IT team should clarify different stage of business which needs ICTs implementation, and if the current IT infrastructure is not adequate, they should take advantage of Industry 4.0 created ICT concepts in the process segments (Savtschenko et al., 2017).

Communication and collaboration within the process are the most important factors to success of Industry 4.0 transformation. Industry 4.0 technologies and concepts allow the entire value chain (equipment, element, and machinery) to communicate in real-time and field level by gathering data, analyzing it, and propose it to management (Gilchrist, 2016). But in reality, in a smart factory all equipment and elements did not have same technical language, features, and protocols. So, it is so crucial for IT team to ensure that new implemented ICTs are fully integrated and harmonized with the previous components and the whole process is interoperable with each other (Chen et al., 2018). In Figure 6.3, IT strategy roadmap is presented.

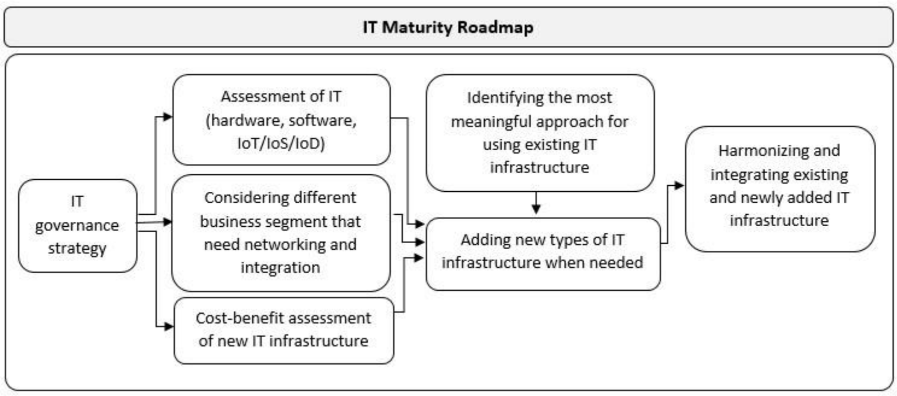

Figure 6.3. IT Maturity Strategies' Roadmap

6.3. Smart Manufacturing Strategies' Roadmap

Transparency, connectivity, and integration are the common features of smart manufacturing (smart construction site). Smart construction site same as other manufacturing systems, try to shift from traditional manufacturing environment to a totally flexible, dynamic and integrated system which rely on data collection sources from interrelated manufacturing operations (Kang et al., 2016). For developing smart connections throughout the manufacturing, implementation of IoT and RFID devices are obligatory, and also the vertical integration of components, databases, machinery, procedure, and people are necessary to create a smart construction site (Da Xu et al., 2014; Gilchrist, 2016).

To obtain process-level data, taking advantage of various procedure controllers (such as SCADA) and automatic mobile elements are necessary. The manufacturing execution system (MES) will be developed due to connected control systems with the central control system. Further, the integration of MES with enterprise resource planning (ERP) enables the required transparency and connection within the process to produce real-time data. A combination of smart ERP and data mining processes will facilitate the creation of a digital twin, which provides the system lifecycle information of projects and any single component of it for the whole production system. The digital twin has a noticeable impact on the expansion of the smart manufacturing site because it provides (Ghobakhloo, 2018). See figure 6.4.

6.4. Smart Supply chain Strategies' Roadmap

Industry 4.0 transformation seriously affected the relationships in the supply chain, primarily because of the development of data creation resources and the vast digitalization of processes (Wu et al., 2016; Zhong et al., 2016). In order to create a smart and digital supply chain, partners need to combine and harmonize their procedure's digital twins with each other. This integration mostly based on ICTs configuration throughout the supply chain which will result in real-time information and access to data. Taking advantage of blockchain technologies can assist the value chain in preserving data consistency and security, which is a critical issue in this revolution due to keeping the intellectual possessions of various stakeholders safe. Therefore, value chain can assimilate the stream of data, activities, finances, materials, and both manufacturing and managerial knowledge, then move toward founding a smart value chain that has a prominent role in digital transformation will be more comfortable. The integration of smart value chain and smart manufacturing enables the collection of real-time information from various stakeholders, customer and operation procedures, which result in additional value in the supply chain (Ghobakhloo, 2018). See Figure 6.5.

