A DATA-DRIVEN REQUIREMENT ELICITATION SYSTEM FOR PRE-PROJECT STAGE

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ABSTRACT

A DATA-DRIVEN REQUIREMENT ELICITATION SYSTEM FOR PRE-PROJECT STAGE

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Requirement knowledge of a building project is the set of crucial statements governing all processes to achieve success by matching the objectives. Briefing is the process of capturing and identifying requirements with the involvement of project stakeholders. Various improvements on deficiencies and gaps, developments on technology, and definitions on frameworks for briefing have been explored and examined worldwide over the past three decades. Knowledge capturing is one of the major processes of knowledge management for creating valuable knowledge. The construction industry adopts and uses various techniques and technologies to increase the utilization of resources.

The major aim of this study is to construct a framework for the elicitation of space requirements of building projects in the design briefing stage. The study considers the deficiencies and gaps in the creation and validation of the requirement knowledge. At the outset, a survey and interviews among industry practitioners in conjunction with a literature review were carried out to state the problem definition and research areas for improving requirement management in the design and pre-design briefing stages. Subsequently, the criteria and objectives were defined to propose a novel system by utilizing the evaluation and discussion of survey results and literature review. In the light of the findings, the proposed framework was utilized to develop a novel data-driven requirement elicitation system integrating database domain and machine learning activities.

The proposed system was tested and validated with seven experiments in which experts executed requirement elicitation of spaces for the same session conditions. As to the judgment of experts, the system's overall performance was regarded as satisfactory. Knowledge capturing from data libraries of completed projects with machine learning activities has been pointed out in the first place as the potential contribution of the system. It also enables the requirement elicitation process without the involvement of experienced project stakeholders. The results were discussed with the recommendations for improvement of the proposed system.

Keywords: Design Briefing, Knowledge Capturing, Machine Learning, Requirement Elicitation

ÖZ

ÖN PROJE AŞAMASI İÇİN VERİYE DAYALI GEREKSİNİM BELİRLEME SİSTEMİ

Çalışkan, Ekrem Bahadır
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Bir yapı projesinin gereksinim bilgisi, başarıya ulaşmak için hedefler ile eşleşerek tüm süreçlere yön veren önemli ifadeler setidir. Brifing tüm proje taraflarının katılımlarıyla gereksinimleri yakalama ve belirleme işlemidir. Brifingin bu hedefleri ile eksikliklerin iyileştirilmesi, teknolojilerin geliştirilmesi ve çerçevelerin tanımlanması hakkında dünya genelinde son 30 yıldır araştırmalar yapılmaktadır. Bilgi yakalama, değerli bilginin yaratılması için kullanılan bilgi yönetimi ana süreçlerinden biridir. İnşaat endüstrisi kaynaklardan faydalanmayı artırmak için birçok tekniği ve teknolojileri benimsemekte ve kullanmaktadır.

Bu çalışmanın temel amacı, gereksinim bilgisi oluşturma ve doğrulama konusundaki boşluklar ve eksiklikler arasındaki ilişkileri göz önünde bulundurarak, mekân gereksinimlerinin tasarım brifingi aşamasında ortaya çıkarılmasını sağlayan bir çerçeve oluşturmaktır. İlk olarak, tasarım ve tasarım öncesi brifing aşamalarında gereksinim bilgisi yönetiminin iyileştirilmesine yönelik araştırma alanlarını ve problemlerini belirlemek amacıyla literatür araştırması ile birlikte uygulamacı projeci müellifleri arasında anket ve mülakatlar yapılmıştır. Devamında, anket ve mülakat sonuçları ile literatür araştırması birleştirilerek değerlendirilmiş, sistem önerisi için kriterler ve hedefler tanımlanmıştır. Bulgular ışığında, veriye dayalı gereksinim belirleme sistemi geliştirilmesi için bir veri tabanı alanı ve makine öğrenme teknikleri entegre edilerek önerilen çerçeve kullanılmıştır.

Önerilen sistem uzmanlar tarafından mekân gereksinimlerini belirlemek amacıyla aynı koşullara sahip yedi vaka çalışmasında test edilmiş ve doğrulanmıştır. Uzmanların değerlendirmesine göre sistemin genel performansı tatmin edicidir. Makine öğrenme teknikleri ile veri kitaplığından bilgi çıkararak öneriler sunması sistemin ilk potansiyel katkısı olarak işaret edilmiştir. Sistem ayrıca, deneyimli proje taraflarının katılımı olmaksızın gereksinim belirlemeyi mümkün kılmaktadır. Elde edilen sonuçlar ile birlikte öneriler söz konusu sistemin geliştirilmesi için tartışılmıştır.

Anahtar Kelimeler: Tasarım Brifingi, Bilgi Yakalama, Makine Öğrenme, Gereksinim Belirleme

To my wife and children Asya, Batuhan

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ABBREVIATIONS

BIM	Building Information Modelling
DBB	Design Bid Build
KC	Knowledge Capturing
KM	Knowledge Management
KMS	Knowledge Management System
IT	Information Technology
İstanbulSMD	Istanbul Association of Architects in Private Practice
İzmirSMD	Izmir Association of Architects in Private Practice
MEKSİS	Higher Education Facilities Investment Decision Support System
RM	Requirement Management
TSMD	Turkish Association of Architects in Private Practice
UK	United Kingdom
UML	Unified Modelling Language
USA	United States of America
WCSS	Within Cluster Sum of Squares
YMESS	The Inventory Classification System of Higher Education Facilities
YÖK	Council of Higher Education (Turkey)

CHAPTER 1

INTRODUCTION

In this chapter, the background of the research is presented, problem definition is declared, the aim and objectives of the study are presented, and the procedure which outlines the flow of the research is defined. At the end of the chapter, disposition of the thesis is provided.

1.1 Background of the Research

In construction projects, briefing process between project stakeholders takes an important role for the success and proper execution of the construction works according to projects' objectives. It is a process for maintaining communication and collaborative work in parallel with the proceeding construction stages. Various terms are used for briefing in the literature considering based on implementation. There are basically two thoughts on construction project briefing. One approach considers the brief as an entity in itself, which should be frozen after a critical period; hence briefing itself becomes a stage or several stages in the design process. The second approach regards brief as a live and dynamic document that develops iteratively in a series of stages from an initial global brief (Yu, Shen, Kelly, & Hunter, 2007). Especially for the statement of project requirements, it is used for understanding the organization's needs and resources and matching these to its objectives (Blyth & Worthigton, 2010). In design and pre-design phase, briefing is a framework for providing all activities for requirement elicitation and validation with the involvement of all project stakeholders.

Requirement management is one the important objectives of briefing process which ensures the requirement elicitation and validation. Although designers usually have their own approaches and thoughts for handling projects, clients want designs that deliver their demands within a set time and budget. Client demands are defined and stated as a result of various processes and the preparation of reports. However, the construction industry has a poor performance in addressing these requirements owing to uncertainty and complexity of project briefs (Shahrin, Johansen, Lockley, & Udeaja, 2010). Moreover, capturing and translating the knowledge from clients to designers or designers to clients is an important issue for the successful requirement processing, which may suffer from lack of time, framework, expertise, *etc*. Barrett listed some suggestions for improvement, such as information has to be presented in a way that is acceptable to individuals; an individual brief taker may be more appropriate instead of an architect; ensuring the involvement of client and user; and finally, a neutral computer-based expert system to back up the weak areas of professionals (P. S. Barrett, Hudson, & Stanley, 1999). Blyth has defined briefing framework with relation to construction project stages and presented the important features and necessities for managing requirement elicitation in briefing process (Blyth & Worthigton, 2010). Lack of open and effective communication, missing clarity of objectives, lack of comprehensive frameworks and formalization and not being able to ensure the involvement of end users are stated as some problems and critical issues for proper requirement processing (Pegoraroa & Carísio, 2017). The tools and techniques to process requirements as a knowledge piece are also listed with their contribution to the requirement elicitation process: interviews, questionnaires, workshops, brainstorming, drawings, collaborative working environments and some research studies and technologies like ClientPro, CBR and BIM (Pegoraroa & Carísio, 2017).

Due to the human/subjective dimensions and each project’s unique context, it is hard to formulate or create a general framework for the requirement elicitation in briefing process and state the usage of it for every case. Considering the design process, architects have a better understanding of architectural problems and can develop their solutions based on their experience, knowledge and skills (Norouzi, Shabak, Embi, & Khan, 2015). The utilization of requirements and a framework to formulate space knowledge differs among designers. Some designers may use formulated and structured brief documents and some initiates further processes for refinement and abstractions. Besides, some architects find the briefing documents annoying and prefer to work free of restrictions (Bogers, Van Meel, & Van Der Voordt, 2008). Experience and design approach of architects, project delivery methods, aspects of sustainability, culture, social, environment and economy are values that are affecting the utilization of the requirement and designing process. Thus, it cannot be stated that the design of any building is only shaped and developed due to space requirements. However, these requirements have a significant place in the total design and construction processes.

Requirements of spaces constitute the knowledge that reflects the objectives of a project, needs of individuals or groups, and perspectives of project stakeholders. This knowledge has to be captured, processed in some activities, and managed for use. Construction industry realizes the benefits of Knowledge Management (KM) approaches and its processes to increase the success in requirement management. KM deals with the optimization and management of knowledge through diverse tools, processes, techniques and technologies to increase performance and value (J. M. Kamara, Augenbroe, Anumba, & Carrillo, 2002). The knowledge cycle includes the main steps of capturing, refining, archiving and reusing to create knowledge in design briefing (Chimay J. Anumba, Charles O. Egbu, 2005). While the sub-processes slightly differ according to researcher; however, in overall they maintain a continuous loop to capture, validate and create the needed knowledge. Some players in construction industry use KM tools, guidelines and concepts for capturing and sharing the knowledge, which are recognized by all industries, however implemented in construction processes; whereas, some of them are being developed by researchers and practitioners for particular stages of the briefing. These tools can be categorized as KM techniques which are non-IT tools like communities of practice, forums, brainstorming sessions and KM tools like custom-design software, expert directories, knowledge bases which use information and communication technology (Al-Ghassani, 2003).

In order to achieve benefits of implementing knowledge capturing techniques, ensuring the comprehensive briefing procedure and sustaining the accuracy of requirement knowledge, several strategies and frameworks were developed and various research projects were run. These are stating both the deficiencies, problems and development areas and presenting improvement for requirement processing in the construction industry. Seeking for knowledge source, capturing and validation methods, ways to manage requirements of spaces in projects and improve the correspondence of briefing outputs to projects success is observed, and they are presented in the literature survey.

1.2 Problem Definition

For the definition of the research problem, both a review of the literature and a survey (questionnaire and interviews) with the industry practitioners were utilized. With respect to the contemporary projects, strategies, development areas, deficiencies or problems of briefing and knowledge capturing for the management of space requirements, the possible issues are explored and then forwarded to experts in the business. The outcomes of literature survey are conducted with the discussion on results of survey among industry practitioners, the group of architects in Turkey. A number of needs deficiencies, and improvement comments are stated for the development on the requirement elicitation process.

One of the important issues is the experience and knowledge level of clients and end users (P. Barrett & Stanley, 1999; Blyth & Worthigton, 2010; Pegoraroa & Carísio, 2017). It directly affects the communication and knowledge transfer between individuals. Project stakeholders need to have the knowledge to decode the message and comments on them (Norouzi et al., 2015). Thus, requirement elicitation process is impacted by a lack of communication. Besides, it is hard to maintain the involvement of the client in accurate level, to capture the knowledge of space usage.

Architects have an important role in defining the requirements of the project. The opportunity of receiving comments for the improvement of briefs should be used and individuals should be clear about the priorities for improving the success of requirement elicitation process (Bogers et al., 2008). Although the space requirements of any project can come to a level at the client side at the beginning, design proposals and works of designer is needed to be processed at this phase to refine the requirements for achieving better success. This is explored throughout the literature review and found in the results of the survey among industry practitioners. As understood during interviews, for some projects defining the requirements could be possible, however for others designer contribution to requirement elicitation stands as crucial factor with their knowledge and experience. The requirements of projects need to be evaluated, refined and articulated from the views of designers. The process of design and discourse approach on projects are not a fixed analytic set of activities for architects. Architects' skills and projects' unique context uncover variations for gathering requirements and utilizing them on design stages. Thus, in which way, ratio and value that the architects use the created and validated requirement knowledge is a divergent discussion.

Like creation of any knowledge, the knowledge of space requirements has to be created, processed and used with verification and validation. Considering the requirement elicitation in briefing process, there are some knowledge capturing techniques utilized in the domain, such as, brainstorming, storytelling, lesson learned tools, post project reviews, workshops, design proposals or interviews (Al-Ghassani, 2003; John M Kamara, Anumba, & Carrillo, 2003; Pourzolfaghar, Ibrahim, Abdullah, & Adam, 2014; H.C. Tan et al., 2010). The involvement of project stakeholders is necessary to apply these techniques. Moreover, technologies such as Building Information Modelling (BIM) bring new approaches to briefing like integration, interaction, and simulations with feedback (Koutamanis, 2017). Architects or project executors use and get benefits from this domain due to their knowledge and experience. Besides, data text mining and knowledge bases stand with the potentiality of being source for knowledge creation. The records of space features, requirements, and relations of existing projects can be used for the elicitation, evaluation and validation base, if the proper methodology for structuring the data and creating the new knowledge is defined.

Requirement processing can be successfully executed with a comprehensive framework and adequate techniques to manage the knowledge (Pegoraroa & Carísio, 2017; H.C. Tan et al., 2010). Lack of frameworks and their non-utilization by project stakeholders are important factors to affect the requirement elicitation process found in the literature review and survey. The compressive approaches of frameworks are hard to develop, and it is difficult to enforce project stakeholders by convincing them with the benefits. ClientPro (J. M. Kamara & Anumba, 2001), DesignTrack (Koskela, 1992)(Ozkaya & Akin, 2005, 2007) and e-COGNOS (Wetherill, Rezgui, Lima, & Zarli, 2002) are some of the research projects that offer frameworks somehow capture and manage the knowledge in construction projects. It is obvious that designers have the role of utilizing this knowledge due to their own way, however these approaches have benefits on controlling the value and flow of project knowledge. The main aim of this study is shaped around the cycle and capturing of space requirement knowledge in construction process, and defining a possible framework for the creation of knowledge that will contribute to the gaps of requirement elicitation process.

1.3 Aim and Objectives

The major aim is to develop a system for requirement elicitation with the integration of ruled-base framework for construction projects. The system takes place in briefing process of pre-design or design stages with the improvements on knowledge creation for building spaces. Since there cannot be a solid statement for the project stakeholders and project initiators for a unique solution of requirement elicitation process, the important and the most contributing approach are tried to be searched and examined throughout the literature review and surveys among industry practitioners, and draft studies on framework development. Thus, one of the important objectives of this research study is seeking and exploring the briefing, requirement management and knowledge management domain conducted with surveys among industry practitioners to underline the statements of problem areas, improvements and deficiencies. In this respect, followings are the objectives of this study:

- Exploring the briefing, Knowledge Management and necessities by extensive literature survey including contemporary strategies and research projects.
- Defining the position and approaches of industry practitioners, determination of problem areas for the development framework through survey and interviews.
- Proposing objectives of requirement elicitations system with regard to merged results and discussion of findings.
- Exploring and identification of data-library and machine learning activities with relations of entities and activities.
- Development of a running system for a data-driven requirement elicitation with limitations for evaluation and executing case studies to provide evaluation, recommendations and performance of the proposed system.

1.4 Procedure

The procedure of the study is outlined with research flow, showing major steps and components in Figure 1.1. At the outset, literature review is conducted in relation with the research objectives. The initial findings on gaps and problems are explored with feedback to objectives. The questionnaire survey and interviews are held to define the focused deficiencies and development areas of requirement elicitation in conjunction with design briefing framework proposal for knowledge capturing. With the merged evaluation and discussion on results of the survey and literature review, decision on the development of a requirement knowledge capturing via structured rule-based system is taken as a data-driven requirement elicitation system. For the development of the proposed system materials and methods are investigated. The developed running system is tested via case studies by experts and the results are given at the end of the research.

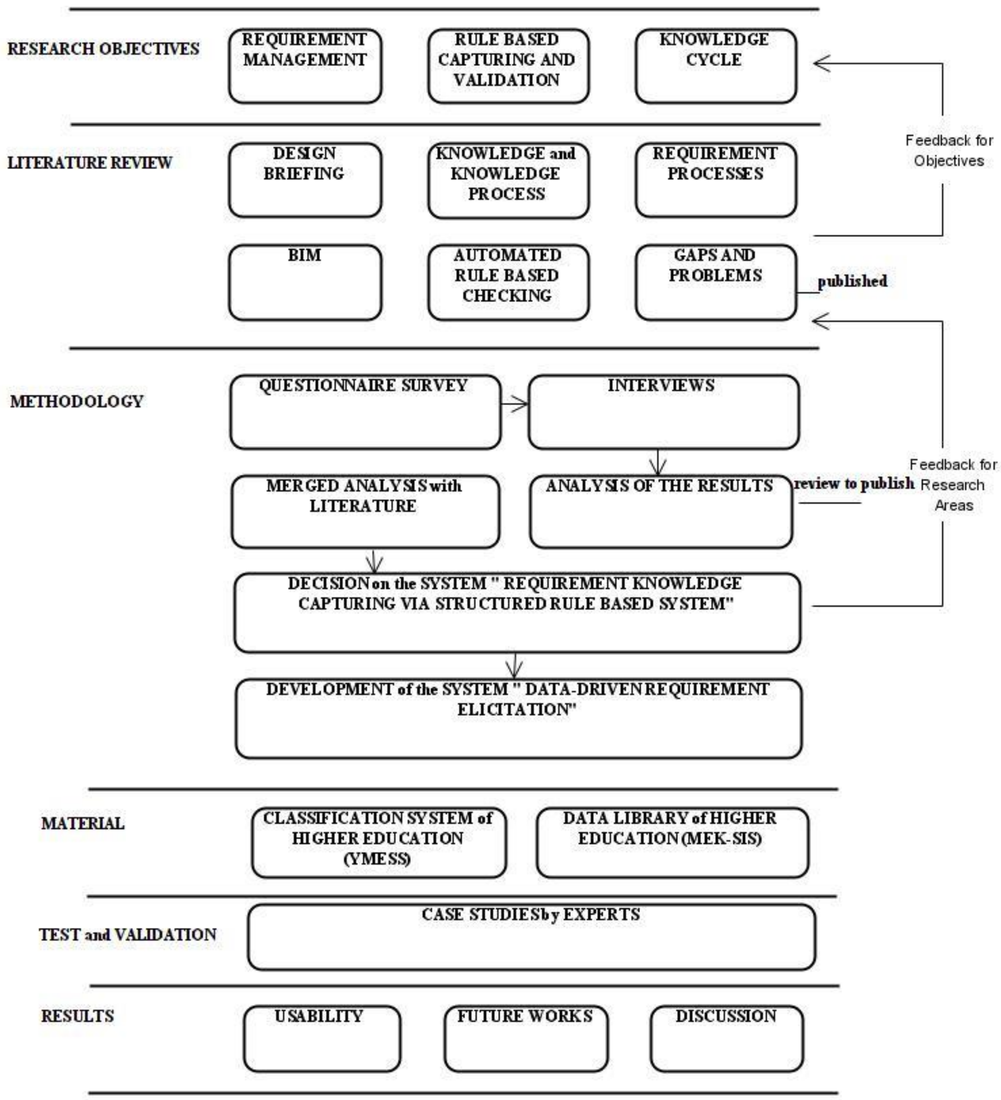


Figure 1.1. Research flow

1.5 Disposition

The thesis is composed of seven chapters, of which, the current chapter is the first one, including the background of the research, problem definition and objectives, procedure of the research and the thesis disposition.

The second chapter introduces the concepts of briefing, knowledge management and requirement management with respect to context of the study. Contemporary strategies, frameworks, research projects and software are explored, issues of Building Information Modelling with potential contributions to requirement processing are presented. The chapter is finalized with the criticism of the literature.

In the third chapter, the survey and interview among industry practitioners are presented. The structure of survey, framework of interviews, and limits and procedures are explained. The findings of survey and interviews are given and discussion of findings is conduction in conjunction with the literature review.

The materials and the methodology of the study are presented in the fourth chapter. Dimension to develop framework and overview of proposed system given. The chapter continues with methods for machine learning activities, data-library as material and software's which are used for the development of the system are presented at the end.

The fifth chapter presents the development of the data-driven requirement elicitation system. First, objectives of the system are stated, then features of the used data library is presented. The machine learning activities and working principles of the system are explored through features of iterations. Limitations of running system and possible expansion remarks are given at the end of the chapter.

The sixth chapter comprises the testing and validation of the developed system. Initially, the material and methods used for cases studies by experts are explained. Subsequently, the results and comments gathered from the experts are presented under the groups.

In the final chapter, the summary of the research is presented, the major findings and contribution of the research are given. Limitations of the study and recommendations for future work are explained at the end.

CHAPTER 2

LITERATURE REVIEW

The literature review presents the topic related to briefing in the construction industry, the necessities and barriers, knowledge dimension and knowledge management principles focusing on requirements. General concepts about the briefing and involvement of project stakeholders in the process are given in order to explain the role of briefing process in requirement elicitation and validation. Then, the concept of knowledge capturing and processes of knowledge cycle are presented. Contemporary strategies and technologies for knowledge capturing in construction are examined to seek on research problems. Building Information Modelling is presented as a final subtopic. Finally, the criticism on the literature is included to emphasize the originality of study.

2.1 Briefing in the Construction Industry

Briefing is the process that continues throughout the project with interaction of clients and other project stakeholders to capture and manage the knowledge for the success of project (P. Barrett & Stanley, 1999). Since briefing is crucial to the success of the construction process, it has emerged and developed in parallel with the development of the construction industry, thus, a considerable number of studies was established for the improvement of a comprehensive briefing.

The term briefing has commonly been used by different parties for varying purposes in construction projects across the world. Various meanings and limitations of the same term are present. To be on the same ground, good communication is compulsory. Communication is about creating a common understanding and it is a dynamic process (Taleb, Ismail, Wahab, & Rani, 2017). While using the briefing term there are different understandings by different parties. Briefing as a process is understanding an organization’s needs and resources and matching these to its objectives and its mission (Blyth & Worthigton, 2010). The process starts with the inception stage and does not finish after completion, where it also runs through the evaluation. The brief is a product of this process at every stage. It is a formal document which is the medium for expressing or communicating the objectives and needs of the client (CIB, 1997). The documents may be frozen and stiff, or they may be developing documents according to the changing circumstances for the project and project success. Briefing as a stage is a set of defining objectives, methods, and instructions in which different parties have a role. It is also sub-part of the whole briefing process. Briefing is a tool for collaborative work for client, contractor, and designer. The aim of the involvement of client and contractor in briefing is to collaborate with the contractor to promote innovation and efficiency in planning and production (Ryd, 2004b).

Briefing documents are checklists which are structured to the intended use at the correct level of detail. Studies show that architects often express dissatisfaction with briefing documents they are presented with (Heintz & Overgaard, 2007). Not only architects but also construction teams and clients are interested in these documents. Such documents are often very long and detailed for the exact information related to the project. Although it is difficult to develop useful methods and frameworks for briefing where a designer’s use is intended, there is also a need for the requirement management of client-end user, planning for the instructed cost and time, and management of the information and knowledge of project stakeholders, the evaluation of the process and project in terms of feedback into the future and the success of project. Briefing and planning have important effects on total construction cost; while they cost about 1.5%, they influence up to 80% of total life cycle cost of a construction project (Faatz, 2009).

An important goal of design briefing process is gathering knowledge about requirements from client and deliver the design project accordingly. Limitations and deficiencies result in shortcomings on closing gaps at briefing process. The Problem is to define and close the gap between paying client, user client and the designer by a successful briefing process in terms of requirement. Figure 2.1 shows the gap between the parties. Although there is a communication between designers and paying clients, it is possible to have common problems at the translation and transfer of knowledge between each other. Closing the gaps could be possible by understanding the user needs better by presenting information in an efficient way *i.e.*, organizational charts, personnel projections, workflow diagrams, visualization techniques, relationship diagrams, *etc.*

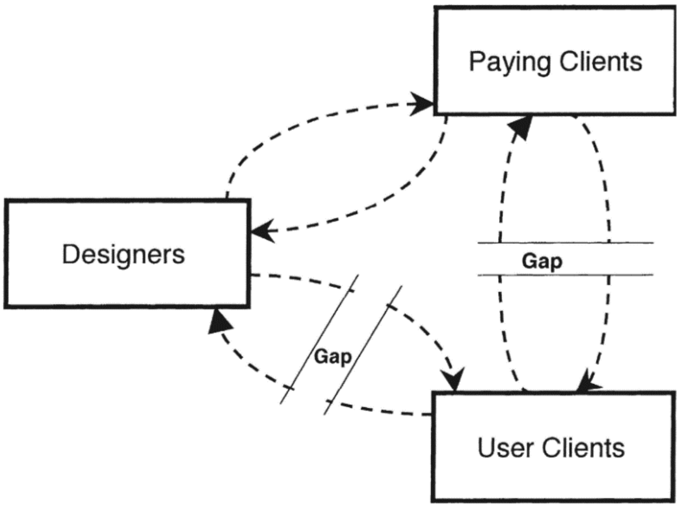


Figure 2.1. User-Needs gap (Zeisel, 1984)

2.1.1 Construction Project Process and Briefing

The construction process consists of all processes that result from planned construction work for a new building, infrastructure or renovation (E. Olatokun & Pathirage, 2015). According to construction typologies and techniques the process may have various kinds of sub and core processes, stages and specifications. Traditionally, the building process is divided into four stages; briefing, planning, production, and (facility) management (Ryd, 2004b). In the 1970s briefing was conceived as a process of discrete steps, where design could not begin until the briefing stage was completed (Blyth & Worthigton, 2010). As for today's view, the briefing is the capturing and transformation of knowledge between client/end user, architect/design team, and construction team with the implementation of new methods and techniques.

The development and process of brief may vary according the specifics of construction, *i.e.*, in terms of type, size and complexity. Complex projects may require much more information flow in terms of knowledge management cycle which involves many multi-disciplinary professionals and may therefor need greater challenges for briefing (J M Kamara, Anumba, & Hobbs, 1999). Briefing continues along the construction process and it is a valuable tool and process that each stage needs. RIBA initiates the construction process in eight overlapping stages from pre-project to use-period of building (*RIBA Plan Of Work:*, 2013). Client's business case, core requirements and strategic brief are stated at strategic definition at the zero stages, then preparation and brief stage present the project objectives including requirements, quality and budget objectives, sustainability aspirations. Development of concept designs and other ongoing stages are realized according to these stages by sustained knowledge and information flow. The simplified model of construction process of RIBA plan of work is presented in Figure 2.2. Client has an important role in all construction processes beginning with statement of demands and continuing through the use of facility. In briefing perspective, construction process could be simplified into three stages in which all activities of briefing and construction are related to each other.

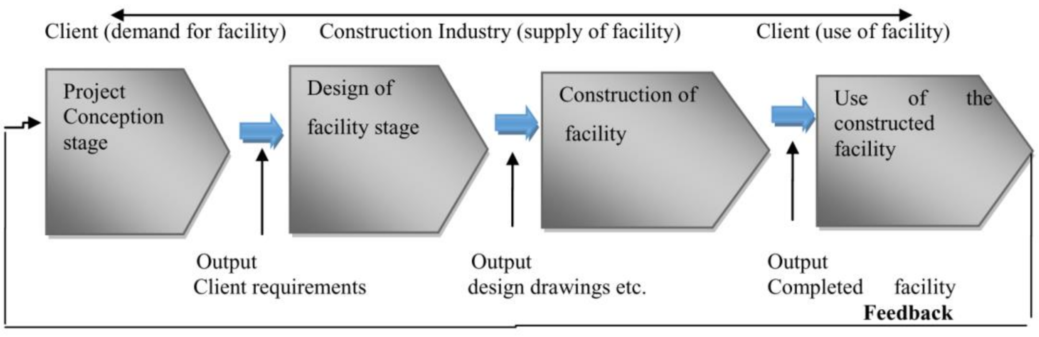


Figure 2.2. Construction process (E. Olatokun & Pathirage, 2015)

2.1.2 Briefing Framework

Good briefing is not only about a right checklist for communication between client and architect but it is also related to understanding the human dimension and has to be a concern for defining the correct structure of the briefing process of a project. Human dimension is about the experience and skills of people involved in the briefing. Barrett listed rule-based and knowledge-based failures about briefing and provided suggestions for improvement (P. S. Barrett et al., 1999): (1) brief takers' reliance on experience, information has to be presented in a way that is acceptable to individuals, (2) individual brief taker may be appropriate instead of architect, (3) client should be involved more to provide the necessary checks to ensure the brief is on course, (4) a neutral computer-based expert system may back up the weak areas of professionals. The suggestions pointed out are the development issues for briefing process. It is hard to state and use a comprehensive framework to think and criticize about. However, the briefing should be taken into consideration for the needs of the requirement management of client/end-user, planning for the instructed cost and time, and management of the information and knowledge of project stakeholders, the evaluation of the process and project in terms of feedback into the future and the success of project (Çalışkan & Pekeriçli, 2020). The briefing starts long before the project and continues long after and connects to the beginning of a new project as shown in Figure 2.3. It therefore continually feeds the upcoming projects by collecting the knowledge through a project lifecycle. The briefing process is segmented into three principal stages for better understanding and implementation of briefing into a construction project.

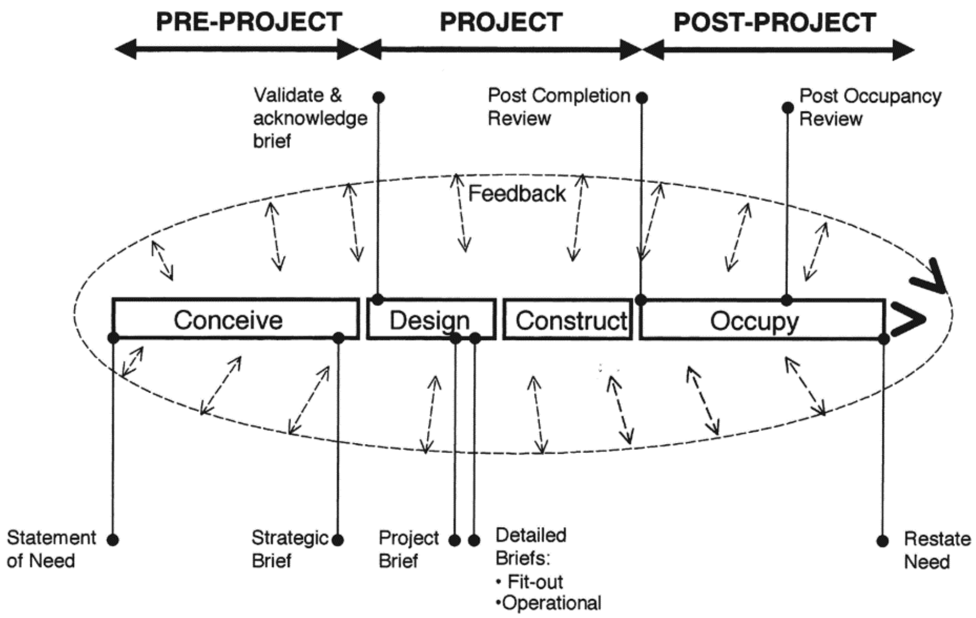


Figure 2.3. Three principle stages in briefing (Blyth & Worthigton, 2010)

Strategic Brief is a document that sets out the aims of the project and describes the organizational expectations (Blyth & Worthigton, 2010). It is a part of the pre-project stage and is more concerned about the desires of construction project completion. It should reflect the objectives of the solution for current needs and ideas that are behind the project. Strategic briefing springs from the current operational needs, but it also takes a longer perspective and focuses on the operation's strategic development plans, its prospects, and the building's potential for adaptation for other uses (Ryd, 2004a). This initial brief is the common source of the problem both experienced and inexperienced client (Yu, Chan, Chan, Lam, & Tang, 2010). There are various tools that are applicable to the development of strategic briefing to accomplish building client's wishes, scenario planning, strategic needs analysis, problem seeking and *etc.*

Project Brief is composed of functional brief, fit-out brief and operational brief (Blyth & Worthigton, 2010). It should communicate with, validate and develop the strategic brief. Transforming strategic brief into project brief could be possible by maintaining communication of client, user organizations, design and production teams. Drawings, 3D rendering of interior and exterior, images, checklists, axonometric and isometric views, models, diagrams and computer simulations are tools for presenting ideas and information at the project briefing in diverse levels of detail.

The post-project briefing is related to evaluation and feedback. Evaluation of project in terms production of a building, project management, and building usage performance makes possible to see in a complete view and brief as feedback for the further project. Evaluation of the process may occur both during and after the delivery of the project (Blyth & Worthigton, 2010). A framework about briefing stages should be identified for the evaluation during the project. The briefing itself can be an evaluation of the project by implementing approval and evaluation strategy into. Post-occupancy evaluation look at whether the building performance is meeting the performance measures identifies in the early briefs, as well as how the users are using the building (Blyth & Worthigton, 2010).

2.1.3 Why Is Briefing Needed?

Briefing is used in parallel with construction process from earlier stages, and does not end with the completion of construction. It is also an important tool and process for post project studies. The main functions of briefing are presented at the following sub sections.

2.1.3.1 Requirement Management

Briefing (also known as architectural programming in the US) is a process through which the client informs others of his/her needs, aspirations, and the desires for a project (O'Reilly, 1987). Defining the requirements of the project, followed by the design and production of building according to these requirements are the crucial tasks for the construction industry. In the traditional approach, the requirements are defined by the client and/or advisors at the initial stage by limited participation of project stakeholders. In some applications, these requirements are fixed and used for the implementation of design and in rest, the requirements are changed and developed throughout the process of the project. The user requirements change and develop according to physiological situations. Maslow's (Maslow & Frager, 1987) Hierarchy of Needs shown in Figure 2.4 defines the essentials of human needs. Understanding the nature and hierarchy of human needs is important because the requirements of the client are not always reasonable and logical for the project parties.

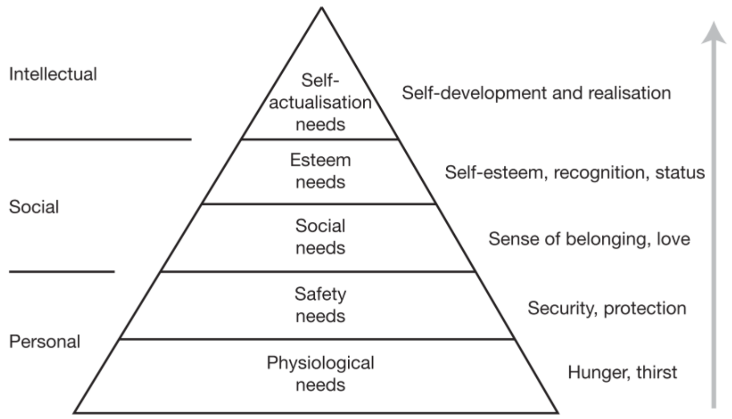


Figure 2.4. Maslow's hierarchy of needs (Blyth & Worthigton, 2010)

RM is mainly issued under the briefing term. It is critical for the successful delivery of construction and hard to accomplish in its effectiveness (Q. Shen, Li, Chung, & Hui, 2004). The terms, that are used to gather, analyse, process and test the client needs, defines various aspect of the subject. RM is related with documentation, storage, communication, tracking and traceability, whereas Requirement Engineering includes elicitation, analysis and prioritization, specification and validation (Bray, 2002). This knowledge comes from the Software Engineering discipline which is dealing with requirements more in last decades because of the rapid technological improvements. The whole process could be identified as requirement processing, and most the authors assumed that the briefing term is a process of identification, articulation, definition and registration of design requirements (Pegoraroa & Carísio, 2017).

Construction clients want to get projects that maintain the accurate designs regarding their demands in appropriate time and budget. Client demands are defined and stated as a client requirement by briefing process that is established by project stakeholders. However, construction industry has poor performance of addressing these requirements owing to uncertainty and complexity of project brief (Shahrin et al., 2010). In addition, capturing and translating the knowledge from clients to designers or designers to clients are important problem areas for successful requirement processing resulting from lack of time, framework, expertise, *etc.* A continuous process for requirements of clients is needed to match them to proper design solutions, thus client requirements processing could be told for this context. Pegorraroa and Carisio summarized some problems as; lack of communication, objectives and decision clarity, client inexperience, involvement of end-user and evaluation of solutions for clients' (Pegoraroa & Carísio, 2017).

2.1.3.2 Cost and Time

The satisfaction of the client could be achieved by translating the client needs into a design that specifies technical characteristics, functional performance criteria, and quality standards and by completing the project within a specified time period and in the most cost-effective manner (Bowen, Pearl, & Edwards, 1999). The construction and design process should continue within budget and time, while the requirements of the project are being met. Clients are mostly satisfied when the completion of construction is within the planned budget and time. Briefing has an important role in communicating clients' requirements for the design and construction teams, the briefing process represents a cornerstone for achieving client satisfaction (Othman, Hassan, & Pasquire, 2005). The budget and planned time of a construction project are estimated in the earlier project stage (inception stage). Briefing is for the management of the process by means of good decision-making.

As the project develops according to inputs, the cost and time parameters may change in both directions. Cost of the change orders and decision revisions increases as project progress in time, at the same time the potential of saving decreases and end with the completion of the project. Figure 2.5 illustrates the relation between cost and time while project progress. Managers responsible for the briefing will need to strike a balance between these two forces, allowing the user to have alternative options until the last responsible moment while giving the project team the relevant information at the appropriate stage of the project (Blyth & Worthigton, 2010).

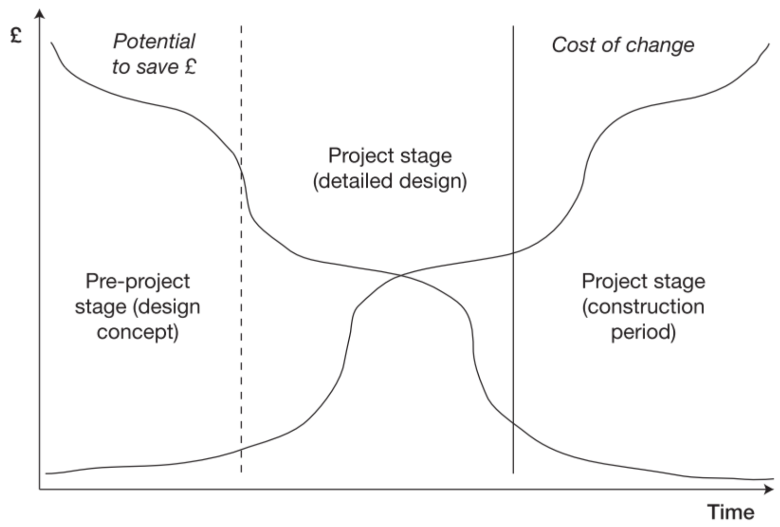


Figure 2.5. Cost and time(*Design for Change:The Architecture of DEGW*, 1997)

2.1.3.3 Communication

The strength of the relationship between different actors and their ability to work together is crucial for the construction industry. A good relationship may have various reasons, but it can be provided by only good communication. Communication is the sharing of meaning to reach a mutual understanding and to gain response: this involves some form of interaction between a sender and receiver of the message. Briefing is a tool and it is much more related to the communication of the client and designer. It affects the information flow between parties and this flow results with qualified information. Higher quality of information will lead to better communication between stakeholders (Tessema, 2008). Norouzi, N. listed the critical factors in effective communication (Norouzi et al., 2015) as follows:

“Semantic: It is important that the receiver of the message has the knowledge necessary to decode the message.

Emotional: Effective communication relies on the content of the message and its emotional impact.

Technical: How information is structured will affect how it is disseminated.”

Communication benefits from accurate knowledge transfer in a short time and minimal effort. Exchange process between the sender and receiver is influenced by the mutual semantic attitudes of the sides. With the gathering and decoding of the message, the response is crucial for effective communication. Emotional impact and the content of the message should, therefore, be in balance where equal value is considered. The structure of information makes it possible to codify the complex and detailed data, and distribute it to a wider area. Briefing, which is a tool for capturing knowledge via communication between stakeholders, should consider the semantic, emotional and technical factors of effective communication.

2.1.3.4 Project Success, Performance and Evaluation

Baccarini identified project success in two components (Baccarini, 1999): Project management success and product success. He stated that the criteria for measuring project success must be set out at the beginning of the project, otherwise different team members will find themselves traveling in differing directions and one or more of them might perceive the project to be a failure. As shown in Figure 2.6, product success is related to the goal and purpose, project management success is related to the output and inputs. The whole success is defined as project success. The briefing is a powerful tool for maintaining information, controlling information flow and management of knowledge to achieve project success.

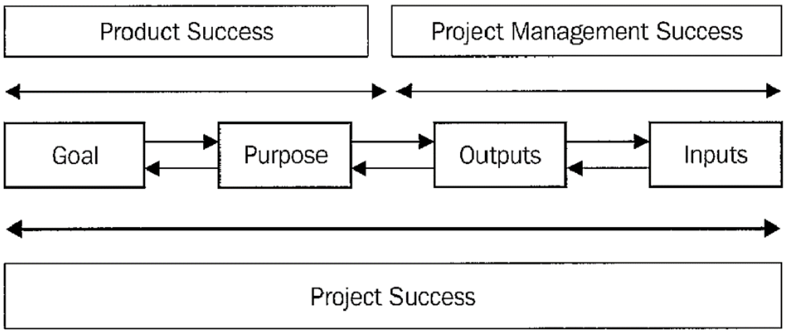


Figure 2.6. Link between framework and project success (Baccarini, 1999)

The performance of the project, determined using feedback, includes information on both the performance of the project team and the performance of the building against the desired project outcomes (*RIBA Plan Of Work:*, 2013). Intended comparison between the performance of the building and the desired objectives is possible by continuing briefing process and records related to the project life-cycle from the beginning till to the in-use stage.

Post-occupancy and pre-occupancy evaluations are related to the evaluation of a building construction project. Post-occupancy evaluation is a diagnostic tool and system which allows facility managers to identify and evaluate critical aspects of building performance systematically. This system has been applied to identify problem areas in existing buildings, to test new building prototypes and to develop design guidelines and criteria for future facilities (Preiser, 1995). For further development, Shen initiates a BIM-based user pre-occupancy evaluation method (UPOEM), which is applied in the architectural design stage for the aim to improve the efficiency and effectiveness of the communication between designers and clients (W. Shen & Shen, 2011). Both Post-Occupancy Evaluation and Pre-Occupancy Evaluation Method use the briefing to gather information and implementing them into the existing or new project. Using a variety of post-occupancy evaluation techniques helps to ensure that the completed project has met the original project brief and provides feedback for new projects (*RIBA Plan Of Work:*, 2013).

2.1.3.5 Knowledge Source

Briefing also acts as a part of knowledge process like knowledge creation and transfer between individuals, groups and organizations. It enables a systematic approach for communication of project stakeholders and with inquired techniques like workshops, brainstorming, *etc*. valuable knowledge for project requirements is created and sorted. Considering these, it can be noted as a knowledge source for construction projects as well as other industries. This dimension of briefing may be better seen via KM principles and processes at furthers sections.

2.1.4 Factors and Barriers Affecting Client Briefing

Various factors affect the briefing and success of the process originated from stakeholders, frameworks, skills, documentation and communication. Briefing is an important process for project success, thus many practitioners and researchers have works about it. It can be noted that briefing process of itself and outputs figure out a way the determine the project context and evaluation frameworks. A recent study carried out shows the barriers and factors affecting client briefing with a ranking in Figure 2.7 and Figure 2.8. It is seen that lacks and barriers have some similar issued between client briefing and requirement processing. The research determined the factors and barriers by literature survey and conducted a 100-respondent survey in UK construction industry using quantitative and qualitative analysis. The communication gaps between client and architect, misunderstanding, lack of proper participation of client in process, and inadequate identification can be stated for the barriers to client briefing process (E. O. Olatokun, 2017). Some of the facts affecting the briefing process are ability of the architect to comprehend and conceptualize the client requirements, clear communication, involvement of the client in the process and allocating enough time.

FACT 1: Ability of the architect to comprehend the client requirements during briefing phase

FACT 2: Clear communication between client and architect

FACT 3: Use of face-to-face communication method

FACT 4: Ability of the architect to be able to conceptualize the client's requirement

FACT 5: Involvement of the owner (client) in the briefing process

FACT 6: Client representation

FACT 7: Allocating enough time to the client briefing process

FACT 8: Clarity of client requirements

FACT 9: Adequate, planning and proper briefing

FACT 10: Experience of the Architect

FACT 11: How familiar the architect is with the design project

FACT 12: Establishing priority levels for various client requirements

FACT 13: Frequent communication between client and architect

FACT 14: Signing off of the requirement document

FACT 15: The architect's level of experience with client briefing

Figure 2.7. Factors affecting client briefing (E. O. Olatokun, 2017)

BARR 1: Communication gaps between client and architect

BARR 2: Misunderstanding and misinterpretation of client needs and requirements

BARR 3: Lack of proper participation of client in the briefing process

BARR 4: Inadequate identification and representation of needs and requirements during the briefing process

BARR 5: Lack of Trust

BARR 6: Relationship

BARR 7: Insufficient time given to the briefing process

BARR 8: Knowledge of the architect

BARR 9: Lack of proper documentation and or changes

BARR 10: Assuming one size fits all

BARR 11: Unstructured approaches for knowledge capturing

BARR 12: Inexperienced Clients

BARR 13: Lack of process knowledge for capturing knowledge

BARR 14: Inadequate attention given to the wealth of techniques available

BARR 15: Type of organisation culture

BARR 16: Trying to capture too much

BARR 17: Capturing knowledge that is not used

Figure 2.8. Barriers for client briefing (E. O. Olatokun, 2017)

2.1.5 Importance of the Client Involvement

Design briefing is about understanding client needs, identifying the explicit knowledge such as project location, construction attributes and validating design solutions with the involvement of project stakeholders. It is a cycle which does not stop, only decrease in frequency according to completion ratio of design. The briefing also runs after construction and in parallel with commissioning of the project. Studies try to examine and present the limitations and barriers for better briefing for years; method and framework have been introduced to gain success against barriers. Inadequate involvement of all the relevant parties to a project, insufficient time allocated for briefing, inadequate considerations of the perspectives of the client, inadequate communication between those involved in briefing, inadequate management of changes to requirements can be listed as general limitations (J M Kamara et al., 1999). Focusing on clients, it can be stated as; they frequently fail to provide a comprehensive list of their project requirements, they do not fully understand their own roles within the building process, briefing is prematurely initiated before alternatives have been analysed by the client (E. Olatokun & Pathirage, 2015).

Design briefing is much more related with requirement elicitation and validation which is defined as requirement processing under the term requirement management. It is critical for the successful delivery of construction and hard to accomplish in its effectiveness (Q. Shen et al., 2004). The terms, that are used to gather, analyse, process and test the client's needs, defines various aspect of the subject. Requirement Management is related with documentation, storage, communication, tracking and traceability, whereas Requirement Engineering includes elicitation, analysis and prioritization, specification and validation (Bray, 2002). Lack of clarity for decision tracking and experience of design team, formalization, comprehensive frameworks and methods have impact on all steps and activities. Lack of effective communication, clarity of objectives, inclusion of end-user and difficulties in accommodating the requirements of all involved have an impact on elicitation, analysis and prioritization and specification of requirements (Pegoraroa & Carísio, 2017). This shows that proper capturing and reuse of knowledge especially from the client and end-user is key element requirement elicitation. Although it is difficult to develop useful methods and frameworks for briefing where a designer's use is intended, there is also a need for the requirement management of client-end user, planning for the instructed cost and time, and management of the information and knowledge of project stakeholders, the evaluation of the process and project in terms of feedback into the future and the success of project.

2.1.6 Designer Roles in Briefing Process

Architects as designers have an important role in briefing process in terms of brief taker, brief manager or knowledge influencer (P. Barrett & Stanley, 1999; Blyth & Worthigton, 2010; Othman et al., 2005). Design and design process is difficult to describe and manage, since they include so many intangible elements such as intuition, imagination and creativity (Zeisel, 1984). Considering this aspect of design, requirements which are trying to state objectives of project should be considered in a more complex way. The experience and vocational knowledge about building typology and construction projects bring an important subjective point of views towards requirements, space relations and pattern of objectives. Subjectivity in this situation is evaluation of items and concluding them into logical objectives via filtering and getting optimal decision by experience-based judgements. Whether the requirements of spaces are stated in a more detailed and organized medium for specific project before the involvement of designer, they are generally updated and revised through different processes such as individual working, collaborative workshops and briefing with project stakeholders under the management of designer for benefit and success of project against initial requirement statement. Besides that it is important to solve the possible technical and social communication problem between the client and the architect (Norouzi et al., 2015). Thus, the clients search and have an agreement with architects who have capability and experience to manage the process of selected project. The completion of briefing process for requirement elicitation and validation cannot be thought without involvement of the designer, however there may be initial and important working stages for creating requirement knowledge to be used for creation and comparison base. As stated in the introduction chapter there are two general thoughts on briefing. One is the brief is fixed and frozen, other is briefing is live and dynamic process. Whether it is, the requirements are processed by designer's studies. As an example; functional diagrams or architectural programs are only stating for the objectives, the context should provide freedom to designer for their creativity and ensure the diversity of the proposals (Mauger & Kubicki, 2013).