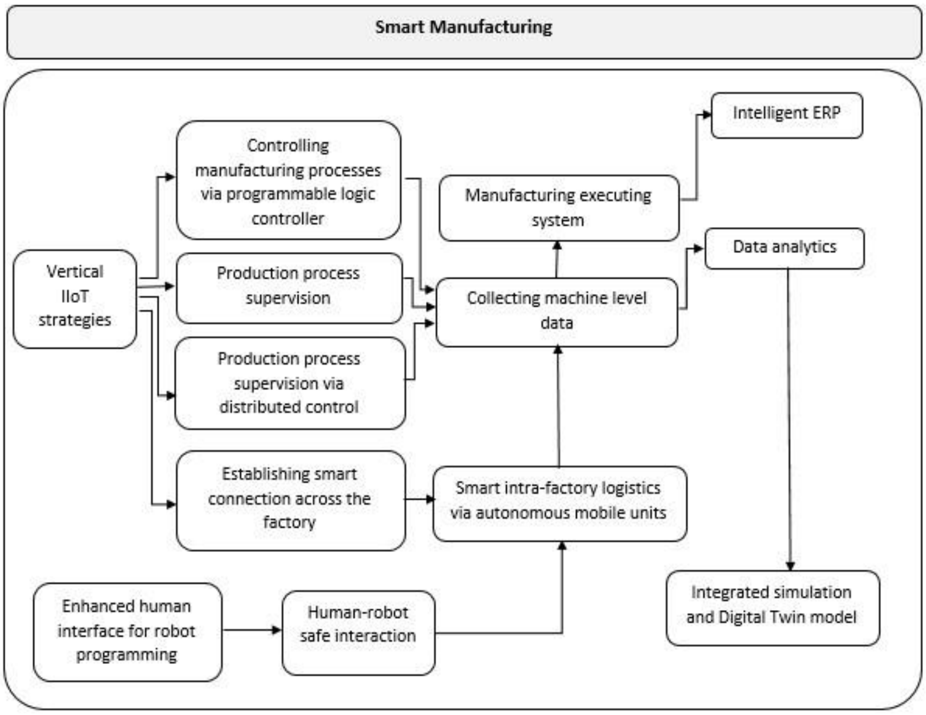

Figure 6.4. Smart Manufacturing Strategies' Roadmap

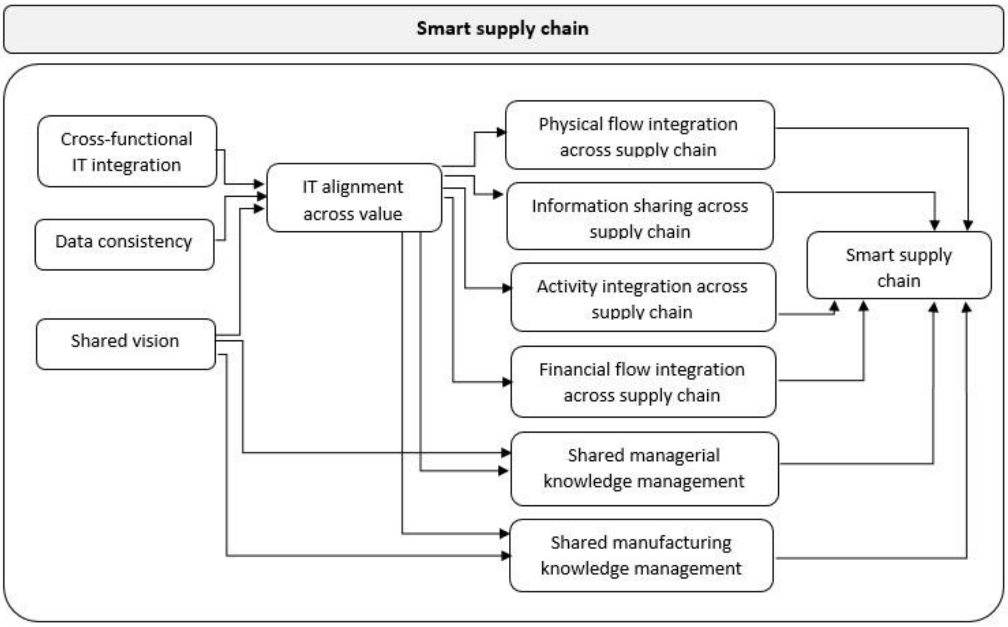

Figure 6.5. Smart Supply Chain Strategies' Roadmap

6.5. Human Resource Management Strategies

The last phase of the strategic roadmap is establishing a human resource strategy. According to researches having capable employees are one of the critical factors for a successful digital transformation. Industry 4.0 by using ICT trends such as CPS, RFID, IoT, IoS, simulation tools, cloud computing, BIM, and cybersecurity can create a reciprocal relationship between the physical and virtual world which require a broad technical knowledge and relevant training from employees (Gilchrist, 2016).