2.2 Knowledge Management and Processes

Knowledge Management (KM) approach has been increasingly recognized by business sectors and researchers by giving to organizations competitive advantages for meeting objectives against the requirements (Hai Chen Tan et al., 2007). KM concerns the optimization of knowledge in organizational level through diverse tools, processes, techniques and technologies to increase performance and value, have return on investment and competitive advantages (J. M. Kamara et al., 2002). KM can be defined as a continuous process of managing the knowledge to create value, increase productivity and gain competitive advantages with identification, optimization and active management by meeting existing and emerging needs (Quintas, Lefrere, & Jones, 1997; Webb, 2017). Construction industry realizes the benefits and necessities of KM approach as other sectors, implements and develops the approach the concept in the process. In a survey at UK 50% of respondents which are from construction industry noted that KM would result in new technologies and new processes for the benefit or organization (Egbu, 2002).

Construction industry generally deals with a project which is 'unique', and should act analytically against problems and hardness of context by making decisions with valuable knowledge. Good KM practices with knowledgeable project stakeholders.

who are supported by integrated information and data sources result satisfied decision making process (Chimay J. Anumba, Charles O. Egbu, 2005). Figure 2.9 shows the knowledge support for decision-making.

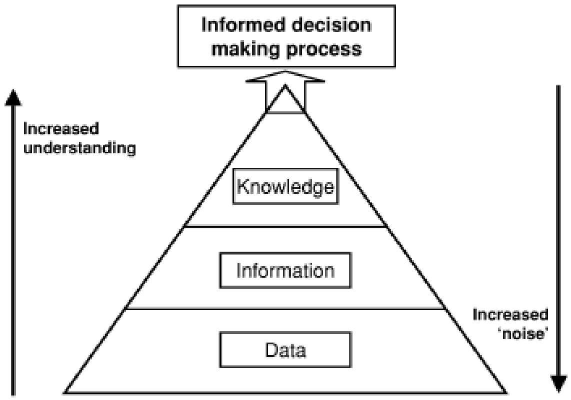


Figure 2.9. Knowledge support (Chimay J. Anumba, Charles O. Egbu, 2005)

2.2.1 Knowledge and Knowledge Types

There are various explanations and studies for knowledge identification. Some views of knowledge in literature presented are (Firestone & McElroy, 2012) :

“ - *Knowledge is understanding based on experience,*
- *Knowledge is experience or information that can be communicated or shared,*
- *Knowledge, while made up of data and information, can be thought of as much greater understanding of a situation relationships, causal phenomena, and the theories and rules (both explicit and implicit) that underlie a given domain or problem.* ”

Knowledge typology is examined by various researchers and practitioners both business environment and construction industry. Dimensions of some are related the usage of knowledge or creation method, some are originated from the transfer concepts, some are separated according to process time and frequency and rest is presented according to contextual situations regarding to specific business environment. Within this section, it is tried to concentrate on types of knowledge which is compatible with construction projects, epically relate to reusable project knowledge and knowledge captured for requirement elicitation. Knowledge types in generic and construction domain perspective are located from the literature comprehensively and shown in Table 2.1.

Table 2.1 Classification of knowledge (H.C. Tan et al., 2010)

Authors	**Classification of knowledge**	
(a) Generic perspective		
Nonaka and Takeuchi (1995); Polanyi (1958)	• Tacit knowledge	• Explicit knowledge
Bhatt (2001)	• Foreground knowledge	• Background knowledge
Blacker *et al.* (1993)[1]	• Embrained knowledge • Embodied knowledge • Encultured knowledge	• Embedded knowledge • Encoded knowledge
Rollett (2003: p. 36)	• Core knowledge • Innovative knowledge	• Advanced knowledge
Ruggles (1997b)	• Process • Factual	• Cultural • Catalogue
KPMG (1998)	• Methods and processes • Company's own markets • Company's own products and services	• Regulatory environments • Customers • Competitors • Employee skills
(b) Construction-domain specific perspective		
McLoughlin *et al.* (2000)	• Know-how • Know where/when	• Know why • Know what
Whetherill *et al.* (2002)	• Project • Organisational	• Domain
Robinson *et al.* (2001)	• Process • People	• Product
Kamara *et al.* (2002b)	• Organisational processes and procedures • Client's business • How to predict outcomes, manage teams, focus on clients and motivate others	• Technical/domain knowledge • Know-who

From the perspective of transfer, convert and creating knowledge, the important knowledge typology consisting tacit and explicit knowledge is underlined. Knowledge management to all intents and purposes took off as a management discipline with the popularization of the words 'tacit' and 'explicit' by Nonaka and Takeuchi (1995) through the SECI model that identified four transitions of knowledge (Evans, 2003). Explicit knowledge or codified knowledge may be understood by people with complementary knowledge who can extract meaning from the ‘codes’ (Fuller, 2012). This knowledge could be defined as transferrable knowledge by rules, codes, language or symbols. Tacit Knowledge comes from the experience and practice and hard to formulate. It can be characterized as inexpressible, ineffable and hard to tell (Polanyi, 2009). It cannot be communicated or transfer in language, codes or symbols as explicit knowledge. Explicit knowledge is packaged, easily codified, communicable and transferable, whereas tacit knowledge is personnel, context-specific, difficult to formalize, communicate and transfer (Kidwell, Vander, & Johnson, 2000). The major challenges for KM in all organizations that in all human activity there is acquired tacit knowledge through experience and internal reflection which is impossible to share with other who have never been in similar learning experience (Fuller, 2012). Design knowledge could be tacit, coming from experiences and also behind some design decisions, or explicit which documented for sharing, accessing, indexing and using. In the construction industry tacit knowledge coming from experienced experts and engineers has an important role in the construction process; in an survey six respondents considered almost 60% of their knowledge is tacit in individuals heads which is hard to capture (Kivrak, Arslan, Dikmen, & Birgonul, 2008).

Another dimension of knowledge for construction domain is about usage of knowledge that has application in the construction project. Types of reusable project knowledge can be listed as (H.C. Tan et al., 2010);

- Process knowledge and knowledge about clients,
- Knowledge about legal and statutory requirements,
- Costing knowledge and knowledge about reusable details,
- Knowledge of best practices and lessons learned,
- Knowledge of performance of suppliers, key competitors,
- Knowledge of who knows what,

The knowledge about the requirement of construction projects is more specified in terms of process, site, client and regulatory. There is need for integration and collaborative working between project stakeholders to manage to knowledge about the requirements. Types of knowledge about requirements are presents as (John M Kamara, Anumba, & Evbuomwan, 2002); client requirements, site requirements, environmental requirements, regulatory requirements, design requirements and construction requirements.

2.2.2 Knowledge Cycle and Processes

Knowledge cycle is defining the knowledge creation and sub-processes which are parts of whole process have role in capturing, archiving, understanding and reusing. Presenting of cycle and processes differ at researchers, however they are thought as a continuous loop for the knowledge gathering and refinement. A common and brief cycle representation is shown in Figure 2.10. Knowledge is captured from a source (individuals, group, world, *etc*.), then it archived with a method, for reuse it must be found and understood and finally the knowledge is created with refinement. The new knowledge may be created from different sources with various methods, on the other hand it must be validated at the design methods and be consistent in its context. Researchers have attempted to enlarge and develop the life cycle and processes according the business process and organization.

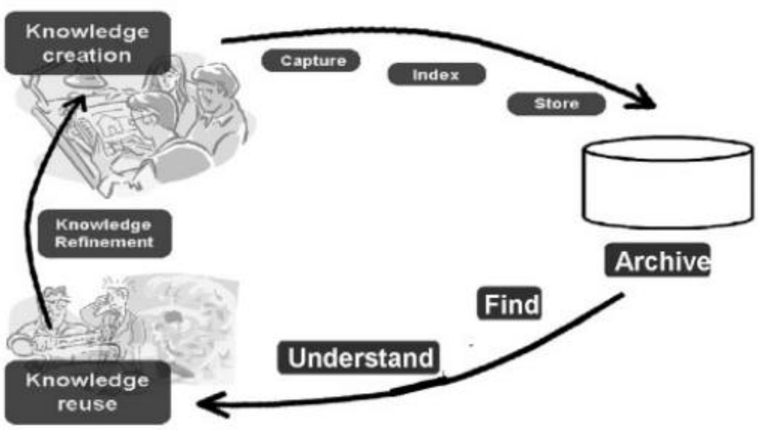


Figure 2.10. Knowledge cycle (Chimay J. Anumba, Charles O. Egbu, 2005)

Four main KM processes (Table 2.2) which have incorporated the notions of knowledge obsolescence and validation, are proposed based on the KM process models (H.C. Tan et al., 2010). Knowledge Capture has sub-processes in terms of identifying and locating for discovery, acquiring and creating; representing and storing for presentation and finding; validating for evaluation and validation. After these, knowledge could be processed for requirement elicitation. Knowledge captured and shared could be reused by adapting, modifying and applying to suitable subjects and intended processes simultaneously. Important and supplementary process of the cycle is to maintain the knowledge for further projects or context by archiving, retirement and refining. The created knowledge could be enlarged, refined or changed by single, double or multi loop processing according to frameworks which is designed and validated for decided usage

Table 2.2 KM main process (H.C. Tan et al., 2010)

Live Capture and Reuse of Project Knowledge (CAPRIKON)		**Robinson *et al.* (2001)**	**Kululanga and McCaffer (2001)**	**Bhatt (2001)**	**Rollett (2003)**
Capture	• Identifying • Locating	• Discovering • Locating • Capturing	• Acquiring • Creating	• Creating	• Planning • Creating • Assessing
	• Representing • Storing	• Organising • Storing	• Storing	• Presentation	• Integrating • Organising
	• Validating			• Validating	
Sharing	• Sharing	• Sharing • Transferring	• Sharing	• Distributing	• Transferring
Reuse	• Adapting • Applying	• Modifying • Applying	• Utilising	• Applying	
Maintain	• Archiving • Retirement	• Archiving • Retirement			• Maintaining

2.2.3 Knowledge Capturing

In previous sections knowledge, knowledge management and process are explored. Capturing, translating and processing of the knowledge are main successors of project study for client requirements. Knowledge is captured from a source (individuals, group, world, *etc.*) with a technique or method, then it is archived since for reuse it must be found and understood, and finally the knowledge is created with refinement (Çalışkan & Pekeriçli, 2020). Dimension and character of knowledge are important to consider from deciding the proper framework, tools, technique or technologies for capturing the client's knowledge. The explicit knowledge coming from site requirements, design specific necessities or construction companies' intentions may be processed by conventional knowledge management practices, however the tacit character of the knowledge clients have about space activities, experiences and insights make harder to capture and reuse. A continuous process with the involvement of client, inclusive approach regarding tacit-ness of knowledge and verifiable conversion principles are essential for requirement elicitation and validation in terms of matching requirements (inputs) to proper design solutions (outputs).

2.2.3.1 Knowledge Capturing Techniques

Construction industry uses KM tools, guidelines and concepts for capture and sharing of the knowledge regarding on beneficial impacts on the process. Some of the tools are recognized by all industries, implemented in construction process, whereas some of them are being developed by researchers and practitioners for particular stages of the briefing and construction life-cycle. These tools can be categorized as KM techniques which are non-it tools and KM technologies which use information and communication technology (Al-Ghassani, 2003). These are defined as; soft concepts which are existing concepts of collaborative learning and learning histories, and in contrast, hard technologies which include ICT applications that are currently being used in the construction (John M Kamara et al., 2003). Techniques can be listed as reviews, communities of practice, forum, brainstorming; technologies are custom-design software, expert directories, knowledge bases, groupware. Although this categorization is generally accepted by researchers, there are no clear borders and limitations about the character of tools, combined approach for the continuous development of capture and sharing's methods, tools and frameworks have strong influences at the present time. A comparison between KM techniques and technologies is shown in Table 2.3. Combined approach adopts a pragmatic view acknowledging that there are strengths and shortcomings in the KM practice solely focused on either technological or organizational, cultural and technique related issues (John M Kamara et al., 2003). Some of the current practices on capture, sharing and reuse of project knowledge conventionally regarding techniques or technologies can be listed as; post project reviews, brainstorming, communities of practice, training, recruitment, face to face interviews, mentoring, text and data mining, knowledge bases, reassignment of people, groupware, case based reasoning, project extranets, lesson learned tools, observation, repertory grid, consensus decision making, concept map and cognitive map (Al-Ghassani, 2003; John M Kamara et al., 2003; Pourzolfaghar et al., 2014; H.C. Tan et al., 2010).

Table 2.3 KM Tools (Chimay J. Anumba, Charles O. Egbu, 2005)

KM tools	
KM techniques	**KM technologies**

• Require strategies for learning
• More involvement of people
• Affordable to most organisations
• Easy to implement and maintain
• More focus on tacit knowledge
• Examples of tools:
  ○ Brainstorming
  ○ Communities of practice
  ○ Face-to-face interactions
  ○ Recruitment
  ○ Training
	• Require IT infrastructure
	• Require IT skills
	• Expensive to acquire/maintain
	• Sophisticated implementation/maintenance
	• More focus on explicit knowledge
	• Examples of tools:
	  ○ Data and text mining
	  ○ Groupware
	  ○ Intranets/extranets
	  ○ Knowledge bases
	  ○ Taxonomies/ontologies

2.2.3.2 Importance of Knowledge Capturing

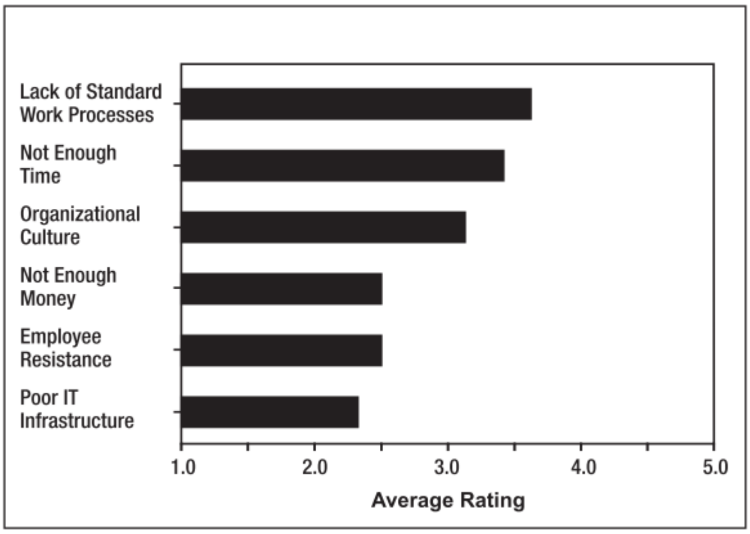
Knowledge sources in the construction industry can be divided into three groups. These sources have overlapping areas however, characterization has beneficial impact on understanding the importance of capturing. First one is individuals or groups who are involved in the construction projects; design team, client- end-users, construction team, supervisors, consultants, contractors and suppliers. The knowledge belongs to this group may have tacit or explicit character according to their convertible dimensions. Second group is originated to unchangeable facts related to site, legislation and regulations, cost and time, project specifications, labour and resources issues coming from the unique project situation. Third source group is coming from organizational or company level which is based on past experiences, knowledge repository of cases and evaluations. Knowledge capturing and sharing is a concept of creation or acquiring essential values, knowledge and frameworks into construction projects. The capturing can facilitate the reuse of collective learning on a project, provide knowledge than can be utilized at the operation or maintenance, benefit client organization with enriched knowledge about the development and project teams for their responsibilities (John M Kamara et al., 2003).

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

2.2.3.3 Barriers for KM

Processes of KM and capturing have various barriers and reason regarding country, project typology, culture and awareness of process. Table 2.4 shows the results of a survey conducted in UK. Lack of standard work process and framework of KM, not enough time and money, culture, employee resistance to process and poor IT infrastructure could be thought as important barriers to implementation of Knowledge Management. Also, consulting firms try to deal with the problems in knowledge capturing by stating and searching solutions for barriers. For instance, Greenes consulting states trying to capture too much, underestimating the time and effort, capturing the knowledge that isn't used and assuming one size/method fits all as common pitfalls for knowledge capturing (Greenes, 2010). Architects as designers and project coordinators take generally most important roles in this knowledge processes also considering the architectural knowledge importance's in construction projects. In a research study in Turkey, barriers of managing architectural knowledge were examined. The results indicated that 13 out of 15 organizations consider lack of standard processes and 9 out of 15 consider insufficient time and money as main barrier (Kayaçetin & Tanyer, 2009).

Table 2.4 Barriers to KM Implementation (P. Carrillo, Robinson, Al-Ghassani, & Anumba, 2004)



2.2.4 Contemporary Strategies, Frameworks and Research Projects

There are various techniques and technologies related to knowledge capturing, reuse and creation. Some of them are designed for knowledge creation by capturing the explicit and tacit knowledge from individuals, groups or communities for the development of various kinds of business sector, some of them designed or cross-organizational learning (Merl & Schönbauer, 2014; Orange, Cushman, & Burke, 1999), some of them are specific KM practices like sustainable construction (M. M.A. Khalfan, Bouchlaghem, Anumba, & Carrillo, 2003; Malik M A Khalfan, Bouchlaghem, Anumba, & Carrillo, 2002) or knowledge transfer on Public Finance Initiatives (PFI) (P. M. Carrillo, Robinson, Anumba, & Bouchlaghem, 2006), and some are related to knowledge transfer between different industries (Green, Newcombe, Weller, & Fernie, 2004). In this section, the ones which presents and supports capturing the knowledge from the client or individual and groups who has the usage and expertise knowledge which have possible process on requirement elicitation and validation.

2.2.4.1 Frameworks and Research Projects

The studies in the literature are given in the section, and at the end the descriptive table conducted for issued important in the research. The Client Requirement Processing Modelling (CRPM) with Quality Function Deployment (QFD) is approach for defining, analysing and transferring the requirements which uses QFD from the manufacturing industry (Figure 2.11). 'Voice of the customer' is translated to 'voice of the designer' by matrix which is quality and functions based correlating what's, how's and target (J. M. Kamara, Anumba, & Evbuomwan, 1999). Elicitation of requirements and validation are done with the weight-based analysing by using the explicit and implicit knowledge independent from the design attempts. ClientPro is software application of CRPM in which calculations made by the program according the framework. Entities and calculation matrix are resulting in solution neutral outputs for defining, analysing and translation of requirements. The user interface makes the involvement of client and individuals representing the client possible who may not have any expertise on this model.

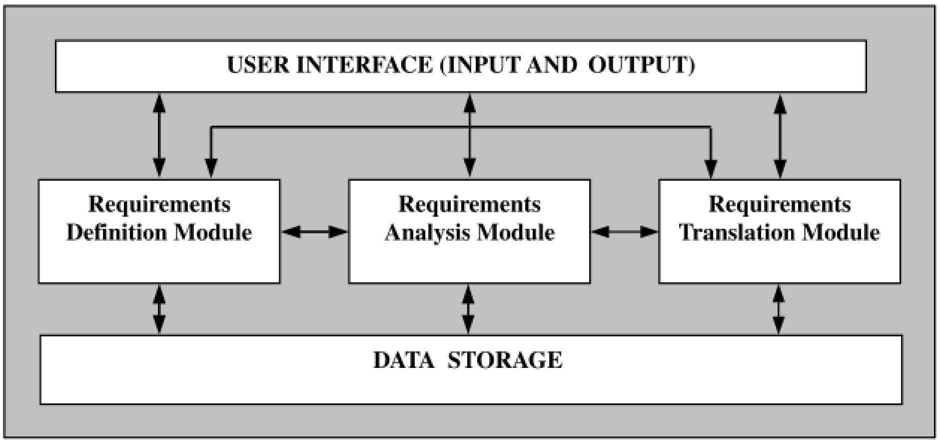


Figure 2.11. System architecture of ClientPro (J. M. Kamara & Anumba, 2001)

On the other hand, another study DesignTrack deals with a tool in the responsibility of the designer/not involvement of the client, but it concentrates on traceability of requirements with design solutions in integrated design environment for requirement spaces. It uses geometric modelling for designs and requirement modelling for capture knowledge and integrated them in a requirement-driven design understanding automation framework (Ozkaya & Akin, 2005, 2007). The prototype software has extensions for IFC or building data model, and the captured knowledge can be used in ongoing project and further projects.

CAPRIKON is research project to develop a methodology for 'live' capture of reusable project knowledge that will reflect both the organizational and human dimensions of knowledge capture and reuse, as well as exploit the benefits of technology (Koskela, L., Owen, 2006). The aim is to capture and validate the knowledge through the project execution lively in an agile way for re-use and dissemination. Reusable project knowledge often exists as mix and explicit knowledge, thus for tacit knowledge a codification strategy for convertible one's, and links, contacts details of knowledge author's captured for which is difficult to convert (Hai Chen Tan et al., 2007). Capri.net (a web-based prototype) is designed for live capture and reuse of construction project knowledge according finding of CAPRIKON project (Udeaja et al., 2008). System architecture of the methodology is pointed out in Figure 2.12; consisting of capture, validation and dissemination of knowledge. The system is capturing knowledge from individual, groups and rationale that make changes and validate them with meetings or online validation (comments, rankings, majority's opinion) with approval of project knowledge manager, recording in project knowledge file (database) for dissemination. This process can be for numerous projects for organizations to establish a database of construction project knowledge by capturing the knowledge created at project execution stages including end user's requirement knowledge.

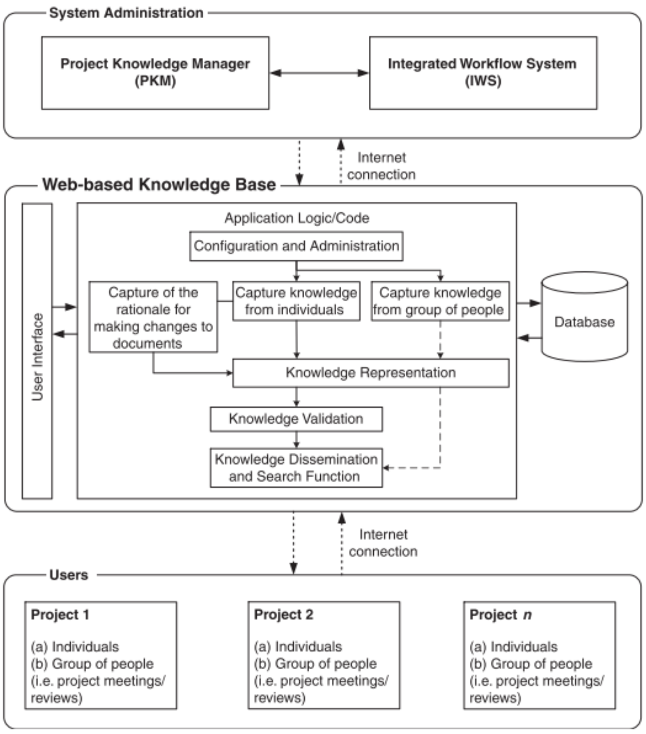


Figure 2.12. Capri.Net and CAPRIKON (H.C. Tan et al., 2010)

e-COGNOS is EU funded project which aims to specifying and developing an open model-based infrastructure and a set of tools that promote consistent knowledge management within collaborative construction environments by using web technology and ontological framework (Wetherill et al., 2002). The project (Figure 2.13) provides web-services to support the major functionalities identified in the classical KM cycle, namely: acquisition, cleansing/transformation, indexing, updating, refreshing, searching/discovering and sharing/dissemination supported by ontology service (EU-Commission, 2003). A knowledge platform for contractors to capture in construction project (KPfC) is introduced to reduce time and cost for solution of repeating mistake, share and retain the knowledge captured (Kivrak et al., 2008). It is a web-based platform that capture the both tacit and explicit knowledge of experienced engineers and experts for contractors, validate and reuse with the retrieval from the knowledge base. (Figure 2.14). It enforces the continuous improvement by transferable lessons learned knowledge and organizational learning by sharing knowledge with companies.

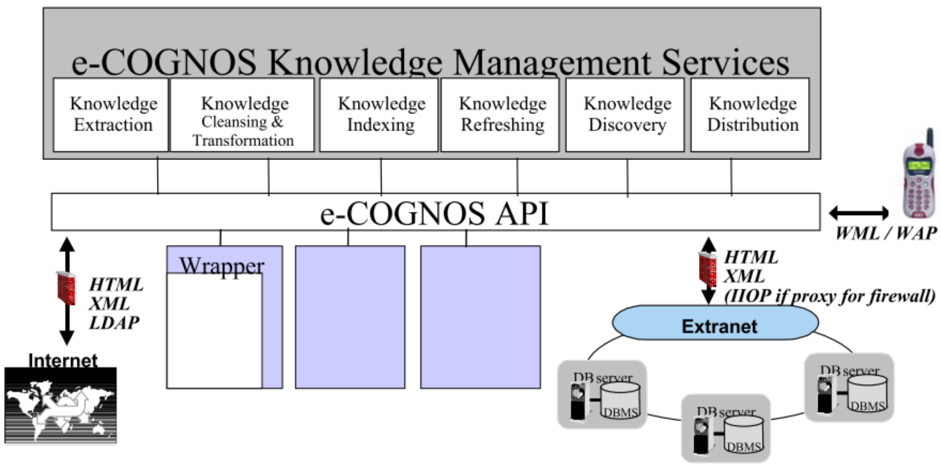


Figure 2.13. The e-COGNOS global architecture (Wetherill et al., 2002)

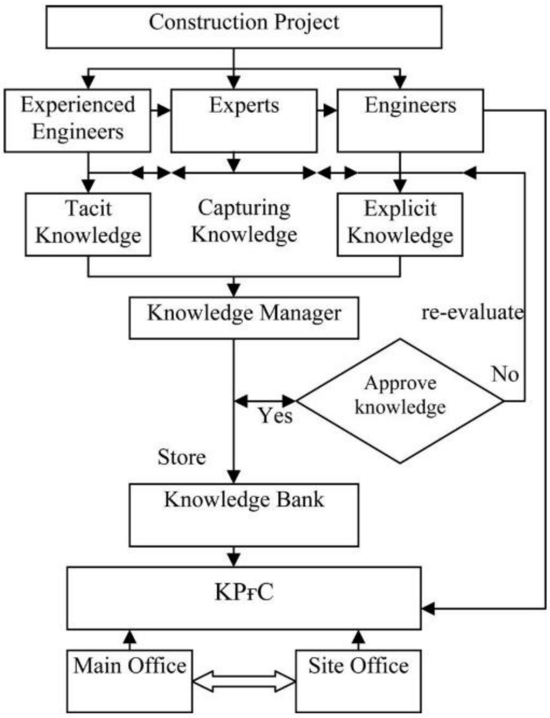


Figure 2.14. Implementing KPfC (Kivrak et al., 2008)

Recently a web based online platform (LinCTool) is introduced to capture and transfer knowledge across projects which has a potential to enhance organizational learning in companies by assigning multiple users having different responsibilities/roles in the learning process, categorizing lessons learned using a taxonomy and retrieving lessons learned considering project similarities (Eken, Bilgin, Dikmen, & Birgonul, 2020). The tool has detailed system lesson entry, editing, searching and accessing for capturing knowledge from knowledge sources (assigned roles) and transferring them into new projects (searching, retrieval mechanism with taxonomy and similarity (Figure 2.15). The centralized system and user management capability result in an approval mechanism under the control of authorized users ensuring quality of the lessons learned. The process model, similarity assessment method and construction taxonomy can be listed among contributions of LinCTool to organizational learning literature (Eken et al., 2020).

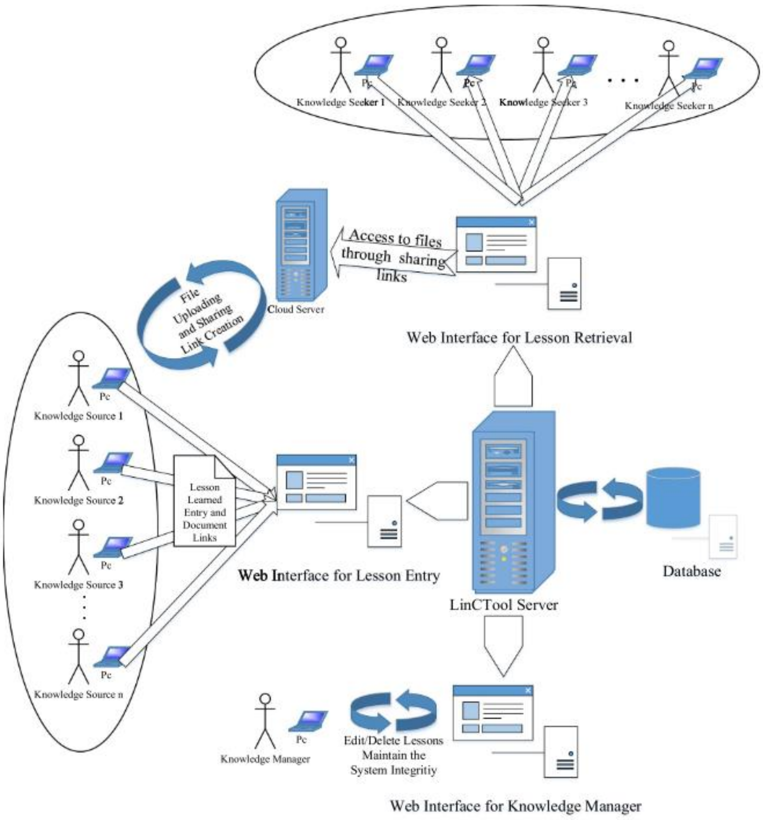


Figure 2.15. Representation of proposed structure (Eken et al., 2020)

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

The system offers an approach to accumulate and reuse valuable knowledge in previous construction briefing. These research attempt to investigate and analyse client requirements in structured framework, represent and store for retrieval and reuse project based (further expansion to cross projects) and implement them with a knowledge base by case-based reasoning.

Design requirements of spaces are connected to user activities and space types in a building. The relation between them explores the requirement in terms of values of requirement types. An automated updating of space design requirement approach is introduced by connecting all user activities and space types systematically for decreasing time and errors at changing (Kim, Kim, Cha, & Fischer, 2015). The method showed in Figure 2.16 is an example of automation on design process with the implementation of technology concepts. This kind of implementations are possible, and developed contemporary regarding various concepts.

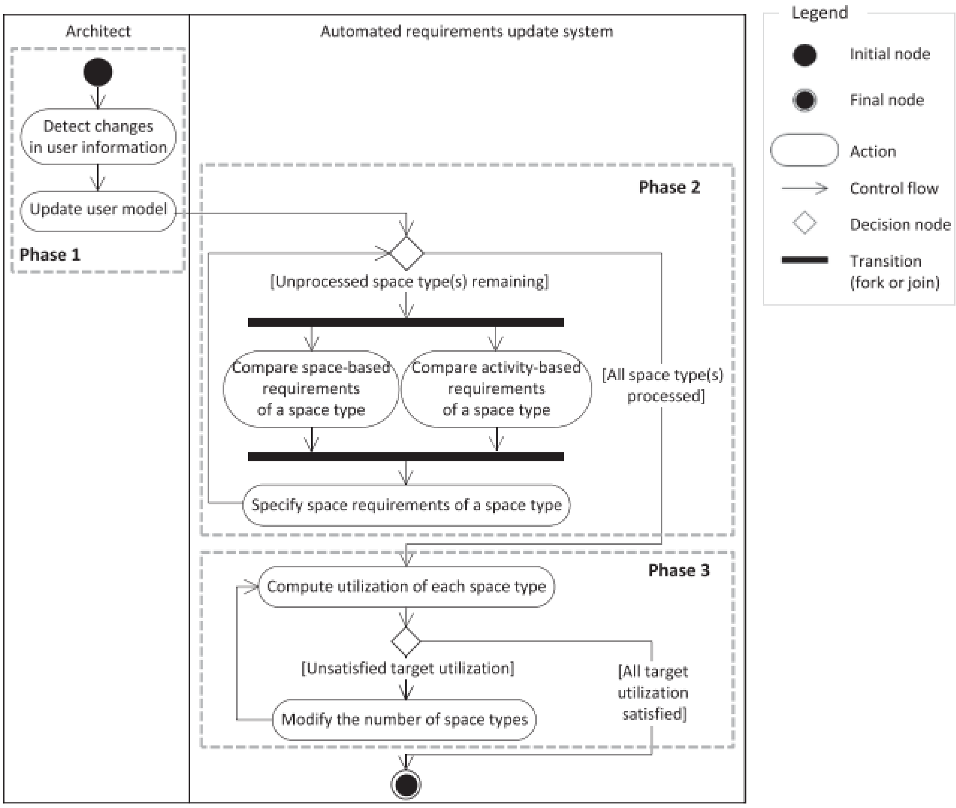


Figure 2.16. Method for automated updating of requirements (Kim et al., 2015)

Building Information Modelling (BIM) is promising development in architecture, engineering and construction (AEC) industry that allows to construct the buildings virtually inquiring the semantic data of components (Eastman, Teicholz, Sacks, & Liston, 2008). One of the important features that BIM brings is the enabling of a useful and meaningful communication environment between designer, client, construction teams. As the models are the virtual prototype of building in pre-design and final design stage, it is possible to develop knowledge capturing and validation at the briefing process by methods or approach with the integration of BIM. BIM-Based User Pre-Occupancy Evaluation Method (UPOEM) supports the designer-client communication with simulating user activities and representing in virtual medium (W. Shen & Shen, 2011). In BIM-based model environment, the schedule of user movements and activities are captured from the end-users, simulated and pre-occupancy evaluation module makes users capable of analyse and give feedback (Figure 2.17). It is possible to use different attributes coming from the end users for maintaining better understanding of further buildings by clients. Another approaches tries to explore potential integration of briefing into BIM in design process with the implementation of briefing outcomes as activities, requirements, constraints and goals (Koutamanis, 2017). The values that can be in BIM environments as custom parameters, parametric extensions and semantic data of model items define a point of view for designing and checking with relation and barriers of briefing outcomes. This approach brings awareness how the briefing outcomes can be in BIM environment at the beginning of design process.

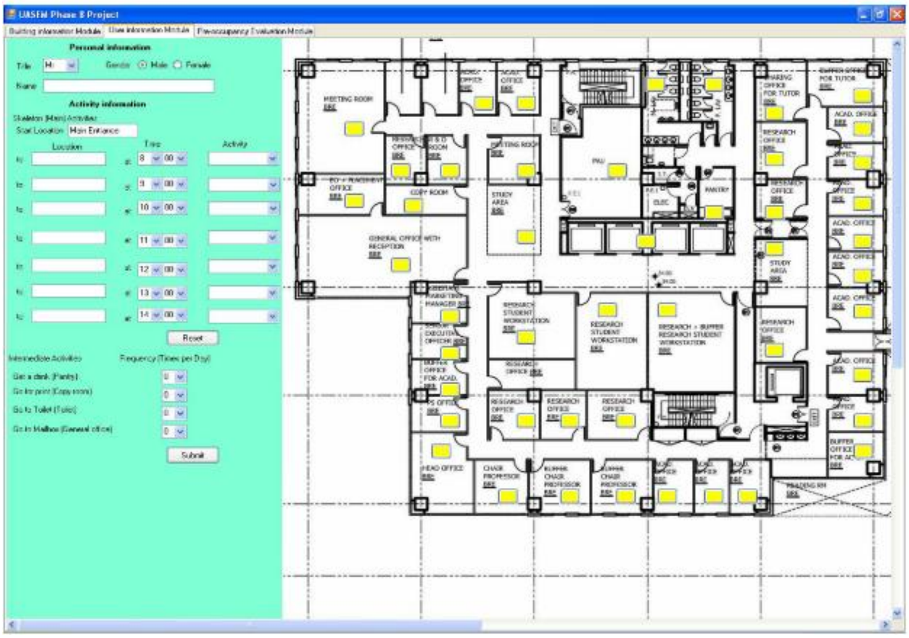


Figure 2.17. UPOEM interface (W. Shen & Shen, 2011)

Technical developments in BIM offer the potential for a new generation of software tools and methods that can automate the checking of design (Greenwood, Lockley, Malsane, & Matthews, 2010). Building codes and specifications, fire and safety issues, construction systems and schedule, clash detections and some other attributes related to data could be checked on BIM according to rulesets defined by experts. These systems support not only checking but also recommendation for solutions against building and client requirements. Figure 2.18 introduces a system for design support by recommending solutions from case-based library according the relevancy of automated model checking results. The importance of this working related to capturing of client requirements is retrieval of validated cases against the design problems in automated environment. The problem is that the system is computable with exact requirements transferred into rules, the uncertain information fails to deal with (Lee, Lo, Tian, & Long, 2019).

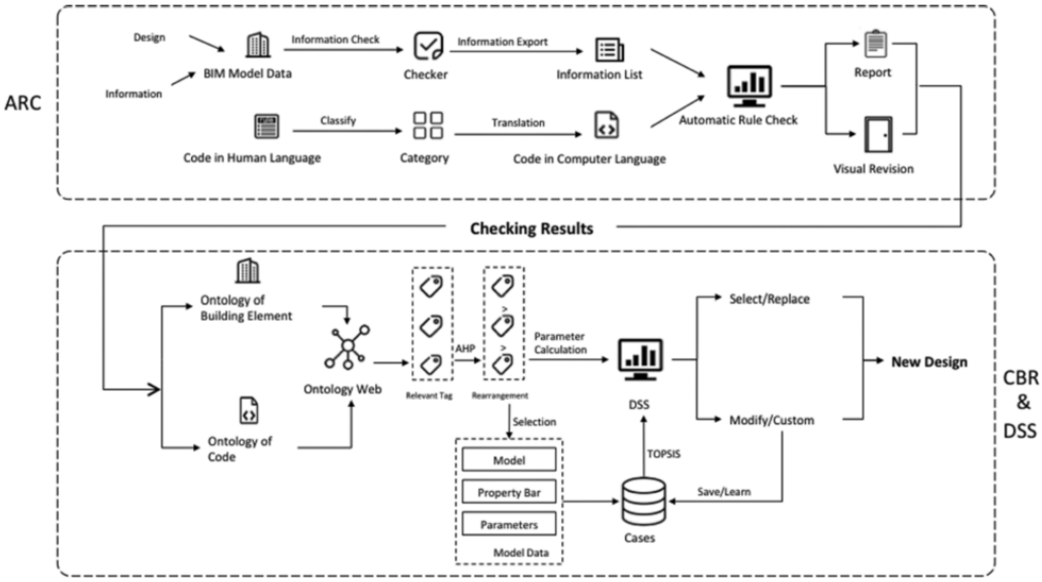


Figure 2.18. Framework of the design support system (Lee et al., 2019)

Developments related with BIM and information technology brings a new point of view to construction companies and design studios that they can virtually build the project regarding with also client requirements and evaluate the process and the product in collaborative environment. Although technology present appropriate tools and techniques, the process of project of execution should evolve into virtual pre-construction concepts to realize these earnings. Fira (Finnish Company) developed an interactive and costumer centric process called Verstas-process to identify business critical requirements of the client organization and to develop those to strategic project requirements and further to technical requirements (Alhava, O, Laine, E and Kiviniemi, 2015). Within the Verstas-process, continuous workshops are established where the client, users, designers and builders got together to combine their skills and plan the project (Fira, 2020). The whole team joins the workshop physically with the instructions and the BIM enables to experience the digitally constructed buildings. The software's related to cost estimation, modelling, automated rule checking, scheduling and collaboration originated from BIM concept are used in Verstas- process to analyse and evaluate the designs against client requirements and contractor's skills (Figure 2.19). Table 2.5 briefly presents the descriptive analysis of 15 different frameworks and research projects considering the dimension of capture, validate, reuse-use, client contribution and requirement processing.

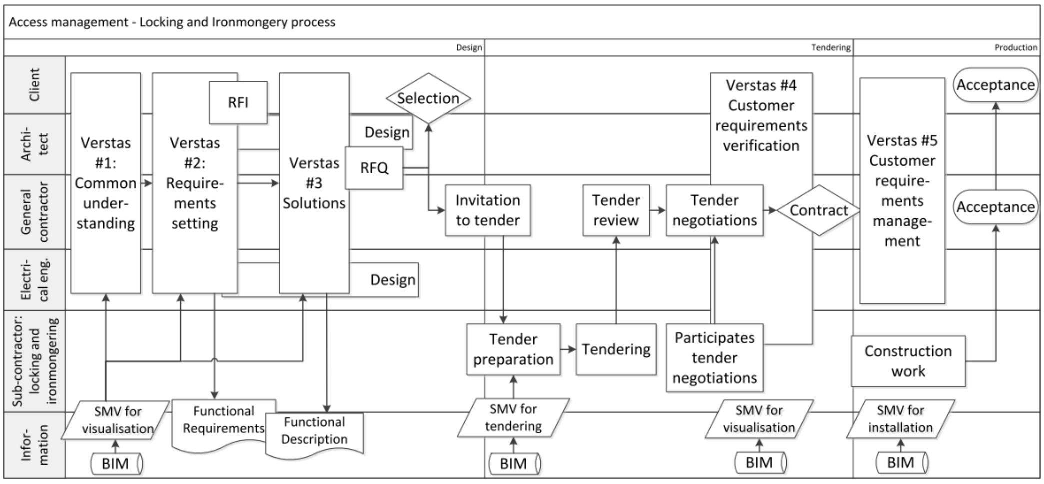


Figure 2.19. Verstas-process (Alhava, O, Laine, E and Kiviniemi, 2015)

Table 2.5 Overview of frameworks and research projects

Name	Date*	Supporters	Description	Software	Capture	Validate	Reuse-Use	Client Contribution Rank (1-5)	Knowledge Dimension	Requirement Processing	Benefits	Notes
1 Client Requirement Processing Model with QFD	1999 2001	Kamara, J. M. Anumba, C J Evbuomwan, N. F.O.	Using the QFD methodology in a CRPM to facilitate the identification, structuring, analysis, rationalization, and translation of explicit and implicit client requirements into solution-neutral specifications for design		-Questionaries' -Structured Interviews	-Quality Function Deployment based Matrix -Correlation with design attributes and client's need	-Calculated Weight based -Outputs	5	-Explicit -Implicit	Define, Analyze, Translate	-Clearly Definition of Requirements at Early Stage '-Reduction of Uncertainty	-Evaluating Requirements independent from design(solution-neutral) -Project Specific -Correlation of Whats, Hows, Target
2 ClientPro			Software for Client Requirement Processing Model	Yes	-same as [1] -software						-same as [1] -User Interface	-same as [1] -Software Application
3 CAPRIKON	2003 2005 2007 2008	Kamara, John M Anumba, Chimay J Carrillo, Patricia M	Capturing the knowledge live through project execution and validating with integrated workflow system		-Entities from individuals -Meetings, review for group -Systematic check for rationale making changes	-Group Decisions at meetings - Responsibility of Project Knowledge Manager	-Dissemination with Project Knowledge File	3	-Explicit -Tacit	- End User's knowledge capture	-Live Capture the Knowledge -Validation and Re-use of knowledge coming from different project -Prevention of knowledge loss due to time lapse -Collective learning	- Capturing and Validating from the Project Execution for maintain and reusing - Role of project knowledge manager
4 Capri.Net		Udeaja, Chika E. Kamara, John M. Carrillo, Patricia M. Anumba, Chimay J. Bouchlaghem, Nasreddine (Dino) Tan, Hai Chen	Web-Based Software for Caprikon	Yes	-same as [3] -software	-same as [3] -online validation	-same as [3] -online connection				-same as [3] -User Interface -Knowledge Base	-same as [3] -Software Application
5 DesignTrack	2005 2007	Ozkaya, Ipek Akin, Ömer	Tool providing a navigation environment for complex design information spaces via enabling requirement traceability	Yes	-Requirement Modeling By Designer	- By User	-Project based -Possibility to expand	0	-Explicit -Tacit(**)	- Design check loop	-Requirement Traceability - Further Extensions including IFC and Data Model	- Plug-in Extension Mechanism
6 e-COGNOS	2001 2002 2003	Wetherill, Matthew Rezgui, Yacine Lima, Celson Zarli, Alain	open model-based infrastructure and a set of tools that promote consistent knowledge management within collaborative construction	Yes	- web based platform for collaborative learning between construction companies - Open ending ontology incorporating taxonyms and classification			1	-Explicit -Tacit(**)	- Outputs Coming from the ontology based database	- Collaborative learning - Cross organizational learning - Expansion for ontology	- The EU funded project
7 KPfC	2008	Kivrak, Serkan Arslan, Gokhan Dikmen, Irem Birgonul, M. Talat	Web-Based System for Knowledge Platform For Contractors	Yes	-Experienced Engineers -Experts -Engineers	- Knowledge Manager	Knowledge Database	0	-Explicit -Tacit	-Knowledge related coming from the database	- Transfer of Lesson Learned and Organizational Learning -Share and retain Tacit Knowledge '-Reduce time for knowledge recall	- Capturing and Validating from the Project Execution for maintain and reusing - Role of project knowledge manager
8 LinCTool	2020	Eken, Gorkem Bilgin, Gozde Dikmen, Irem Birgonul, M. Talat	A lessons-learned tool for organizational learning in construction (online software)	Yes	-Entities from individuals assigned role	-Knowledge Manager	-Lesson Retrieval	0	-Explicit -Tacit	-Knowledge related coming from the database	- Transfer of Lesson Learned and Organizational Learning -Share and retain Tacit Knowledge	- TUBITAK Project

Table 2.5 (continued)

	Name	Date*	Supporters	Description	Software	Capture	Validate	Reuse-Use	Client Contribution Rank (1-5)	Knowledge Dimension	Requirement Processing	Benefits	Notes
9	A framework for identification and representation of client requirements in the briefing process	2004	Shen, Qiping Li, Heng Chung, Jacky Hui, Pui Yee	Structured Framework for identifying and reprensenting client requirements by integration of value management with function analysis system technique		-Briefing workshop	-Value(weight) assignment - How-why relations	-Project based -Possibility to expand	5	-Explicit -Tacit(**)	Define, Analyze, Evaluate	- Provide structure framework for to investigate Client Requirements - Clear definition of requirements in the logic of How-Why	- Participation and effective communication among client, project team members and expert is needed
10	A case-based reasoning system for using functional performance specification in the briefing of building projects	2010	Luo, Xiaochun Shen, Geoffrey Qiping Fan, Shichao	System from facilitating Functional performance System by Case based reasoning in the construction briefing	Yes	-Briefing workshop	-Value(weight) assignment - How-why relations -CBR	- Project based - Possibility to expand	5	-Explicit -Tacit(**)	Define, Analyze, Evaluate	- Provide structure framework for to investigate Client Requirements - Clear definition of requirements in the logic of How-Why - Retrieval of Cases	- Participation and effective communication among client, project team members and expert is needed - CBR implementation
11	Automated updating of space design requirements connecting user activities and space types	2014	Kim, Tae Wan Kim, Youngchul Cha, Seung Hyun Fischer, Martin	Method for automated updating requirements by connecting design user activities and space types	Yes	- Entry of changing user activities	N/A	- Project Based	0	-Explicit	- Design check loop	-Reduce error against manual updating - Definition of relation between requirements and user space activities	-Change management
12	UPOEM	2011	Shen, Weilin Shen, Qiping	Bim-Based User Pre-Occupancy Evaluation Method for Supporting the Designer-Client Communication in Design Stage	BIM integ.	-Entry of end user	- Activity Simulation Model - Evaluation of User's with outcomes	- Project Based	5	-Explicit	- Design check loop	- Client and designer communication with the representation of user's space activity in BIM	-Potential for further application aiming that client have better understanding of their future environment
13	Approach for integration of briefing into BIM	2017	Koutamanis, Alexander	Approach for defining activities, requirements, constraints and goal in BIM for processing of design	BIM integ.	- Entry of briefing outcome in BIM			0	-Explicit	- Design check loop	- Defining relations and limits according to briefing in BIM	-Potential for integration of briefing outcomes as design parameters
14	An Efficient Design Support System based on Automatic Rule Checking and Case-based Reasoning	2019	Lee, Pin Chan Lo, Tzu Ping Tian, Ming Yang Long, Danbing	Propose a design support system, using automatic rule checking to identify the compliance of rules and adopting case-based reasoning to provide recommendations via ontology and semantics	BIM integ.	- Design Model - Case Based Reasoning - Automated Rule Checking	- Case Based Reasoning - Automated Rule Checking	Knowledge Database	0	-Explicit -Tacit(**)	- Design check loop	- Solutions are indexed and integrated from case database according automated rule checking results	- Case based solutions have potential to develop concept of automated rule checking from explicit to tacit
15	Vertass Process	2009 2020	FIRA Construction Co.	Interactive client centric design management process with the collaboration of client, users, designer and contractor	BIM integ.	-Collaborative Workshops	- Collaborative Workshops - BIM - Decision Making	- Project Based - Possibility to expand	5	-Explicit -Tacit	Define, Analyze, Evaluate	- All project stakeholders involve the design process - Virtual construction and evaluation with BIM	- Process / approach which is developed by a construction company with the continuous collaboration of project stakeholders at the beginning of project

x Dates are presented for some articles that authors published
xx Tacit that can be convertible

2.2.4.2 Commercial Software Applications

There is a diverse set of software applications introduced and licensed that have capabilities of knowledge processing in terms of capturing, validating and distributing the project requirements in the construction industry. Some are attempting to link the requirements and specification with design process conventionally, some are developing tools and parameters with the earnings of technology, especially of BIM. These show that managing the knowledge properly by gaining value at time, cost and quality has an important market value for software's developers.