According to the experts' point of view, companies should properly evaluate their workforce technical knowledge and identify their current skill shortage to overcome the Industry 4.0 transition requirements (Hecklau et al., 2016). While the existing workforce does not have adequate knowledge and skills, however, they are already experts and conscious about the company's procedure and norms, current employees have a noteworthy benefit for the new upcoming value chain, so the best option is to train them and prepare them to adopt the modern technologies and concepts which is proposed by Industry 4.0. Hence, companies need to execute a comprehensive cost-benefit analysis of industry 4.0 initiatives in the human resource and value chain. Also, they should try to employ a multi-skilled workforce, which is motivated to adapt to new technologies and concepts (Shamim et al., 2016).

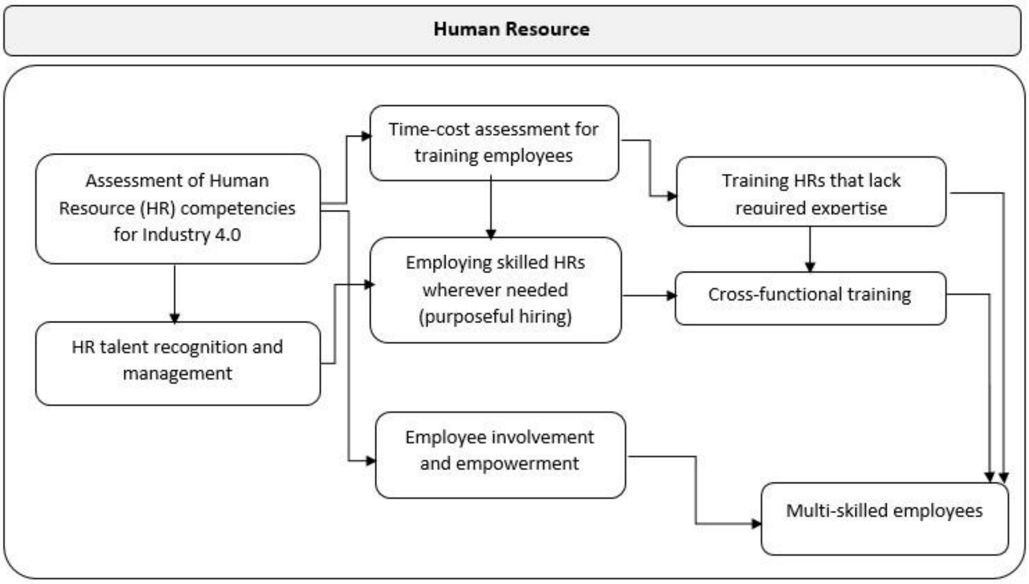

Figure 6.6. Human Resource Management Strategies

CHAPTER 7

CONCLUSIONS

7.1. Summary

Industry 4.0 is the advent of new industrial revolution that is focused on digital manufacturing environment and digital value chain. Via this transformation it is possible to obtain and analyze data from anything in the value chain (machines, elements, and human) and create a more flexible procedure which result in higher productivity, efficiency, quality and decrees in cost. Industry 4.0 will revise the workforce models, modify the economic profile, nurture the industrial growth, and boost productivity. It is eventually altering the competitiveness of companies and regions. It will lead to greater efficiencies and change traditional production relationships among suppliers, producers, and customers—as well as between human and machine.

Notwithstanding the proposed advantages of industry 4.0 technologies, the construction industry has failed to incorporate these creative techniques to preserve with their colleagues in mechanical and automotive engineering. The construction industry performs a central position in the economy and social development of countries by developing creative alternatives focused on human and social issues. It provides an environment where resources such as labor, capital, materials, and machinery are imported to create the infrastructure in an economy. Despite its significance in the economy of all countries, the construction industry is described by conventional methods and low adoption of information and communication technologies (ICTs). This hesitation to embrace modern technologies and concepts leads to low-quality infrastructure production, which affects the construction industry whole performance and social picture.

Nonetheless, there are multi-layered challenges featured to construction industry which needs to take into consideration. For example, the construction industry is comprised of a high number of SMEs, which makes it reluctant to make investments in new technologies and research and development (R&D). The whole construction supply chain is profoundly affected by a close collaboration with various participants in the project, which makes the projects complicated, site-based, and require an advanced level of technological and theoretical knowledge and experienced workforce.