Briefbuilder is cloud based software that is available with monthly subscription and usable for requirement management of construction project ('BriefBuilder', 2022). Requirements of project coming from all project stake holders including client are captured into a web-based system by an interface (Figure 2.20). The requirements of spaces, locations and objects are defined, compared and analysed, verified by instructed phases and methods and if needed linked with BIM models. Tracking of knowledge source and verifications, comparison between items and versions are taken into consideration.

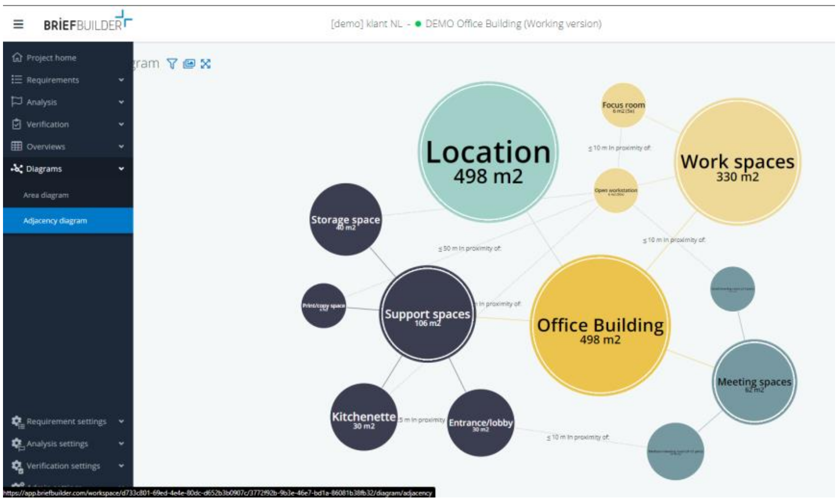


Figure 2.20. Adjacency diagram ('BriefBuilder', 2022)

Specification software Avitru of Deltek is a cloud and database based editor that can create, edit and collaborate project specifications (‘Avitru’, 2020). Creating and importing third party specifications including international standards and industry spec. is possible and real time collaboration between team make trackable environment. One of the important features of software is directly link to MasterSpec (industry standards for projects) and it makes it possible to import project specific standard after purchasing. MasterSpec product selection tool that provides the design professional unbiased, objective information on building products written by professional architects and engineers, and vetted by AIA-sponsored architectural and engineering review committees (‘AIA’, 2020). Although the knowledge is not coming from the client or project specific environment, reusability of revived and verified knowledge of specifications is valid contribution to knowledge library. SpecLink is another specification software which can be linked to be BIM model as previous one, but it is more developed in terms of knowledge management through project life cycle with collaboration and coordination features. It is cloud based and link specs to BIM model, real time collaboration of project stakeholders and 3d walkthroughs without a BIM software license is possible.

dRofus is cloud based software which brings a centralized data centric approach to BIM with involvement of all project stakeholders (‘DRofus’, 2020). It does not only have a requirement capturing and management purpose, but also project management for whole project cycle from design to facility management. It has room templates and global item catalogues for facilitating design across knowledge library. The captured client requirements can be standardized and reused for other projects within the company. A level of BIM knowledge is compulsory for usage, but the owner/client can track and make entry if necessary (Figure 2.21). The explicit knowledge and tacit knowledge which could be formulated and written into text about the requirements can be defined, analysed and compared with the design solutions. Plug-in related to known BIM modelling software make it possible to link data in-between. All the tracks related to inquiries, changes and coordination are recorded for verification.

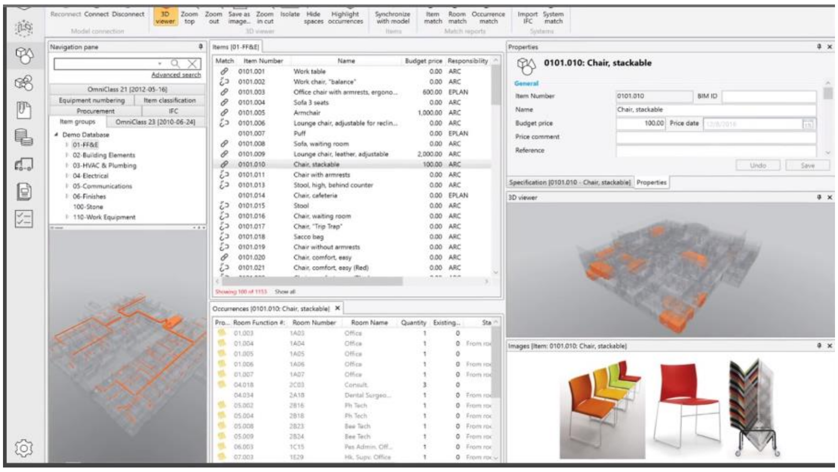


Figure 2.21. Interface of dRofus (‘DRofus’, 2020)

The commercial software focusing on managing requirements and knowledge through project lifecycle with capabilities of capture, define, verify or maintain are tried to be explored. With the developments in construction industry regarding technology, especially BIM, the systems are figured out how are they implemented in BIM or How do they manage the knowledge in BIM environment? As known, BIM concept includes semantically linked information or knowledge object, thus resulting in capability to integrate and process other forms of knowledge. There are other software and software developers like OpenBuildings Designer (‘Bentley’, 2020), Edificious (‘ACCA Software’, 2020), Tekla (‘Trimble’, 2020) and Autodesk (‘Autodesk’, 2020) which contributes to the capturing, verifying and sharing of knowledge in briefing design, construction and maintenance process by their cloud services, coordination and collaboration tools, virtual construction representations and document management. Nowadays BIM seems as a knowledge capturing technology by itself, perhaps in the following time it can be clearly defined as such by researchers and practitioners. Table 2.6 is presented for the important attributes of the software’s regarding knowledge process and benefits.

Table 2.6 Overview of commercial software

	Name/ Company	URL	BIM Integration	Required Knowledge	Features	Capture	Validate	Reuse-Use	Client Contribution	Knowledge Dimension	Requirement Processing	Notes
1	**BriefBuilder** BriefBuilder	https://www.briefbuilder.com/	Yes	Only for BIM Integration	-Cloud(web) Based - Requirement Management - Link to BIM Model	-Entities from outputs of briefing	- Create Verification Phase and assign to a role	- Project based - Company based	- By system user	-Explicit -Tacit(*)	Define, Analyze, Evaluate, Manage	- Text, Worksheet - Diagrams - Comparison with design
2	**Avitru** Deltek	https://avitru.com/software/spec-editor/	Yes	Only for BIM Integration	-Cloud and Database Based - Specification Software - Link to BIM Model	- International and National standards - Industry Speficition	- pre-validation of sp	- Project based - Company based - import 3rd party	- By system user	-Explicit	Define, Review	-Collaboration for specification preperation - Work with MasterSpec Masters
3	**SpecLink** Building System Design	https://bsdspeclink.com/	Yes	Yes	-Cloud Based -Specification Software - Link to BIM Model	-Entities from outputs of briefing	- Create Verification Phase and assign to a role - pre-validation of specification	- Project based - Company based - import 3rd party	- By system user	-Explicit	Define, Analyze, Evaluate, Manage	- Text, Worksheet - Diagrams - Comparison with design - Collaboration, Coordination - Streamline at constuction and maintance - 3D without other BIM software
4	**drofus** NEMETSCHEK	https://www.drofus.no/en/	Yes	Yes	-Cloud Based - Data and Project management - Link to BIM Model	-Entities from outputs of briefing Import international standards	- Create Verification Phase and assign to a role - Integrated design validation	- Project based - Company based - import 3rd party	- Directly	-Explicit -Tacit(*)	Define, Analyze, Evaluate, Manage	- Text, Worksheet - Diagrams - Comparison with design - Collaboration, coordination - Streamline at constuction and maintance

x Tacit that can be convertible

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

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

2.3 Issues of Building Information Modelling

The Architecture, Engineering, and Construction (AEC) industry has long sought techniques to decrease project cost, increase productivity and quality, and reduce project delivery time (Azhar, 2011). With the developments in Building Information Modelling, a virtual model of building in which 3D geometry of building elements with the semantic data exists, making design, construction, facilitation of the buildings before the construction process possible. BIM is not only technology change but also process change, by enabling a virtual building represented by intelligent objects that carry detailed information it alters all of the key processes involved in putting together (Eastman et al., 2008). The core function of BIM is to provide users with the ability to integrate, analyse, simulate and visualize the geometric or non-geometric information of a facility (Li, Wu, Shen, Wang, & Teng, 2017).

2.3.1 BIM and Briefing Studies

One of the important features that BIM brings is the enabling of a useful and meaningful communication environment between architect and client. As the models are the virtual prototype of building in pre-design and final design stage, it is possible to set mutual understanding in the briefing process. Tessama explores the BIM tools and conventional drawing methods and identifies specific improvements BIM brings to architect client communication (Tessema, 2008). Cloud-based systems of BIM are widely used by project and construction teams for communication and coordination, it seems to be a part of the briefing process.

There are numbers of commercial briefing software that connects to BIM: (‘DRofus’, 2020), (‘BSD SpecLink’, 2020), (‘Trelligence Affinity’, 2003), (‘Avitru’, 2020). Some are requirement specification tools that connect the data, produce conventional documents and also link them to BIM, some are for a spatial aspect of the briefing, creating room overviews and bubble diagrams by schematic representations and establishing links with model elements (Koutamanis, 2017). These applications are improving the capabilities of BIM and briefing, whereas briefing should be evaluated as a whole process of a construction project in which information and communication are the main focus. BIM systems offer a centric database for all layer of information and it is tried to reach to this level. The systems mentioned above generally keep the information in their database and work with BIM by link established (Koutamanis, 2017). Koutamanis tried to explore a test for the integration of briefing outputs in BIM model by defining activities, requirements, constraints, goals and matching them with attributes of elements. He also stated that there is a misconception that connections between brief and design start only once a design exists, it is possible to transfer briefing information to BIM before starting to design to correct the misconception. BIM allows for storage and retrieval of briefing information in a comprehensive, shared central model (integration).

2.3.2 Automated Rule-Based Checking Systems

Rules and regulations have been used for years in architecture to develop designs by people in written documents and drawings. Some attempts for using software language and systematics to check the design and construction process were done, however the significant development and interest in automated rule-based checking systems have had a chance with BIM. This brings the possibility of evaluation and checking the semantic data of the 3D objects and their relations according to pre-coded rules of software language. Who is capable of coding and structuring the rules, is important question for AEC industry, but still system has big opportunity to save time for repeating activities and prevent the mistakes resulting from human cognition.

Technical developments in BIM offer the potential for a new generation of software tools and methods that can automate the checking of design (Greenwood et al., 2010). Building codes and specifications, fire and safety issues, construction systems and schedule, clash detections and some other attributes related to data could be checked on BIM according to rulesets defined by experts. The important issue is the consistency in interpretation of these rulesets with a machine processable format and written rules. Industry tries to develop usage of automated rule systems, rules ontology and compatibility of platform to enable possibilities of computers. There are some lacks and limitations that can be noted: less user-experience on system, lack of understanding of architects on coded rules, compatibility of BIM models to rule checking platform, lack of open-coded environment, adaptability of platform to open-coded environment and verification of results.

2.4 Criticism of Literature

The briefing in the construction industry and its' usage, importance, knowledge dimension and processes, capturing and contemporary strategies and research projects are explored throughout the literature survey to obtain multi-dimensional view on the relevant research area. Especially the requirement knowledge elicitation process via some techniques and technologies are focused to underline the specific issues that construction industry deal with for the project execution. The limits of rationality are hard to be stated, since the requirements of any project cannot be gathered and fixed through project without the contribution of the individual, especially designer. There is significant level subjective evaluation coming from the experience and creativity dimension of designer among requirements of project, thus it cannot be fully altered as any calculation or computation.

The factors and barriers affecting the client briefing are presented at the survey. Communication gaps, misunderstanding, inadequate identification of requirements, insufficient time, experience level of architect and lack of structure/frameworks are important example of barriers. Ability of individuals, good and effective communication, involvement, use of different method and analysing/evaluating the outcomes are significant factors. All factors have a different level of impact which varies among projects and organizations, and barriers affect the project and briefing success in diverse levels. This study mainly focused on an area that is used for space requirement knowledge creation before design phase of projects that can be handled after by designers, architects or client for the definition of space objectives. Thus, the contemporary studies and frameworks whether they use techniques or computer technologies like BIM, whether they focus or specific issue on requirement knowledge process or draw conceptual frameworks for knowledge management are investigated for the decision on improvement for requirement knowledge elicitation.

The deficiencies, problems and improvement areas that are stated at the survey for knowledge processes to gather the requirements are also part of a briefing process. This research is seeking a possible framework or system to improve architectural programming for space requirements. So, the effects of project stakeholders' experience, identification of requirement knowledge, usage of recorded knowledge and structured frameworks that use technology considering time and experience level of users are focused in this context.

Since the multi-dimension of requirement elicitation process in briefing like knowledge, stakeholders, time and unique context of building process and human perception on needs, the studies try to explore and identify possible gaps and underline the development areas. The comprehensive approaches or frameworks are hard to develop and implement to architects or brief-takers to be used in briefing process. Temptation on using experience and pre-tried approaches take more place in briefing process than organized and ruled procedures. Practical implications of any research study and development via evaluation of industry experts should be sustained to present improvement at this vocational practice. Thus, feedback from practitioners by stating the objectives of the research is contributing way to expand the era, then to focus a significant phase or gaps of requirement elicitation process. In the next chapter, the survey and interview among industry practitioners are presented for which conducted and discussed with the connection of literature survey.

Knowledge capturing for the design process and construction industry is important for the requirement elicitation and validation to enrich project success. Dimension of knowledge related to requirements coming from client and end-user varies and may be hard to capture and validate. Considering survey and findings, a structured framework or a strategy which is capturing knowledge from standards, clients and previous knowledge libraries, and which is validating them via automated system to pre-verified, collaborative approval and BIM-based virtual representations for non-convertible knowledge may have contributions to knowledge and requirement management in construction project in terms of project based designer-client communication and creating a knowledge library that can be usable within and across company. This is an ultimate and general statement for the proposing a comprehensive research field in the continuation of the literature survey. The limitation and definition of the system objectives are determined and presented after the field study with industry practitioners.

CHAPTER 3

SURVEY AND INTERVIEW AMONG INDUSTRY PRACTITIONERS

Literature review about the knowledge management, knowledge cycle and their definitions sub-parts are explained and conducted in a view of design briefing. The purpose of the literature review for this research is to identify the possible gaps, problems and development areas within the field of study. Furthermore, contemporary strategies, technologies and research were explored to assist the development of research and proper solutions. Since the vocational practices among architects have a vital role on the developments or evaluations of the design briefing process and management of the knowledge at this process, it is so valuable to maintain knowledge from industry practitioners (architects) about the briefing and knowledge processes of their own experiences. To attain this knowledge about the problems, procedures and problems areas of the subject, survey and interviews were made in different sequences. First, a quantitative survey was completed, then interviews were held with the initial evaluation of the survey. The objectives of these to field work among architects are; to evaluate the findings of literature survey by seeking the specific problems and defining gaps, to determine the contemporary condition of practitioners of Turkey and their position to briefing and requirement knowledge management, and to explore the new knowledge/views to problems/success in design briefing for requirement elicitation and validation.

Survey studies are used to ask large number of people questions about their behaviours, attitudes, and opinions (Marczyk, DeMatteo, & Festinger, 2005). The questions, sample group and procedure of the survey should be developed according to objectives of the research study in respective to consistency and accuracy. Commonly, the samples are surveyed through questionaries or interviews, and survey can vary from highly structured questionaries to unstructured interviews (Ghosh & Robson, 2015). The themes that are aimed to measure, which are obtained from literature synthesis, should show the relationship between facts. Quantitative approaches seek the factual data, to study how such facts and relationships accord with theories and findings of any research executed by literature (Ghosh & Robson, 2015). Thus, a structured questionnaire is developed to measure and evaluate the important issued, factors, advantages, difficulties and problems of requirement elicitation and validating methods in client briefing process among architectural practitioners. Furthermore, a part for survey including two open-ended questions is also implemented to understand responded thoughts about the issue in qualitative manner.

The main objective of the survey is to state the facts and relationship that are underlined in the literature survey for improving the briefing processes. Findings from the previous studies are tried to be measured and tested how and in which degree be parts of the research questions. The objectives of the survey which was held for “Knowledge Capturing in Design Briefing Process for Requirement Elicitation and Validation” listed below;

1- Test and identify the issues found by literature among industry practitioners.
2- Explore the correlation between the facts and their existence.
3- Contribute the determination of problem areas and the development of framework at requirement management in briefing process.
4- Determine the position and situation of industry practitioners among briefing process

Interviews are one of methods for collecting data from respondents. The focus of interviews is determined according to research objectives. They can be thought as an additional data source for research due to its’ communication difference than questionnaire survey. As seen in Figure 3.1, by designing the framework of interviews due to objectives of survey, the communication may be in one-way or two-ways. With application of questionnaire survey, the knowledge about industry practitioners’ situation against research interest are collected. Semi-structured interviews are held with industry experts with implementation of pre-results of questionnaire survey for underlining possible problems of requirement management and focusing on specific problem statements. 11 interviews were completed with the architects, to be partner of/have a design company and to have 5 years of experience or more.

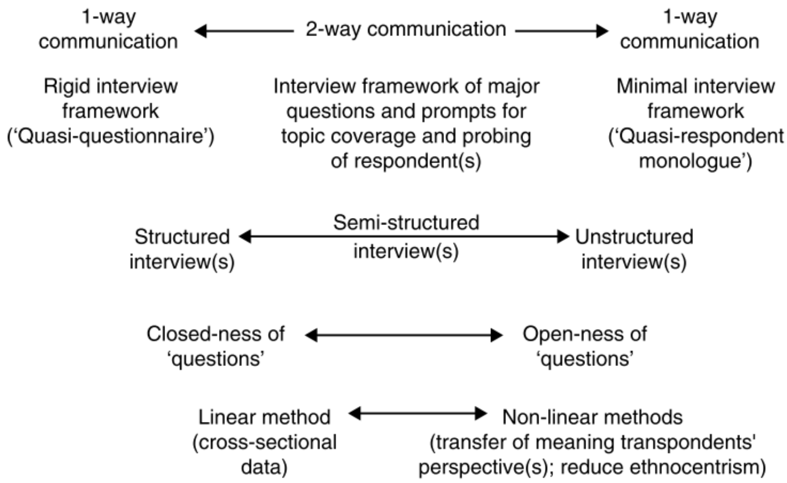


Figure 3.1. Types of interview (Fellow & Liu, 2008)

3.1 Structure of the Survey

The survey consists of a multiple-choice questionnaire and open-ended survey questions for both gathering the information of choices and progress, and for enlarging the research by the involvement and expression of the contemporary practices of the participants. The survey is divided into three themes. First theme is related to organizational information, the second is for knowledge capturing in client briefing process and the last theme is related to the process for requirement elicitation and validation. The explanations about the questions in order are below;

- Question 1: Identification and contact information of respondent.
- Question 2,3,4: Asked to know number of employees, total area and category of projects that architect involved lately to measure the relation of knowledge procedures between company profile

- Question 5: Asked to learn the project stakeholders that the company has communication with at pre-design and design stages.
- Question 6: Defining the usage of BIM
- Question 7: Evaluation of the techniques used in briefing for knowledge capturing
- Question 8: Asked to learn the record method and measure their importance of briefing knowledge
- Question 9: Evaluation of the importance of items for the success capturing the requirement knowledge in briefing process.
- Question 10: Open-ended question for getting the thoughts about possible problems for gathering requirement knowledge from the client.
- Question 11: Evaluation of the importance of some cases for success of briefing process in relation to project performance and client satisfaction.
- Question 12: Open-ended question for getting the thought about impact of knowledge cycle and processes in the client briefing process.
- Question 13: Evaluation of the actions that are used for stating and validating the client requirements for the process performance and success.
- Question 14: Asked to identify and to measure the processes for the management of requirements knowledge which company uses
- Question 15: Evaluation of the items that briefing success affects

3.2 Framework of the Interview

Structure of the interviews may result in a condition that only the answers of questions could be taken. Semi-structured interviews maintain the communication in both way for collecting data contributing the research. In this context, interviews are planned in 4 parts which has no strict boundary in the session, in which the approach of the interviewees can be understood. For each interview, respondents were asked with same framework and whether they prefer online or face to face. The subjects and objectives of parts are listed;

Part 1

- Duration of experience
- Typology and dimension of projects
- Client typology
- BIM and CAD usage
- Project management approach
- General requirement processing procedure

Part 2

For the situations that the project requirements are given by the client in detail, items below are investigated;

- Analyse procedure of requirements
- Methods of working on specifications
- Interpretation methods of requirement into projects
- Tracking approach and validation of requirement to proposal with or without client
- BIM or technology experiences on this process

Part 3

For the situations that the project requirements are not given by the client in detail, items below are investigated;

- Requirement elicitation procedure
- Requirement presentation and validation methods
- Usage of design proposals to visualize the requirements
- BIM or technology experiences on this process
- The problems of working on requirements without getting any approval

Part 4

In this part, Figure 3.2, Figure 3.3, Figure 3.4 are shown to respondents to present them the capabilities of requirement management within a framework. A ruled system for requirement elicitation and framework capturing, refinement and conversion are explained. At this level of research, the system or developed framework has not designed yet, preliminary studies about improvement on requirement elicitation are presented to seek possible gaps and promising approaches via comments. Their views on following items are tried to be understood about the framework proposal of requirements.

- Difficulty and problems on designing framework,
- Possible areas or process that this framework cannot work,
- Difficulty and problems on running framework,
- Suggestions of developments and problems,
- Contribution of framework for architectural practice,
- Possible useless feature or objectives of framework.

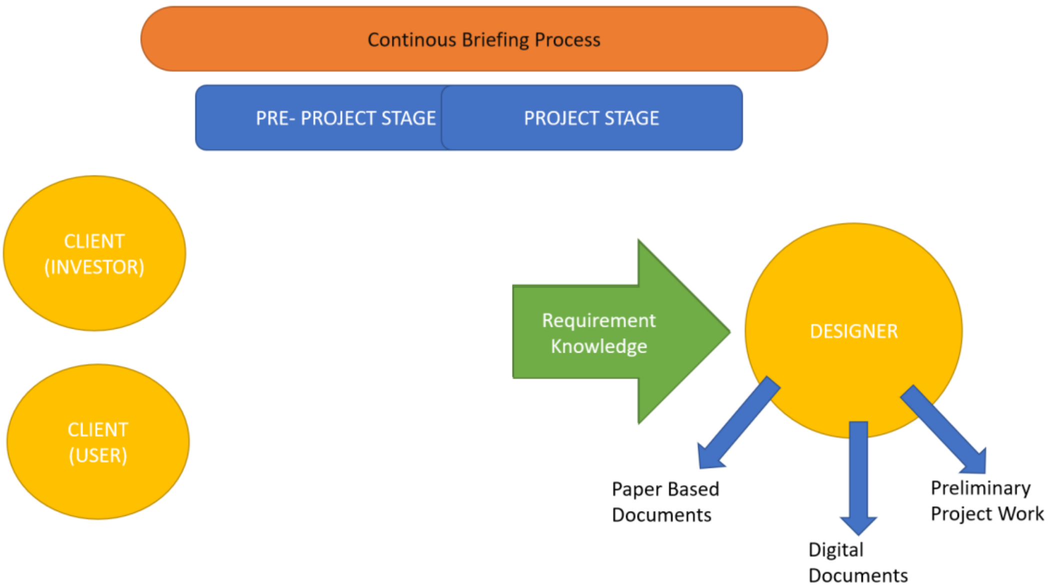


Figure 3.2. Interview visual 1

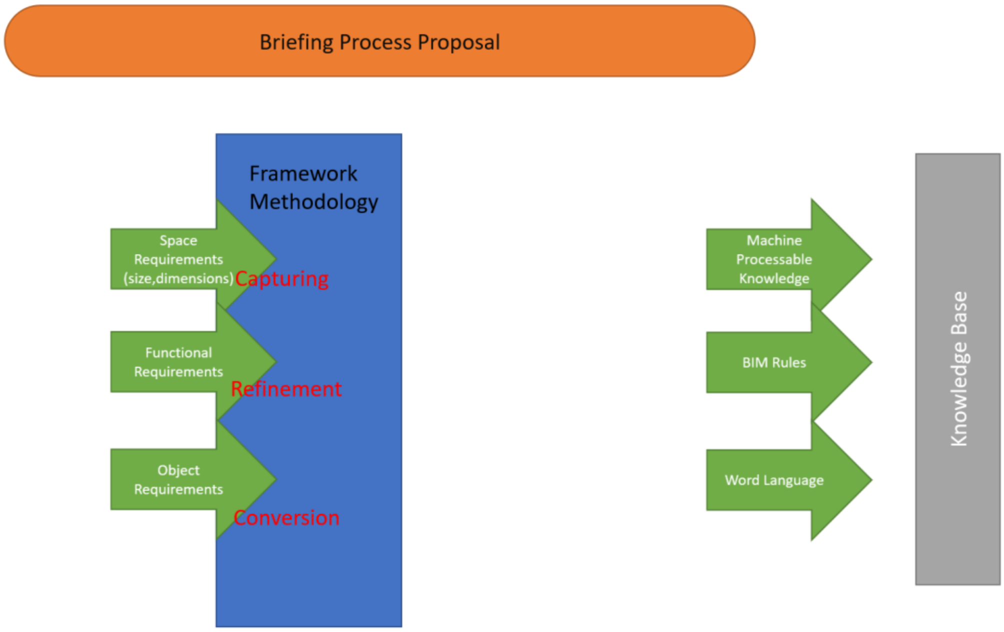


Figure 3.3. Interview visual 2

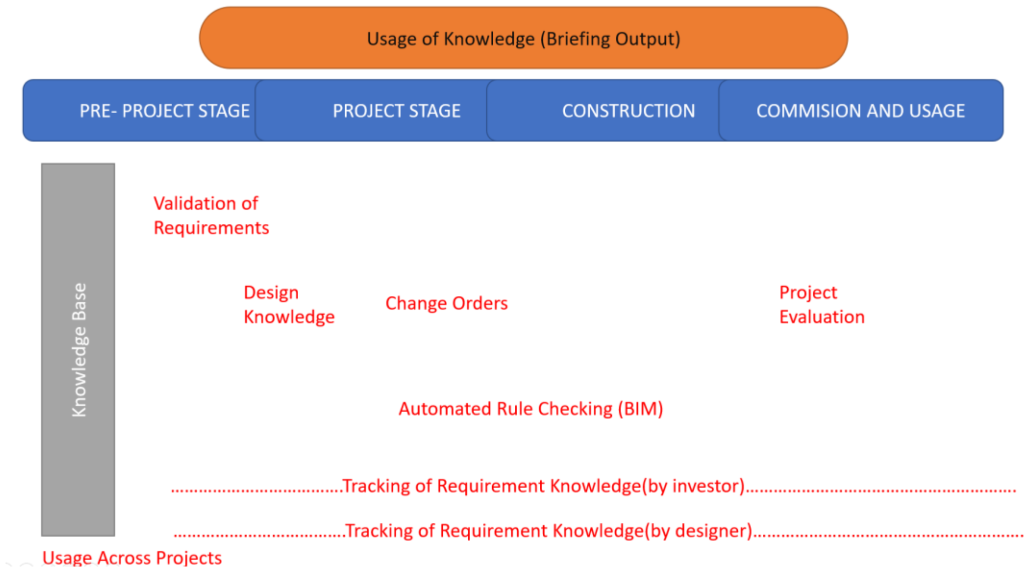


Figure 3.4. Interview visual 3

3.3 Sample Limits and Procedure

The survey was held among the industry practitioners (architects) those who participate in the architecture design process and the manage the knowledge coming from the client briefing process. The instructions and explanations are stated at notice and survey approval page to underline the objective of the study. Questionnaire was delivered to respondents by the online survey system of Middle East Technical University (Metu Survey) which is based on LimeSurvey ('Metu Survey', 2021). The announcement of the survey was done through TSMD, İstanbulSMD, and İzmirSMD. Approval of the survey was taken at 23.06.2021 from METU Ethics Committee with number 254-ODTU-2021. For the interview process, call was done after the survey results taken via same method.

3.4 Findings of the Questionnaire

The time interval of the survey is between 23.06.2021 and 17.09.2021. The announcement of the survey was made by e-mail and mobile contact group for communities stated before twice. 106 unique users reached the survey, however 82 of them preferred not to complete. Although the total number of participations by respondents is low among the users reached the survey, the findings of survey that 24 industry practitioners involved exposes important views, cased and facts.

3.4.1 Respondent Profile and Organizational Information

The respondent profile is stated as; working as an architect/project coordinator/partner at an architectural design company/office in Turkey. All the 24 respondents taken into consideration suit the criterion. 20 of them is from Ankara, 2 is from İstanbul and 2 is from Adana. Participation from İzmir or any other city does not exist. Table 3.1 summarizes the profile of the respondents and their companies regarding employee's number, project work category and amount. The majority of them has 10 employees and below, and they have completed over 100.000 m^2 projects for last five years. There are also 4 companies that have employees over than 20 and 5 companies that have finished projects below 50.000 m^2. It can be noted that respondent's group has a representative feature while comparing and evaluating their employee's number and completed works' amount. Respondents were asked to select by multiple choice for their working projects, thus the percentage of project category means the ratio of category for all respondent by each category. Residential, education, office buildings and sport facilities take the majority, whereas public, service buildings, hotels and accommodation are at the average distribution. There is important amount of health care buildings and approximately 25% amount of environmental and interior design. Also, there are some examples of factory, transportation and religious buildings. These results have importance for both exploring the market position of architectural offices and evaluating the knowledge about the research objectives in terms of validation and consistency.

Table 3.1 Respondent's profile

Number of Employees	
Respondent	Employee Number
14	0-5
4	6-10
1	11-15
1	16-20
4	Over 20

Completed Project Area (Last Five Years)	
Respondent	Total Area
3	0-25.000 m2
2	25.000-50.000 m2
1	50.000-100.000 m2
9	100.000-250.000 m2
9	Over 250.000 m2

Worked Project Category	
Category	Percentage
Residential Buildings	79,17%
Education Buildings	70,83%
Office Buildings	83,33%
Public Buildings	58,33%
Service Buildings	62,50%
Sport Facilities	70,83%
Hotels, Accommodation	58,33%
Health Care Buildings	41,67%
Conservation	16,67%
Environmental Design	20,83%
Interior Design	25,00%
Factory	4,17%
Transportation	4,17%
Religious Building	4,17%

Communication paths and frequency with project stakeholders (Figure 3.5), and BIM usage (Figure 3.6) were asked to respondent to understand their profile in terms of project process and capabilities. Knowledge and requirement management are related to stakeholders that a company has a communication. The experience at BIM is a significant issue to evaluate their approach to technics of technologies that can be implemented to project briefing process. In the project stage, the communication with client (investor) and project engineers take part in likely always, whereas communication with consultants and client user tends to decrease. It can be understood that participation of users to project process is less than investors. In the respondent's' profile of working, communication to construction team is less than other project stakeholders and the relation to facility management teams is almost not existed. By exploring Figure 3.6, some significant results about the BIM usage of companies could be seen. Primarily, BIM usage for different categories is ordered according to evaluating data by frequency of usage. Collaboration, design and document management take the first ranks, and client briefing, procurement and facility management take the last ranks. By looking the never usage marks, it can also state that there is an important ratio of not BIM usage for all categories, although there are also users. Besides, N.A. prompts not applicable that is for respondents who do not any ideas what is asked in the survey. By evaluating it with never and rarely usage it seen that awareness about BIM on categories especially construction management and below is very low.

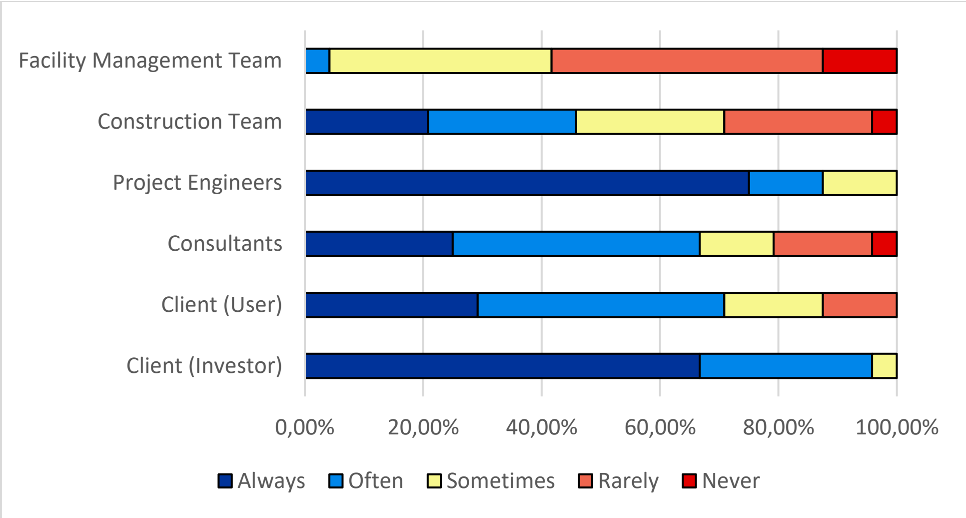


Figure 3.5. Communication with stakeholders

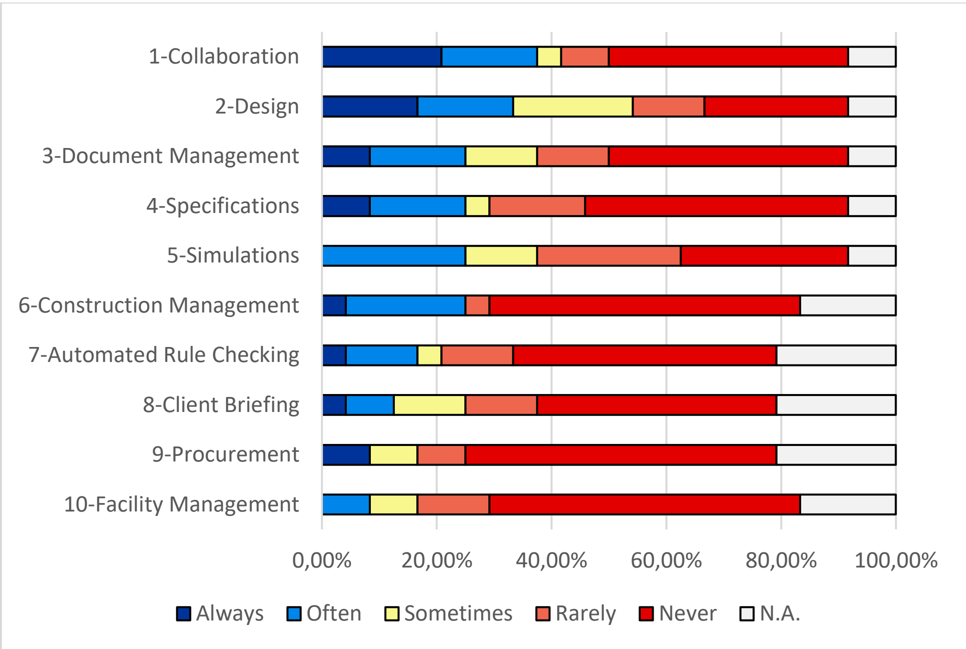


Figure 3.6. BIM usage

3.4.2 Knowledge Capturing at Client Briefing Process

In this theme, respondents were asked about their briefing process, approaches and important issues about the knowledge capturing about the project requirements. The results and analyses are given orderly as in survey.

Item 1

The techniques and technologies stated from the literature review were asked and the evaluation of answers can be seen at Figure 3.7 with effectiveness scale. The choices are organized with impact factor to comprehend better. Proposals stands as the most effective way to manage requirements of project in briefing process. Secondly, interviews, observation and brainstorming have contribution to briefing for working on requirements. Scenario analysis, sketches, diagrams and workshops take part in the process in a lower ratio. However, it can be seen that questionaries, BIM environment and storytelling are nearly not effective due to the survey.

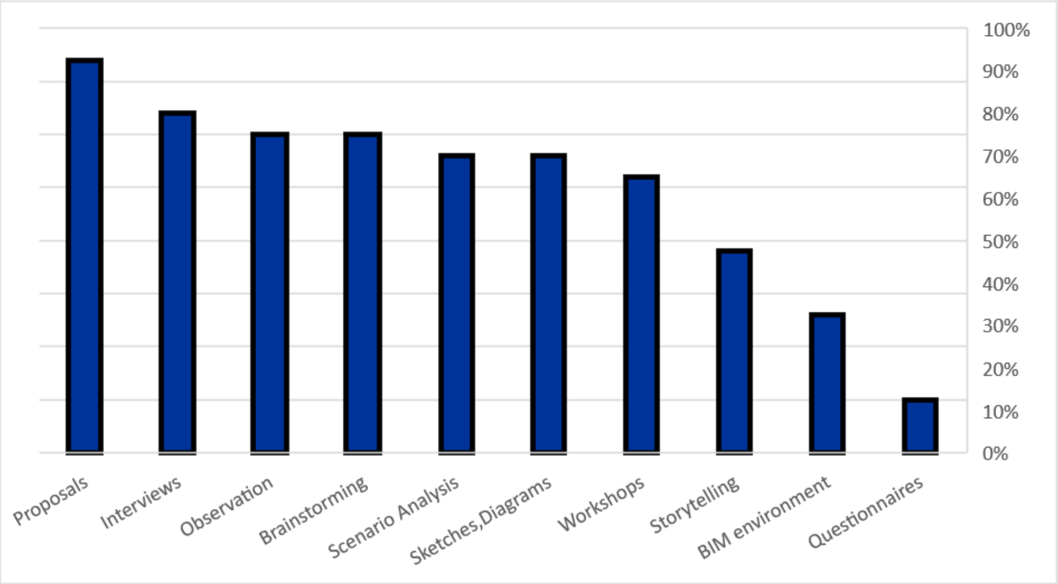


Figure 3.7. Effectiveness of client briefing techniques

Item 2

Taking records is the fundamental of knowledge processing for both requirement managing and any procedure that data or knowledge take part in. To work on continuous cycle of knowledge the recorded data is tracked, recorded and examined in almost all systems. The system that is used in recording is important to be open for implementation of different alternatives or proposals. By looking to Figure 3.8 in this point of view, it can be said that digital text-based usage is at the promising level and paper-based records are lower comparing to digitals. But the lower usage ratio of using computer processable format and structured database stand as an area to improve to initiate processes about requirement knowledge. In addition, there is explicit fact that the usage and importance level of recording way of respondents are seem in parallel.

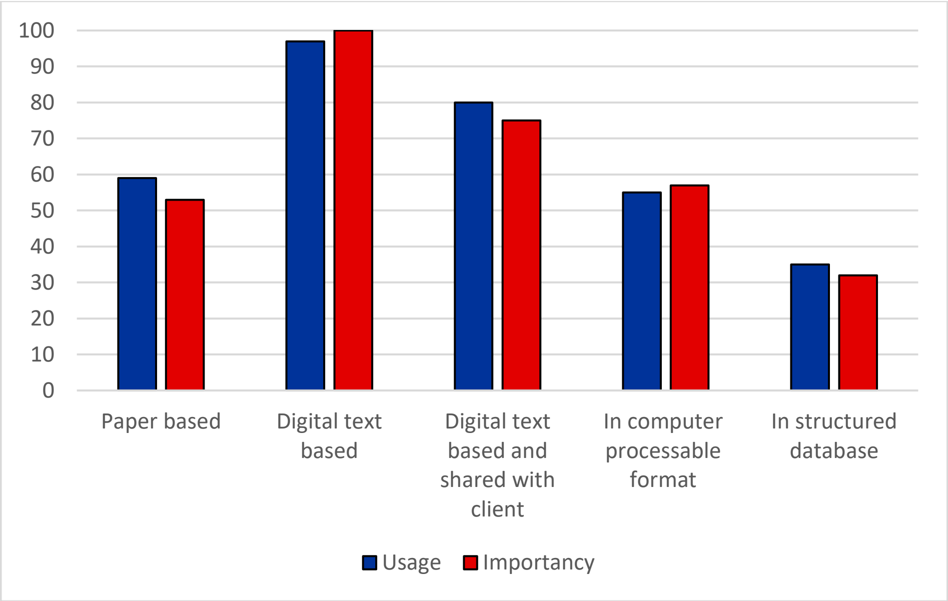


Figure 3.8. Recording of client briefing

Item 3-4

Problems, gaps and deficiencies are explored at the review section that are important in client briefing process for elicitation and validation of requirement knowledge of architectural projects. Also, methods, approaches and issues that contribute the success of briefing process are specified. Based on findings on literature review, respondents were asked for item 3 that is evaluation of importance on the success of capturing requirement knowledge (Figure 3.9), and asked form item 4 that is evaluation of importance on the success of overall briefing process (Figure 3.10). Defining the objectives of the project and open-effective communication with project stakeholders are the most important things for gathering requirement knowledge. Also, in parallel with review literature review, involvement of user client has contribution for capturing requirements for the project for stating the objectives of space. Taking records, evaluating them and getting approval of outputs related to requirements are issues that responds give great importance. Comparatively, usage of comprehensive framework and methods is seen as less important resulting from within the bounds of possibility of initiating them for client typologies. It is fact that, client has an important role and right on deciding the briefing procedures and frameworks.

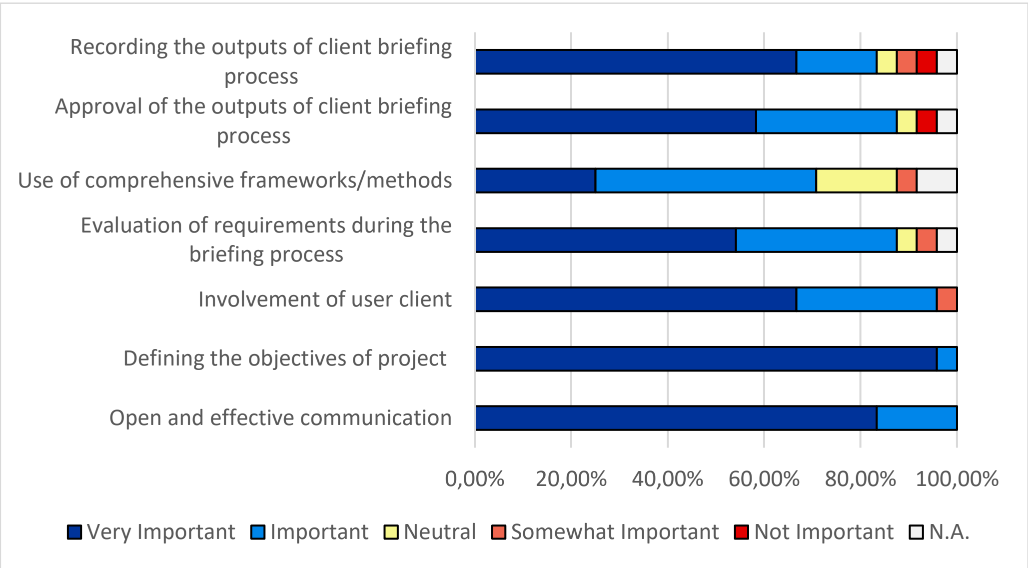


Figure 3.9. Items' importance on success of capturing requirements

Overall project performance and satisfaction of client are affected by briefing process, since briefing process is an important part on project life cycle for defining objectives as input. The issues that affect the success of briefing in relation to project performance and client satisfaction are explored in Figure 3.10. Designer experience is at the first rank, and also inexperienced client has importance, are meaning that the knowledge of individuals and experience on the industry have significant value. This situation was stated so many times in researches that are dealing with briefing process and knowledge management era. Misunderstanding the needs and inadequate identification and representation of requirements are other important cases for the success of briefing, which are also related to experience of individuals on managing the process. Time needed for repeating works and overall briefing process should be also taken into consideration to sustain success and necessities. Besides the evaluation of 4 Item, respondents were asked about the problems during the gathering knowledge of requirements due to their experiences. The statements that are not coinciding to survey fully are listed below:

- Unable to gather knowledge from the ones who are out of the industry
- Unable to analyse of requirement by comparing them with the project budget
- Not thinking of future developments or needs by client
- Not stating the objectives of project by clients clearing before starting the project with designer
- Inexperienced client on both architectural projects and briefing process

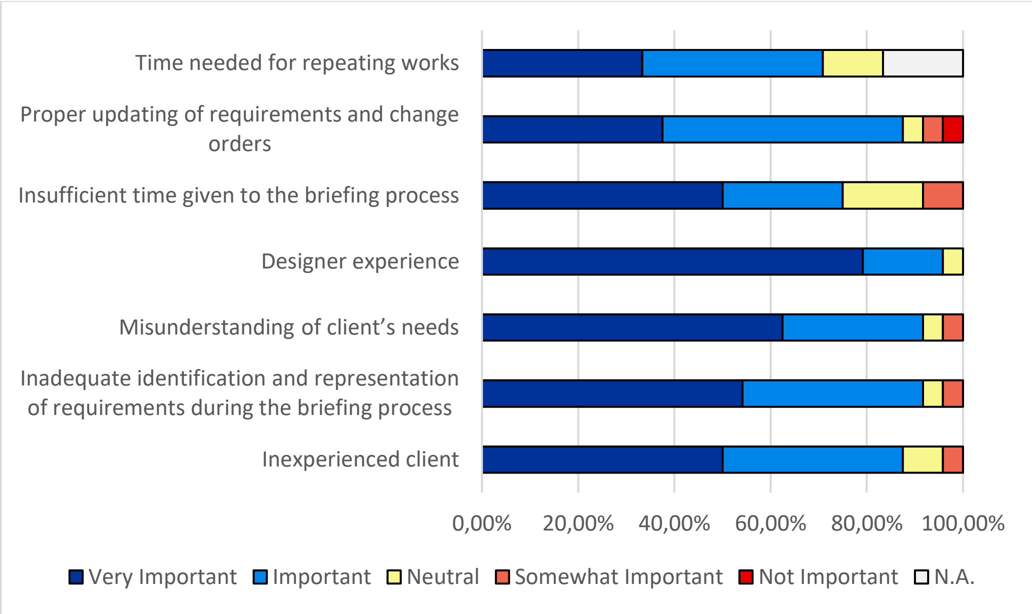


Figure 3.10. Items' importance on success of briefing process

3.4.3 Processes for Requirement Elicitation and Validation

In this theme, respondents were asked about processes to initiate a knowledge cycle for requirement elicitation and validation. More detailed and defined actions for capturing, indexing, understanding, validating and reusing of requirement knowledge are presented in the survey to evaluate the situation and approaches of practitioners on managing the needs of client and project. Also, the importance and contribution of briefing process to project work are tried to be investigated. The results and analyses are given orderly as in survey.

Item 5

The requirement knowledge of a design project is one of important inputs project environment. Designers start and execute project phases with the analysis of this knowledge by some actions for evaluation and validation. As seen in Figure 3.11, validation of requirements before design phase is very important, and clear statements, usage of designer experience for the evaluation has also great value for importance, which are emphasizing that designers prefer the cases that the requirements are clearly defined, validated before design and also evaluated by their experience. The experience and knowledge of designer cannot be ignored for validation of requirement as for executing the briefing process for capturing knowledge from client. Design proposals are also important medium to present ideas and relations for evaluation of requirements with client, possibly because all requirements cannot be illustrated to inexperience client without 2D/3D representations. Respondents give less importance to evaluation of requirements with specification library and knowledge bases than others. It is seen that they also have importance, however the approach of validating requirements with client before or during the proposals including clear statements has priority.