Given these circumstances, there was a need for research to find out that which technologies are presently linked to the Industry 4.0 concept (research Q1), what is these technologies state of the art in the literature and the construction industry (research Q2), and what is the Turkish construction industry status about these technologies (research Q3-Q5).

In order to answer the research questions, a methodology was designed with three steps. At first step, a systematic literature review was done to propose a definition for Industry 4.0. Then the second literature review was conducted to clarify the technologies state of the art in the construction industry. The main aim of this study was to take initial steps for embracing Industry 4.0 technologies in the Turkish construction industry. To pursue this goal, a close-ended questionnaire was distributed among Turkish construction industry engineers. So, their awareness rate towards Industry 4.0 technologies is examined, then technologies utilization rate and the required time for their implementation in the industry was asked, and at the final part, the provided benefits by Industry 4.0 technologies were rated.

7.2. Contribution to Theory and Practice

Although the number of participants in the questionnaire was not high, the research was intended to take the initial steps to implement the technologies of the fourth industrial revolution in the turkey construction industry. By reviewing the literature, a list of Industry 4.0 technologies that already linked to the construction industry has been prepared, and the views of Turkish engineers on the usability and benefits of these technologies were presented. This research paves the way for future studies that want to conduct research on neglected technologies and propose implementation frameworks for these least-known technologies but extremely essential to increase efficiency in the construction value chain. Also, look for the benefits they offer, such as the exact amount of time and cost savings that these technologies can provide to industry and the economy.

This study can contribute to several ways to the Turkish construction companies that want to remain competitive in the national and international market, and embracing new era technologies is one of their missions. Firstly, companies can access a general idea of Industry 4.0 and its main technologies in the construction industry. Being familiar with the latest technologies empower companies with a great management vision. Secondly, this study can provide a vision for companies to assess their process digitization level. Finally, they can come to the idea that combining one of these technologies with the already used one (such as BIM) can provide more extensive benefits in different dimensions. For example, integration of Radio Frequency Identification tags with BIM platform can create real-time visibility and monitoring ability.

7.3. Discussions of Results

As discussed before, Industry 4.0 technologies in the construction industry were categorized into three clusters of Smart Construction Site, Simulation and Modeling, and Digitization and each of these clusters is beneficiary within the value chain.

(1) Horizontal integration: There is a high number of participants involved in construction projects value chains such as architect, customer, contractor, designer, suppliers, and subcontractors. Hence, implementing cluster 2 and cluster 3 technologies can assist in creating an appropriate environment on the construction site to improve communication and collaboration. Taking advantage of Cloud Computing with the integration of Augmented Reality,

Mobile Computing, Building Information Modeling, and Radio Frequency Identification tags can profoundly affect the collaboration environment in projects.

(2) Vertical integration are resulting from the development of IT systems, procedures, and information stream within the business by use of automation techniques (cluster 1) and digitization and virtualization technologies (cluster 3).

(3) End-to-end digital integration of engineering across the entire value chain: by using technologies from all clusters, a comprehensive approach of digital engineering during whole construction phases will be gained.

In general, embracing Industry 4.0 in the construction industry, amount of difficulty and hesitation will be reduced. It will boost collaboration and communication, efficiency, and quality among project stakeholders.

Through the questionnaire, research question 3 to 5 was answered. The results are summarized as follows:

7.3.1. Awareness

According to analyzed data, 37% are aware of Industry 4.0 technologies, 29% have incomplete information about them, and 34% have no information. Although Turkey's awareness rate is higher than South Africa's, 37% of awareness is not satisfying for Turkish construction industry which is a critical sector for the country's economic development.

Building Information Modeling is the most well-known technology in the Turkish construction industry. After that Simulation Tools/Models, Mobile Computing, Augmented/Virtual Reality, and Prefabricated Construction obtains a logical position in the industry. However, Cyber-Physical Systems, Radio Frequency Identification, Internet of Things, Big data, Cloud-Computing, and Human-Computer Interaction which are the leading technologies of construction industry have been neglected.

Among the four participating groups in the questionnaire, consultants and academicians with an average above 3.5 were the most aware group, then designer and contractor with a slim difference ranked as the third and fourth group. A remarkable point is consultants' high awareness in smart factory technologies such as Cyber-Physical Systems, Internet of Things, and Radio Frequency Identification, despite the low average of these technologies in all part of this study.

Also, a minor comparison was made between participants working in the national and international market. The international market players are more aware of Industry 4.0 technologies. This slight difference can be aroused from their partnership with local companies that already adopt some of these concepts.