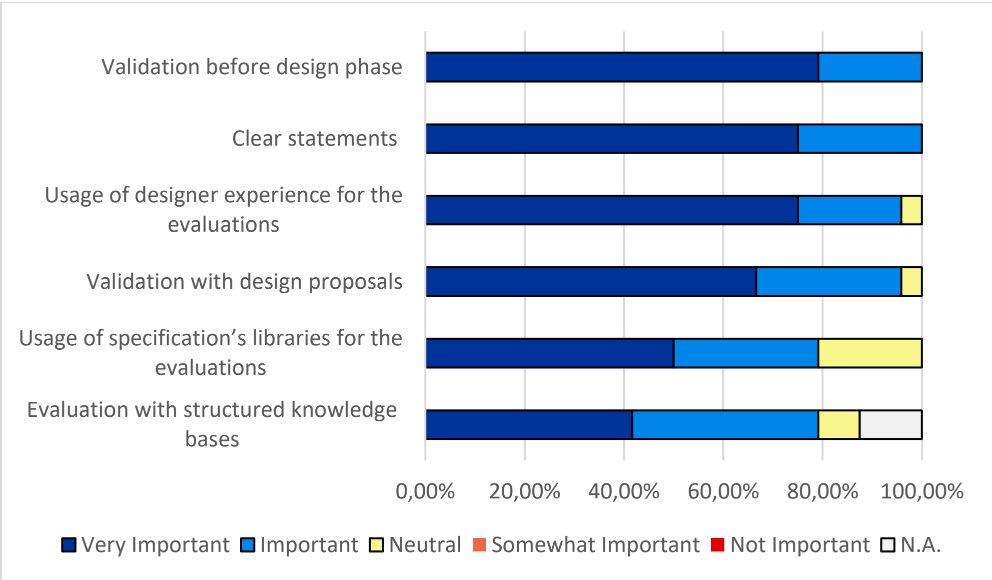


Figure 3.11. Importance of actions on client requirements

Item 6

Based on the literature review, knowledge can be managed by some process to maintain continuity of knowledge usage. In can be understood from the Figure 3.12 that validation of requirements with design proposal has significant usage and importance. Although it is stated that validation before design is more vital than validation with design proposals at item 5, item 6 results in the vitality of proposals. This is discussion issue, in which trends of practice of Turkey especially due to client profile makes evaluation of requirements in proposal phases, not before design. However, designers have tendency to prefer validating requirement before starting the design phase. Indexing, archiving and reusing of requirement knowledge have significant value for both usage and importance. With the utilization of various managing system for knowledge, respondents try to control requirement knowledge for the contribution to both ongoing and other projects. Usage of computer processable techniques and automated rule checking at BIM are extremely low comparing to others, however the importance of BIM is more noticed than computer processable format.

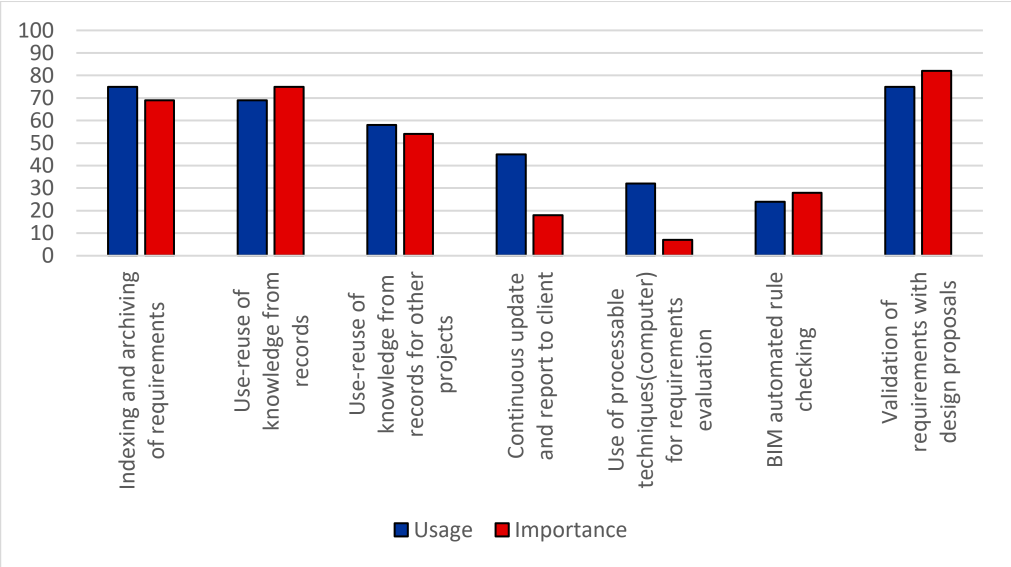


Figure 3.12. Knowledge processes for requirements

Item 7

The effects of briefing process were asked to respondents to understand their general approach to successful briefing for elicitation the project requirements. What issues and in which level that they are affected by the briefing are tried to be explored. It can be stated from Figure 3.13 that briefing success is effective on design success, time-budget of design and reduction of re-work. Clear, validated and little changed knowledge of requirements bring advantages to design process. Better decision making and client satisfaction are also affected by briefing success, besides productivity and profit are increased. It can be noted that design briefing success affects the construction phases, but in a level of others. Respondents were also asked in an open-ended question in this theme what they are thinking about the impact of storing, finding and reusing of requirement knowledge during the client briefing process. The statements which have importance are listed below:

- It is important to analyse and record requirement knowledge captured based on typologies.
- Transfer of experience may be done via documentation of knowledge
- The record of knowledge is important for re-creating of design scenarios due to changer orders.
- The record makes evaluation inputs(requirements) and outputs(project) possible.
- Requirement management shortens the way to accepted design, but also takes more time.
- Every question related to projects can be answered from the records.

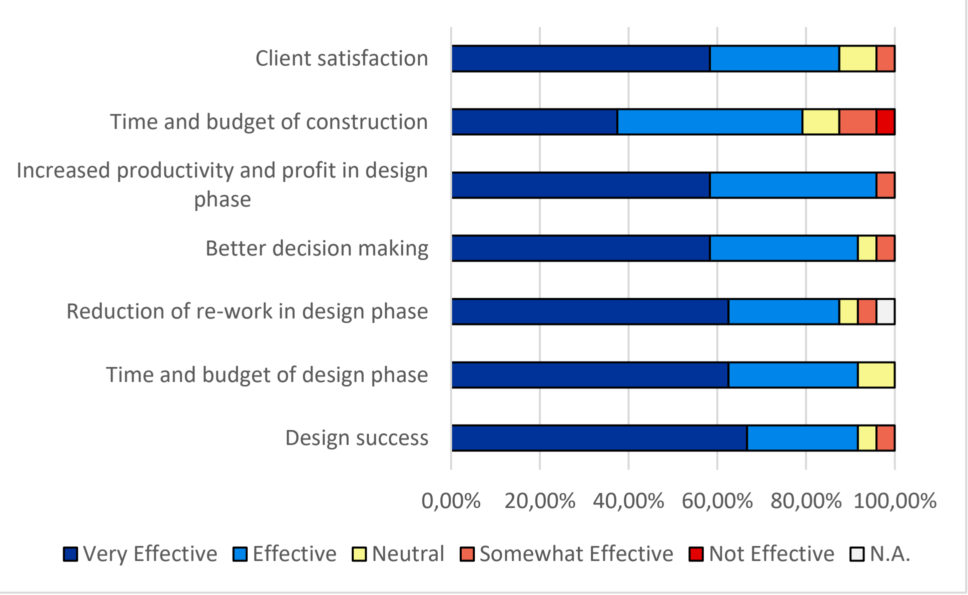


Figure 3.13. Issues that briefing process success affect

3.5 Findings of the Interview

Interviews have started after the survey and were completed at November 2021. 11 architects from Ankara who are owner or partner of a design company were asked for interview, with their choice the interviews were held by online meeting methods.

Part 1

The results for part 1 and profile are presented at Table 3.2. Average experience of interviewees is over 20 years and project typology that they completed is in wide range. The group has experience on so many project types and sizes like residential, mix-use, health care buildings, office and public buildings, sport buildings and hotels. It can be stated that restoration and conservation projects and structural renovation project against earthquake are out of experience. Overall rate of client type is 30% public, 70% private and there are companies which are dealing with especially international projects. BIM usage and future plan and expectation for BIM are also asked. For interview group 24.55% of all projects are completed with using BIM tools and methods. Some uses due to client wish, some uses for their development and some uses BIM for not all process of project, for the parts like project proposal and 3D representations. However, in general companies have tend to integrate BIM usage in their offices in time. They are looking forward to comprehend the time issue for adaptation, budget for expertise and software license, proliferation among project stakeholders and client. Briefly, it can be stated that potential of BIM is noticed, but the market and compatible working conditions are waited for. Only 1 office uses BIM for all projects without using CAD drawings. They use CAD only by conversion due to communicate and collaborate to whom only use CAD drawings.

Requirements of the project and usage phases of them in to the project were asked to understand their working experience on them. Approximately in 1/4th of the projects the requirements are submitted by client before the works on studies are initiated. For the 39,09% of the projects, requirements are tried to be elicitation and validated with client by some techniques and studies of designer. Lastly, in 33,64% of the projects, there is no submission of requirements and they are tried to presented and then validated with client by preparation of design proposals according the objections of project. This diversity is stimulating situation for the research, since one of the important objections is to explore the experiences and approaches about managing and implementing the requirements into project studies.

Table 3.2 Interviews' profile

Duration of Interview	39 minutes
Total Experience	20,27 years
Participation to survey	45,45%

Client Public	30,00%
Client Private	70,00%
Project Archive	100,00%

Requirement Submission by Client before Project	26,36%
Elicitation and Validation of Requirements with Client before Project	39,09%
Presentation and Validation of Requirements by Project Proposals	33,64%

BIM Usage	24,55%

CAD Usage	10 respondents

Part 2

The statements for the situations that the requirement studies are done before the project work are listed below;

- **Interviewee #:** Requirements are submitted by project specification document in high level of detail for international clients. The requirements are investigated manually and imported to BIM environment as written text. The evaluation for requirements with project is made manually by using output documents of BIM model and specification documents.
- **Interviewee #:** Requirements are submitted by project specification document which is hundreds of pages. Team members are assigned to analyse and prepare brief documents for project initiation. Submission of

requirements is beneficial, but it is also a challenging work to deal with it.

- **Interviewee #:** For the projects which there is market research by experts and consultants, the requirement documents present the spaces and relation in quantity in more detail. The design work may be held with these inputs considering the legal and site issues, design intentions and experience.
- **Interviewee #:** The requirements should be presented and gotten approval from client via design proposals, even if they submitted. Because the client has not enough experience and technical knowledge to evaluate requirements with design.
- **Interviewee #:** Requirements are submitted rarely before the project. Besides when they are presented, it is so beneficial situation for designer to start to project after analysing the requirements. However, for this situation there needs to have high qualified clients in terms of respect to knowledge and labour work of project stakeholders.
- **Interviewee #:** Requirements about the space relations, object relation and electromechanical needs may be submitted before the project. They are so beneficial for solving the problems of project in further steps and in also thinking about general layout of design proposals.

Part 3

Elicitation and validation of requirements are done before the project work and during the design proposals by designers for various examples. Some companies have objection for getting the requirements before the project work by some meetings and session, but some companies think that the requirements could be only managed by design proposals. The statements for different interviewees for this about requirements' feature, procedure to work on and experiences are listed below;

- **Interviewee #:** Requirements are prepared and presented thinking the projects conditions, using own experiences and documents before the project work. Without general consensus on requirements, design studies do not start.
- **Interviewee #:** It is important to use project archive for evaluating the new project requirements. However, the knowledge of investigating the archive properly is belong the working team members. If there is system to index and find the needed knowledge of requirements, the experience can be externalized.

- **Interviewee #:** There is attempt to maintain requirement and relation knowledge of project typologies after the completion to use them for further project
- **Interviewee #:** For some project, requirement knowledge is not needed. They should be figured out by designers with experience and studies. Client wish is to benefit from the company experience.
- **Interviewee #:** By looking the client typology, it is stated that clients can be only communicated with design proposals, thus any study about preparation of requirement in written or digital documents by client or design is meaningless.
- **Interviewee #:** Getting approval of requirements, whether they are prepared by documents or design proposal, is vital for a designer to complete project successfully.
- **Interviewee #:** While in the requirement preparation for any project legislation, universal specification should be considered.
- **Interviewee #:** The attempts for understanding, recording and transferring about knowledge of requirements will always sustain significancy, since the experience and knowledge of designers and team members determine the quality of the projects.
- **Interviewee #:** BIM usage for design proposals is good for presenting the design and requirements to client for evaluation and validation. Clients can understand the project environment and designer has an easier and flexible way to develop the project.

Part 4 / Benefits and Possible Contribution of Framework Proposal

- A control and tracking system for unexperienced client.
- Reworks of analysing requirements and tracking change orders can be reduced dramatically.
- Dependency to individuals for knowledge by library system will be decreased
- May help on work of unexperienced designers
- The processes and calculations are done more easily and rapidly by computer
- If the system can work independently from experience and time of designers, it has a significant contribution to managing the requirements.
- Mistakes, misunderstanding, difference of interpretation originated by people will be reduced into minimum

Part 4 / Possible Problems of Framework Proposal

- Compatibility problems of IFC and data loss on BIM
- Every knowledge cannot be coded or transferred into computer format
- Hard to change the available procedure and tends of construction industry
- There needs level of experience for initiating the system
- Experience and vision of designer will stay always for managing the requirements.
- It can only deal with quantitative data, has no process for analysis or inference
- There will be a need for labour work and experience to execute the system
- It creates bureaucracy and make it obligatory in terms of procedure of project execution. This situation is also considered as a benefit of system.
- Needs high detail level of input for the system resulting in profit loss due to time.

Part 4 / Comments and Suggestion on Development of the System

- A system for converting the requirements documents into format that computer and BIM environment can work
- It is hard to collect data in project process. The system can be used for refining and storing knowledge after completion of project.
- A system for analysing and converting data from the legislation.
- It should have a module for similarity and typology checking
- There should be option for designer to change and interfere in the system due to his/her intentions and approaches
- The system may be considered in communities and construction industry that have institutional procedure and knowledge
- There is no any situation that a computer cannot solve. There is only time issue to wait for development.
- Execution of the system differs according to the client and project typology

3.6 Discussion on the Findings

The survey and interview about knowledge capturing in design process for requirement elicitation and validation which was held over industry practitioners explores the contemporary practices and approaches of respondents among the research era. Beside the results related to objectives of this study, further analysis and interferences could be held for the investigation of cases: BIM usage, position in the market, project typologies or processes and *etc.* The results of the items and themes designed for the survey and thoughts of interviewees were presented at the previous section. The outcome of the results was evaluated by discussion for stating the situation of industry practitioners against the issues clearly.

3.6.1 Actual Situation and Approaches

Open and effective communication with project stakeholders for capturing requirement knowledge and defining objectives of the project is distinctly important for the success of briefing. However, architects have communication with client and project engineers above 65%, whereas with user and consultant is under 25%. Even though the involvement of user in the briefing is stated as important (item 3), it is sustained occasionally. Another issue is that capturing the requirement knowledge from an individual without technical experience stands as a significant problem for briefing process. By looking at Item 1 (efficiency of briefing techniques), it can be seen that design proposals are the certain technique for client briefing. Interviews, observation, brainstorming, scenario analysis, and sketches are used extensively. Reasons for preferring the techniques that architects can sustain interactions with individuals are to improve communication level and to increase the knowledge transfer between inexperienced clients and users. In addition to these, designer inexperience, misunderstanding of client's needs, insufficient time and inadequate representation of requirements negatively affect the success of briefing (item 4). Thus, with the proper representation tools and methods in sufficient time needs and requirements could be captured and validated by project stakeholders who have adequate level of experience.

Validation of requirements before design phase with clear statements is considerably important (item 5). But, the requirement evaluation by designer experience or with design proposals are also taken into consideration. One third of the interviewees prepare the project requirements by themselves and present them by design proposals, even though most of them prefer to start designs with approved requirements. They stated that clients usually ask for the preparation of project requirements from the architects with design proposal, and for most of the clients the only way to work on requirement is via project work. Item 6 shows that validation of requirements with design proposals is used often and stated as important. The conflict between expectation of requirements before design and actual state of validating them design proposals results from various reasons. Lack of client experience, involvement of users for capturing requirements, practice choices on evaluation of requirements on 3D proposal instead text or diagram-based representations, non-usage of comprehensive methods and frameworks can be stated as critical factors.

Knowledge processes like indexing, archiving, retrieving and reusing are utilized reasonably widely; however, computer processable formats and BIM are not used sufficiently to manage the knowledge. Client briefing is usually recorded (item 2). Digital text-based documents are used often, in contrast, computer processable format and structured database are used less. The importance of taking records whether in text to manage the knowledge is done by architects, besides a level awareness of knowledge process for capturing, validating and creating requirements was observed on respondents. However, the execution of these processes and techniques/technologies usage are not observed. Usage of structured database, computer usage capturing and evaluation for requirements with or without knowledge bases and BIM usage are not considered for management of requirements. Besides, it can be stated as BIM is not utilized widely, when done, notably for collaboration and design, and partly for document management, specifications and simulations. BIM environment is used at a level of design proposals, sometimes for all project process. But, the capability of BIM like automated rule checking is almost never used and not signed as an important process for requirements.

There is general consensus about the broad and inclusive effects of briefing success over project issues. Design success, time and budget of design phase, reduction of work in design phase, better decision making and client satisfaction are directly affected by success of briefing for requirement gathering. Also briefing as a recorder and processor of knowledge adds important value for transferring the experience between parties and evaluating the requirements.

3.6.2 Discussion on Improvement for Requirement Process

Client experience level and also the knowledge of project stakeholders have significant effect on requirement elicitation and validation in briefing system. A knowledge base that is router and evaluation source can reduce the problems related to experience. By this working principle the briefing process can be close to independent from individuals' knowledge level. Also unexperienced designers or designers who have lack of knowledge can benefit from the knowledge base. However, it is not meaning that all the process can be done without the involvement of users and designers. Project unique context is so related to human perception and actions coming from experience and knowledge. The computing and learning capabilities of machines can contribute the process by inferences resulting from complex calculations. These calculations are hard to manage by humans in terms of time and mental capacity. Additionally, a ruled system with the integration of computer can decrease mistakes and misunderstanding between project stakeholders.

Possible problems of system were stated under three important headings; compatibility problem of BIM files (machine environment), limits of the knowledge process and needed experience level for the usage of the system. First one is also contemporary problem in BIM world that is data and meaning loss between different software's. Building Smart Community is working to develop a common file system called IFC and release for compatibility of different companies (buildingSMART, 2022). Second is related to dimension of knowledge, all knowledge cannot be coded or transferred into machine readable format. Human may need other techniques to understand knowledge and communicate between for project process. Thus, text-based recordings, visual medium or some methods like scenario analysis or workshops will stay in the briefing process. Third problem is need of an experience level of project stakeholders. The experience is related to methodology, not construction industry directly. Every stakeholder should accept this situation to run the framework. Generally, the client is decision maker for consideration of briefing process. So, with the acceptance, a level of bureaucracy will be inserted. It may be problem or undesired progress for designers or clients.

Architects as industry practitioners have an important role on issues that are worked on to developed with their experience of project works. Comments and suggestions on system are enlightening some important lacks of improvement areas for requirement management. One of the important approaches for briefing is to make possible to convert the written requirements to computer processable format that can be transferred to BIM rules. The studies, development on ontologies and executions of some software continues on this subject. Also, it is noted that converting and transferring the knowledge from legislation to BIM environment is important. Some countries use this approach for project evaluations and submissions, researchers try to develop the automated systems. Other important comment on system is related to designers' decision boundary. Whether the system state proper or not, designers should have the option or right to revise the knowledge according to his/her intentions and approaches. Machine or ruled system may have calculations and recommendations; however, this stays in a boundary that designer can change and make decisions. Also, the building typology, client type and project delivery system are effective on the system working. Execution of briefing and systems part should differentiate due to these conditions.

CHAPTER 4

MATERIAL AND METHOD

This study aims to develop a system for requirement elicitation and validation with a ruled framework for the improvement of briefing process. The framework inquires some methodologies to capture knowledge from the library for establishing an initial and comparison base for users. In this chapter, first the dimensions that are considered to develop frameworks throughout the research are briefly presented, then proposed framework and activities of the system are explored. At the end, the data library and software are presented.

4.1 Framework Studies

Barret states that even though a number of published briefing guides exist, very few brief takers really use them, they rely on their experience (P. S. Barrett et al., 1999). Thus, it should be considered that the system, frameworks or guide for requirement elicitation at the briefing process have practical implication and evaluation by users while presenting an improvement or solution to particular process or problems.

4.1.1 Dimensions to Develop Framework

Table 4.1 present the merged findings from literature survey, questionnaire survey and interviews that are used to seek and develop a developing framework. The objective is to design, develop and test a requirement elicitation system that can be used for the pre-project stages.

Requirement knowledge of any project reflect the rational objectives and client needs. The final decisions are generally made by investor client and designer if he/she has responsibility. User client and designer have role as router on development of requirements. They have requirement knowledge on objected project; however, their knowledge source is generally different. Investor client and representative occasionally make valuable comments on requirements if they have past experience on actual project environment. But the perception of requirements may vary since the technical and practical experience are different from construction industry experts. Misunderstanding of needs, unable to set common ground for evaluation are resulting from this experience differences. For some project executions, randomly all project stakeholders can have a good level experience on practice and requirements, as a result at this project's the satisfaction about communication and understanding each other may be better.

Designer's knowledge is coming from experience, practical and scientific background. So, process on requirements is much affected from designer's knowledge on ongoing project typology. Investor client and representative's knowledge on requirements is mainly governed from reports, strategic briefing and feasibility studies prepared by other individuals or organizations. If they have not any particular experience on objected project, it is hard to handle a beneficial and contributing briefing medium for requirement elicitation. On the other hand, user clients have crucial requirement knowledge on spaces and space relations that should be considered. The problems to gather this knowledge are to communicate with them by same technical language and evaluate the needs considering the overall project objectives. It is so hard for anyone which has not enough vocational practice and requirement knowledge to manage needs and objective with a clear processing by thinking small parts and evaluating them as a part of wholes at the same time.

Table 4.1 Findings of literature survey, questionnaire survey and interview

Stakeholders / Dimension	Client (Investor)	Client (Users)	Designer	Client (Representative)
Decisions on Requirements	Generally, decision maker	Router on space relations	Router and decision maker	Involved with assigned role
Requirement Knowledge	No, may be experienced project	Yes	Yes	No, may be experienced project
Experience on Practice	No	No	Yes	No, may be with pre-assigned role
Knowledge Source	Given reports, strategic briefing.	Experience by usage	Experience, practical and scientific background	Given reports, strategic briefing.
Collaboration	Hard to spare time	Hard to spare time and to organize	If involved, yes	If involved, yes
Communication	Use of same language	Use of same language	Use of same language	Use of same language
Re-use Requirement Knowledge	Corporation level knowledge base	Past experience (tacit knowledge)	Corporation or project level knowledge base, experience	Corporation level knowledge base, experience
Use of Frameworks	Should be enforced	Should be enforced	Ready with benefits	Should be enforced

By exploring the dimensions at the table, collaboration to process can be maintained with involvement and sparing enough time. Both in the literature and survey, it is seen that collaboration is important, however sparing enough time is obstacle. Collaborative work environment is definitely one of the important objectives of any project. Diverse project stakeholders contribute the completion and success of construction projects. Technological improvement like BIM or cloud-based working gives better opportunities and skills to construction industry. Communication is sharing same meaning to reach mutual understanding (den Otter & Emmitt, 2008). It is seen in the research, main necessities for successful communication are using same language meaning same technical experience. Project stakeholders may have diverse background and it is hard to set a common base for mutual perception. Individual and organizations are seeking some techniques or rules to understand each other better with the implementation of evaluation or comparison sources. Sometimes they use organizational and institutional past experience or regulations about the requirements to have better understanding of each other.

Past experience and project knowledge could be facilitated from structured libraries or individual's mind of experience. Second part is also part of human's perception and decision mechanism throughout designs and any problem solving. It is hard to convert or transfer because of tacit knowledge. Thus, corporation or project base knowledge base are beneficial to re-use valuable knowledge as it can be seen in some studies presented in the survey. Both in the literature and survey, the importance of frameworks and methods are stated. Users are hard to be convinced to use, they may utilize from frameworks with the enforcement of usage at first. But generally, the designers whose main works is about are aware of the importance of this kind of frameworks if they can be used by without additional experience. In addition, experts tend to use technology like BIM or computations for requirement elicitation and validations process although a few of them utilize these methods.

Table 4.2 presents the dimensions focused on requirement knowledge elicitation and validation. Sparing enough time is important for requirement processing. Successful requirement elicitation and validation using less time may be preferred by project stakeholders. Since the involvement of involvement of them is need in process, whether it is at beginning, in the process or after some studies according the accepted procedure. Requirement statement of project cannot be completed without contribution or approval of relevant project stakeholders. These documents, diagrams, visuals or some computer-based formats presenting the requirements of building are dynamic due to comments and development by users and designers.