7.3.2. Utilization rate

The utilization rate of Building Information Modeling and Simulation Tools/Models is above 3. Overall, according to respondents rating, the utilization rate of industry 4.0 technologies in the construction industry is low except the Smart Construction Site technologies. Almost 21% of respondents claimed that these technologies are already implemented. 38% of respondents believe that these technologies will be embraced by industry in short-term, and almost the same number of respondents said that it would take a long time (more than 10 years) to implement them.

Although contractors rate the utilization level of these technologies above 3, from different stakeholders' point of view is almost same. This small difference can be generated from the primary role of contractors in the construction phase of project. Building Information Modeling, Simulation Tools/Models, and Prefabricated Construction are the most implemented technologies from all stakeholders' standpoint. These findings are following Osunsanmi et al. research in 2018 which represent simulation cluster as the most known and implemented technologies in the South Africa construction industry

7.3.3. Benefit and Impact Rate

Time and Cost Saving: the respondents' rate Building Information Modeling, Prefabricated Construction, Internet of things, and Mobile Computing as the most effective technologies in saving cost and time for projects. Unaware of other technologies great potential, such as embedded sensors which can create a useful basis for cost savings.

Enhancing Quality and Sustainability: the world in confronting with material scarcity and climate change. The construction industry has an unpardonable contribution (up to 40%) in the world energy consumption and raw material usage. Hence producing high-quality and sustainable projects is the most. One more time the same scenario happened here, the impact rate of technologies that are well-known in the sector is higher than others. The other neglected technologies such as CPS, RFID, PLM, and Big Data create a tremendous potential to enhance the quality of projects.

Enhancing Communication and Collaboration: The impact rate that technologies gained here is logical as Building Information Modeling, Cloud Computing, Mobile Computing, and Big Data are producing a data communication platform. It would have been better if Cyber-Physical Systems and Radio Frequency Identification were among them.

Enhancing Safety: in Turkey, almost more than 30% of occupational casualties belong to the construction industry. Building Information Modeling, Prefabricated Construction, and Simulation Tools are the most efficient technologies.

Enhancing Decision Making: making knowledgeable decision on construction site is a critical activity. Given the highest rate to Building Information Modeling, Big Data, Cloud Computing, and Augmented/Virtual Reality were in accordance with publications.

Industry 4.0 implementation has reaching consequences for whole industry players. Embracing this revolution will provide many advantageous for the manufacturing and its value chain. It will increase quality, communication, effectiveness, and productivity. Moreover, it can boost sustainability, safety and most importantly the poor social and cultural image of construction industry, which attract capable and smart people. To use full potential of these technologies legal, technological, and political challenges should be encompassed. For instance, with implementing Industry 4.0 in companies, the value chain and companies structures will face with many changes. This implementation will be expensive and the amount of benefit is unclear. Companies need to concentrate data protections and security. In view of these multi-faceted obstacles it is evident that businesses must be encouraged to implement policies, measures and financial programs through the Government. Taking these multilayer obstacles into account, it is evident that companies must be encouraged to implement via government funding projects, creativities, and obligations.

7.4. The Strategic Roadmap

As far as the fourth industrial revolution is concerned, the main issue is to clarify how it is possible for a company to make the transformation toward Industry 4.0 concepts and technologies from the traditional manufacturing method. In order to fulfill this gap, a strategic roadmap would be beneficiary for companies and their value chain. In a strategic roadmap it is necessary to clarify steps, time-line (short-term, medium-term, long-term purposes), and a cost-benefit analysis. No need to mention that there is no strategy and roadmap to fit all types of companies and value chains, so each company needs to tailor it according to its capabilities, features and infrastructures. The roadmap proposed in this study covers general steps that any manufacturers need to undertake for triggering the transformation towards ICTs. This roadmap consists of five phases which tried to cover both technical and strategical aspects of implementing and transforming toward digital value chain and environment

7.5. Limitations and Future Studies

Extra efforts among academicians and industry players are required to implement the innovative concept of Industry 4.0 in the complicated environment of the construction industry and push its traditional borders. In current publications except the technical aspect others such as environmental, social, ethical, cultural, and economical facets remained neglected. As discussed many times, construction industry resist for implementing Industry 4.0 technologies and undergo digital transition, the result is the shortage of theory knowledge. For example, an effective cost-benefit analysis for implementing and using these technologies and concepts has not been proposed yet. It has been cleared that before any implementation, there are unanswered fundamental which needs to take attention and cover the publication shortages.

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