Knowledge for requirements can be captured from individuals, organizations and knowledge bases, and can be validated by consensus, experience or some evaluation methods like surveys and field reports. General approach is seeking an initiation and comparison point or base to create validated knowledge to be used by designer for the development process. Records of knowledge is vital for all processes and tracking, besides the techniques of recording affecting to use and re-use knowledge. Re-used knowledge from knowledge bases can be used for creation of new requirements due to project or organization typology, but knowledge sharing and using same ontology are important. Experience of individual about the processes and project typology for executing any requirement elicitation and validation process. The guides or structured frameworks of which some examples are presented in the literature survey is helpful to achieve success against lack of experience.

Table 4.2 Dimension for requirement processes

Process / **Dimension**	**Requirement Knowledge Elicitation**	**Requirement Knowledge Validation**
Time	Needed	Needed
Involvement of Project Stakeholders	Needed	Needed
Capture	From individuals, organizations, knowledge bases	By consensus, evaluation with experiences, surveys
Records	Needed for process and tracking	Needed for process and tracking
Re-Use	Creation and Evaluation	Evaluation
Structured Framework	Rules and Order	Rules and Order
Experience on Process and Project Typology	Needed	Needed

4.1.2 Proposed Framework

Requirement elicitation and validation is important part of project execution that is taking role in identifying needs and objectives. It is a complex issue that can be accomplished by sparing time on process with the involvement of project stakeholders in proper procedure via frameworks. Within this research, a data-driven system is proposed for improving the process of requirement creation for projects. The system should be used as a part of any compatible briefing framework which may be executed with proper implementation. The designer's experience dimension, user's knowledge on spaces and statements of investor clients stands as an interrelating subject to be part of system. Within this research study, from the beginning there is an attempt to search for gaps, lack and improvement areas on requirement elicitation and validation in construction projects in briefing stages. Both the studies, approaches and strategies in literature, and the evaluation through experts are conducted with framework improvements. Unified Modelling Language, was used to design, make models and represent the studies in order to maintain rational relation of objects, activities and states.

4.1.2.1 Unified Modelling Language

The objective of UML is to provide system architects, software engineers, and software developers with tools for analysis, design, and implementation of software-based systems as well as for modelling business and similar processes (OMG, 2017). Because of its capability to describe, explain and evaluate the systems and theories based on object oriented, not only software industry but also other disciplines can use for their problem areas. Graphical design notations have been used for a while, but important value of diagrams is in communication and understanding, and it should have a high level of abstraction to facilitate discussion about design (Fowler, 2004). The first object-oriented language is generally known as Simula-67, developed in Norway in 1967 (Rumbaugh, Jacobson, & Booch, 2004). In the continuation, there are many languages and methods designed and used by different parties. It is a relatively open standard, controlled by OMG, an open consortium companies (Fowler, 2004). There are diverse static and dynamic views and diagrams that can be used in UML, in this research activity and use case diagrams are used to develop system.

The use case diagrams shows actors, the use cases and the relationship between them to describe which actors carry out which use cases and which use cases include other use cases (Fowler, 2004). It is one of the five diagrams in the UML for modelling dynamic aspects of systems, and it is important for visualizing, specifying and documenting the behaviour of an element (Booch, Rumbaugh, & Jacobson, 1999). Figure 4.1 shows an example of use case diagram.

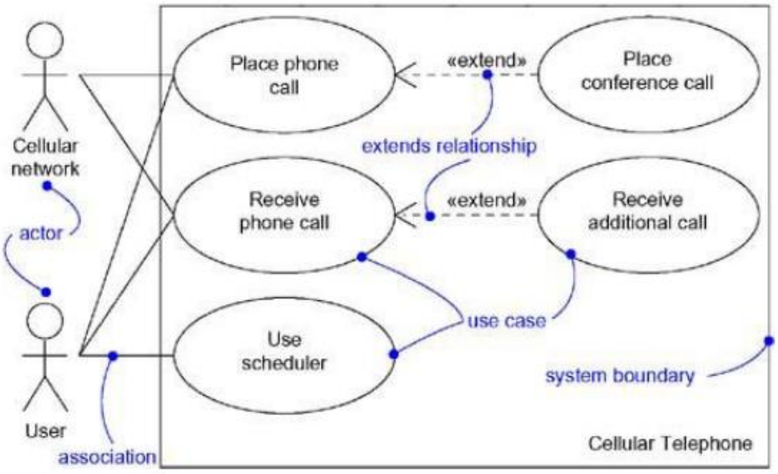


Figure 4.1. Example of Use Case Diagram (Rumbaugh et al., 2004)

Activity diagrams are a technique to describe procedural logic, business process, and work flow, they are showing dynamic aspects of system as use case diagrams (Fowler, 2004). In Figure 4.2 , an activity diagram exploring the main notations (fork-merge, activity node, actions, choice and flow) is shown. One of the diagrams of UML showing dynamic aspects of system is state machine diagram. They are used for behavioural aspects of system and states of activities to figure out lifetime process of a flow in the model (Fowler, 2004).

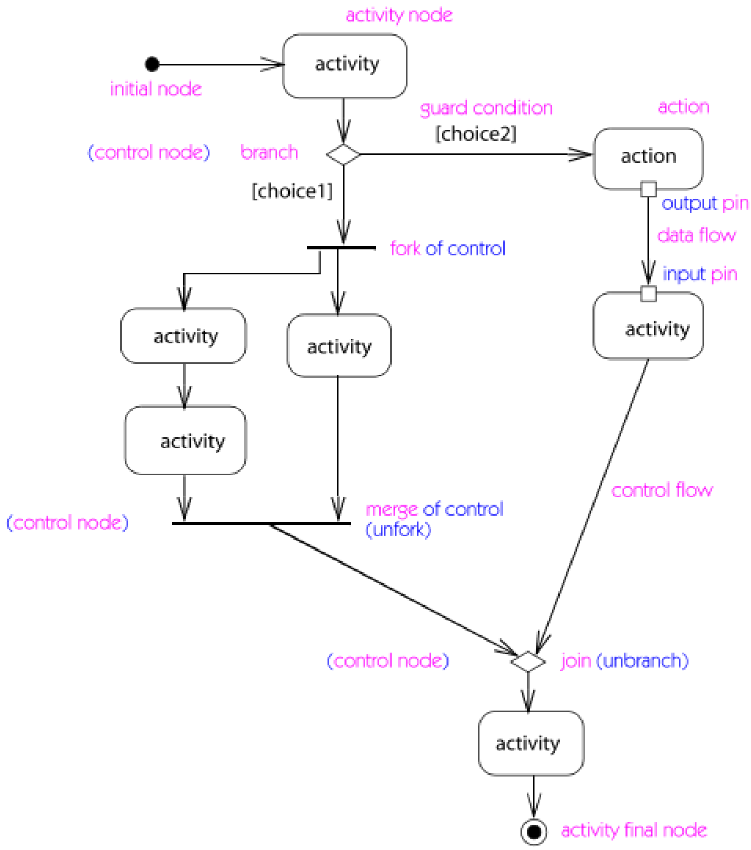


Figure 4.2. Example of activity diagram (Rumbaugh et al., 2004)

4.1.2.2 Statements on Dimensions

In this section, the statements and decisions of dimension which are explored at Table 4.1 and Table 4.2 are presented orderly. The research study is to develop a system for situations described at the following parts.

Table 4.3 shows statements and objectives of research to develop a system as a proposal for the requirement elicitation and validation, after the survey of literature and industry experts. Decision on requirements needs the involvement of project stakeholders, especially investor and designer. Besides for a success of this process a good level of requirement knowledge is compulsory. For the situation in which, non-existence or involvement of project stakeholders, it is objected to define base and create a method for requirement knowledge creation. Besides by this, the dependency of process in projects is aimed to decrease. For example, for public process, it is impossible for involvement of client as individuals who can make whole decisions with responsibility. There is a seeking of base, method or legislations to set a rational common environment for evaluation and creation of requirements. In addition, DBB project, the designers take role after the project objectives are stated. Thus, there is need of initiation and evaluation base for requirement processing. A database of requirement knowledge for building typology can act as knowledge source with valuable method for inference.

Table 4.3 Statements on dimensions for research objectives

Dimension	Situation	Objective of System
Decisions on Requirements	Non-Existence or involvement of project stakeholders	Define a base for evaluation
Requirement Knowledge	Non-Existence or involvement of project stakeholders	Create a method to capture knowledge rather than individuals
Experience on Practice	Inexperienced project stakeholders	Decrease the effect of experience level
Knowledge Source	Given reports, strategic briefing.	Conduct completed cases as a knowledge source
Collaboration	Hard to spare time	Ruled framework for involvement of different project stakeholders
Communication	Use of same language	Explanatory relations
Re-use Requirement Knowledge	Independent Sources	Define a common knowledge base
Use of Frameworks	Should be enforced	Should be enforced

Collaboration necessity is somehow decreased with the framework; however, the rules and methodology sustain the working environment with the communication route. Since the framework has own rule and explanatory guidance, the communication level is objected to be increased, while using same technical language. The knowledge of requirement which comes from completed cases and also update of actual projects is recorded in the system and this makes possible to re-use them among new projects. The most the important necessity is enforcement of individual to use the system. This can be sustained via ensuring validity and benefits of the proposed system which will be tested within the research. The framework is also proposed to contribute the designers' studies and user's needs an evaluation and comparison base.

Table 4.4 shows the objectives of proposed system under the requirement processes. The time needed for requirement elicitation and validation is objected to decreases, thus the possibility of creating more alternatives for evaluation with reduced workload could be existed. Independency of project stakeholders from elicitation and presenting as base for validation are important. Also, the requirement knowledge from project stakeholders can be implemented to the system as an opportunity. Proposed system as methodology is defined as knowledge sources for creating requirement knowledge from data-libraries with some methodologies, and give possibility to take records and to re-use knowledge by iterations, cycles. The system works as a structured framework with the aim of elimination of experience of project typology which is intended to work on. Experience of individual has an important role of requirement process and so, it is one of the important facts for unsuccessful results. Thus, the system proposes an inference of requirement knowledge from completed cases' library.

Table 4.4 Objectives of system for requirement processes

Process / **Dimension**	**Requirement Knowledge Elicitation**	**Requirement Knowledge Validation**
Time	To decrease	To decrease
Involvement of Project Stakeholders	To maintain independency within the proposed system	To present a base for validation
Capture	From knowledge base, entries of users	Recommendation of system, validation through users
Records	By iterations	By iterations
Re-Use	By iterations	By iterations
Structured Framework	Yes	Yes
Experience on Process and Project Typology	Eliminated, work of proposed system.	System contributes

4.1.2.3 Position of System in Briefing Framework

The techniques, tools, methods and technologies which are used to capture the knowledge from individuals, groups are organizations mainly from requirement processing are presented in literature survey. The usage and problems of them are examined via survey with industry experts. They are valuable, valid and important for briefing framework. Proposed system is to be take a part in general briefing framework by serving contribution to requirement elicitation and validation process. Figure 4.3 shows the user roles and relation to activities which are taking role in briefing process for requirement elicitation and validation. Face to face interviews, project proposals, surveys, meeting, queries and other activities are used for knowledge capturing with the involvement needed project stakeholders. Data driven requirement elicitation system adds value and opportunity to process as another knowledge capturing framework with involvement of any user. It can be also used with the integration or parallel uses of other capturing activities to improve requirement elicitation process. The integration of data driven system with other is not studies in this research, since both it is an expansion feature. The outcomes of these activities could be used for elicitation, evaluation and validation of requirements, and project inputs for designers.

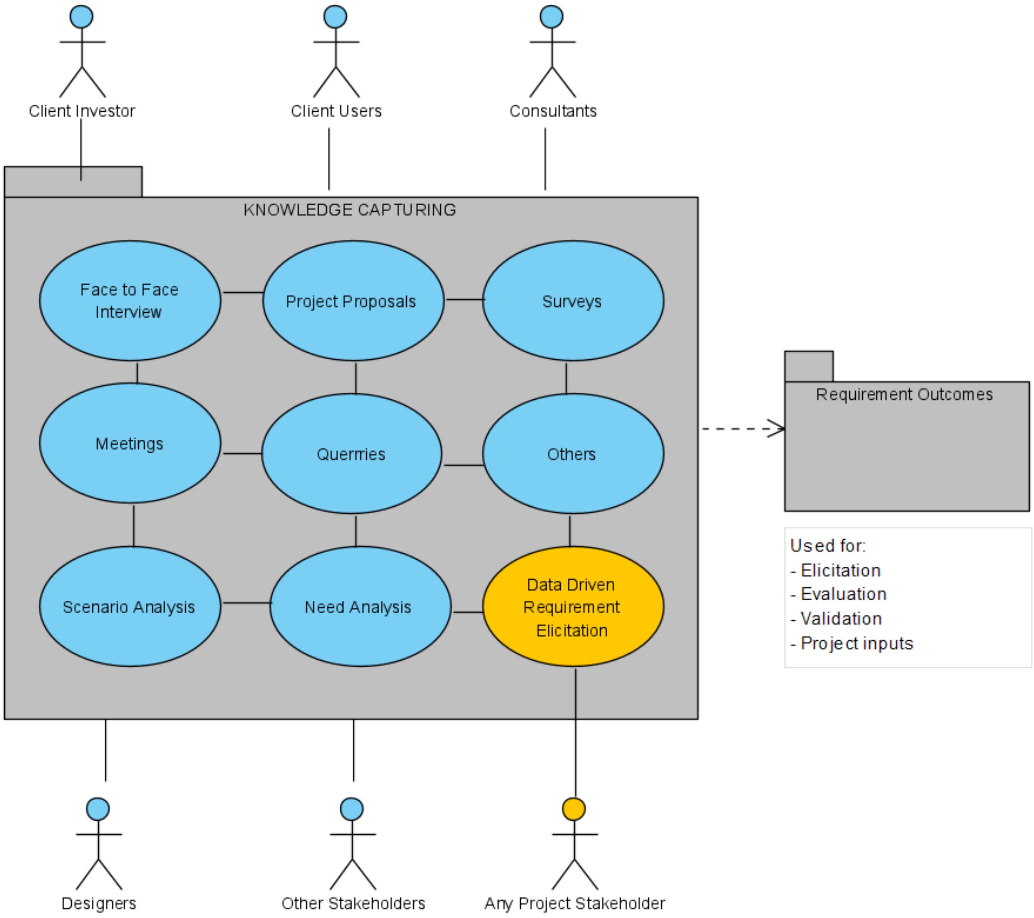


Figure 4.3. Position of proposed system

4.1.2.4 Overview of the Proposed System

Figure 4.4 shows the main framework of the data driven requirement elicitation system. There activities that make possible to capture knowledge from data library. These activities are presented at the next section. The nodes and stores are static knowledge which interact between user activities and previous activities. User activities are related to entries, examinations and comments of the system user. The components, iterations and activities are developed due to main objectives, and presented at the next sections. The space requirements which are gathered as a result of these framework could be used for further process, designer refinement, project studies and BIM rule checking. Requirements of a project are to be captured in a level within the system, they should be expanded, evaluated and detailed according to project scale, context and execution. However, the knowledge coming from the methodology are objected to define the layout of the building requirements and evaluation base for knowledge captured from other stakeholder with diverse activities.

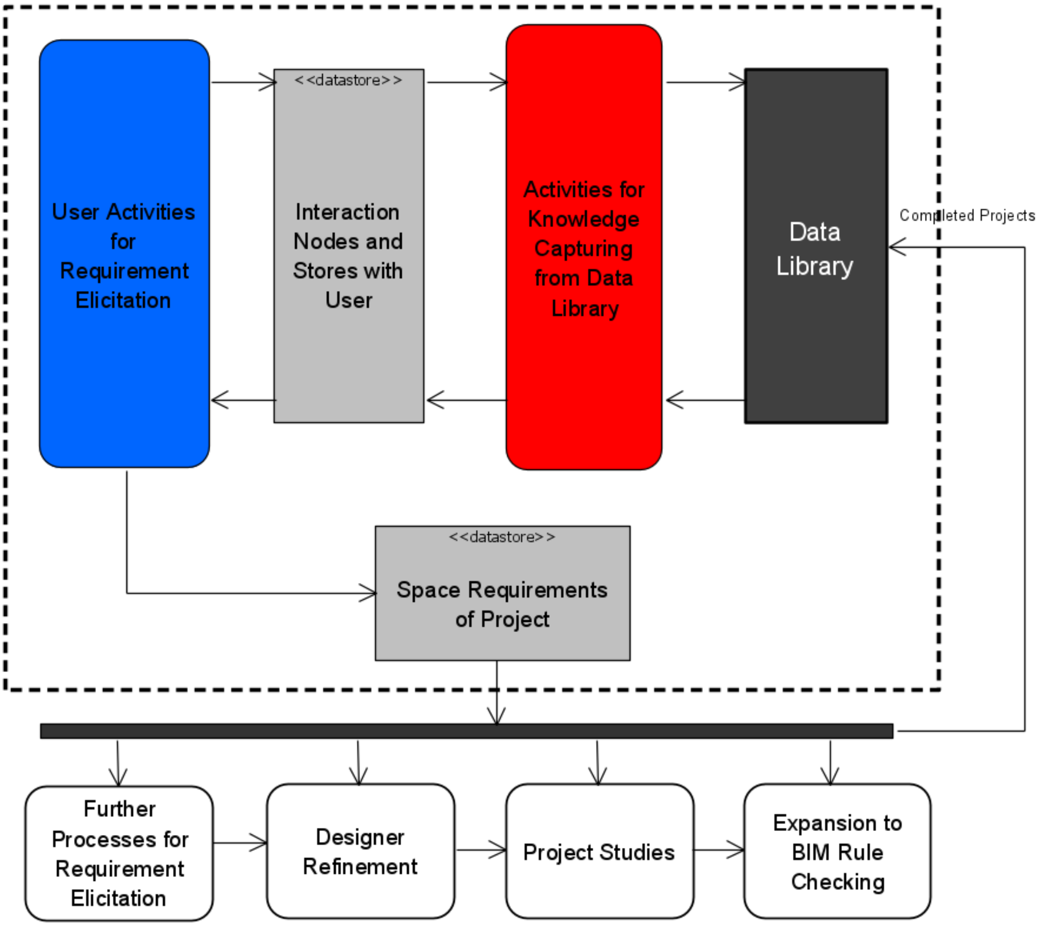


Figure 4.4. Overview of proposed system

The tags of data library make the system outputs compatible to the execution of automated rule checking. The application on converting and transferring the knowledge from this system to the BIM rule environment is adaptable, since the dimension of knowledge is formal for computing of machine. The requirement of spaces can be examined during and after the process by designers, architects who have experience and knowledge on actual project. The system offers to them a layout from space requirement to work on and make more detail via their subjective evaluation and development. The knowledge created and presented with the iteration of system could not act instead of designer contribution the architectural project development. On the contrary, it is objected to improve the requirement elicitation and validation process by putting right and valuable knowledge coming from data-library with machine learning activities.

4.2 Methods for Machine Learning Activities

Machine learning and data mining methods are used to find and analysis trends and patterns in existing information by calculating statistical opportunities. It is obvious that finding patterns is not new thing for human being, however with the machine capacity on calculation, it makes possible to seek for big and complex data sets in faster and accurate process. Machine Learning is the science of programming computers to make possible learn from data to dig into large amounts of data for discovering patterns (Géron, 2017). Many machine learning approaches originated from the concepts about the human learning like decision trees (Quinlan, 1986). It may also help human to learn from inspected information.

The machine learning is classified in two main group: supervised learning and unsupervised learning. In supervised learning, there are input and output variables they used algorithm to learning mapping function from the input to output, whereas in unsupervised learning there are input variables that machine learns by modelling the underlying structure or distribution in the data (Brownlee, 2016). There is no teacher in unsupervised machine learning and it is possible to find nothing to learn.

Clustering algorithms are initiated to analyze patterns and relations in data sets and transfer to information to knowledge. Besides, data clustering is an important method in data mining to discover knowledge from data that is used in pattern recognition, document clustering, image processing, bioinformatics, social networks, crime prediction, location prediction, behavioral analysis and so on (Awad & Hamad, 2022; Fahim, 2021; Jain, Sharma, Bhatia, & Arora, 2017; Nie, Wang, & Li, 2019; Özmerdivenli, Taşyürek, & Daşbaşı, 2022; Qi, Yu, Wang, & Liu, 2016).

K-means clustering algorithm is most used clustering machine learning algorithm for descriptive analysis on data sets, it starts with random selected number of cluster centroids, and then every data is assigned to nearest centroid, the means of assigned data are calculated by repeating iterations of new centroids until finding the similar or same value of group means and centroids (Jain et al., 2017; Sarıman, 2011; Sinaga & Yang, 2020). The main objective of K-Means clustering algorithm is to seek pattern of different entries with diverse variables by minimizing the sum of the distances and their respective cluster centroids (Cui, 2020). There are also other machine learning algorithms in types of parametric and nonparametric algorithms for making assumptions from diverse data sets (Brownlee, 2016). However, K-means clustering algorithm is used in this research study since the main objective is to seek and explore the pattern and groups of spaces. The data consists of dimensional information of spaces like area, height and occupancy number, and using this algorithm is the simplest and effective learning activity to define space groups and relations.

4.2.1 K-means Clustering Algorithm

K-means clustering algorithm is an unsupervised machine learning algorithm that are used to discover and identify the inherent groupings in the data (Géron, 2017; Sinaga & Yang, 2020). Figure 4.5 shows an example of clustering human group by examining two different features of individuals. K-means algorithm starts with random selected number of cluster centroids, and then every data is assigned to nearest centroid, the means of assigned data are calculated by repeating iterations of new centroids until finding the similar or same value of group means and centroids (Jain et al., 2017; Sarıman, 2011).

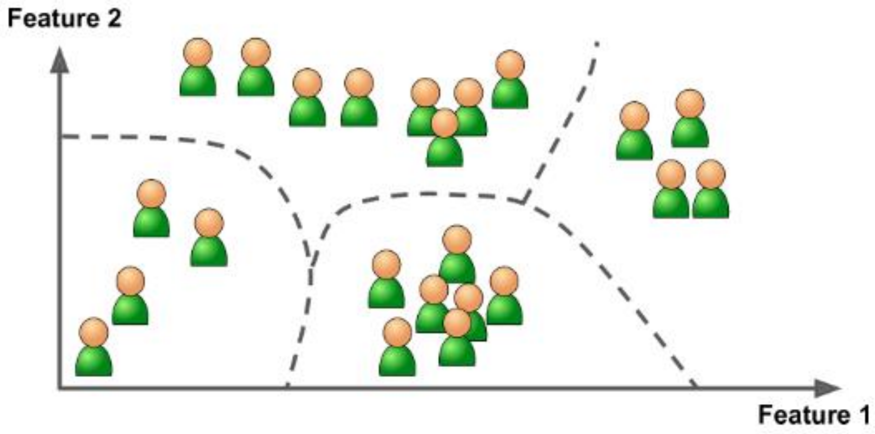


Figure 4.5. Clustering (Géron, 2017)

The important thing for K-means clustering is to choice of cluster centroid number at beginning of the execution and at examining the results (Sinaga & Yang, 2020). There diverse proposal to choose the right K after multiple execution of algorithm such as; variance based approach, structural approach, consensus distribution approach, hierarchical approach and resampling approach (Chiang & Mirkin, 2010). The main goal of K-means algorithm is to minimize the sum of distances and their respective cluster centroids, thus elbow method is a proper method of deciding number of cluster in which the total distance of data to their centroids for different numbered clusters are calculated (Cui, 2020). To increase the total number of clusters will results in decreasing the sum of distances, however the ratio of reduction may be dramatically high or low. At this point in which the sum of distances does not change or decrease comparatively less, it is stated as optimum number of clusters. The clusters and members of clusters may be part of any pattern and relations that should be evaluated by humans due to objections or analyze by computer in defined relation framework. The aim is to explore existence of any pattern in given data set.

Figure 4.6 shows the presentation of elbow technique and formula of WCSS. WCSS is sum of squares of distances within the cluster. It is seen from the example there is a dramatic decrease of WCSS from 1 cluster to 3 cluster, however more than 3 cluster the decrease in the value comes near two zero. It means that making more cluster is out of the limits of minimum cluster description, making more groups which should be examined with some additional approaches and objections. On the contrary, for 1 and 2 cluster the value is relatively high, and it means that the data is arranged around far centroids.

$$WCSS = \sum_{P_i \text{ in Cluster 1}} \text{distance}(P_i, C_1)^2 + \sum_{P_i \text{ in Cluster 2}} \text{distance}(P_i, C_2)^2 + \sum_{P_i \text{ in Cluster 3}} \text{distance}(P_i, C_3)^2$$

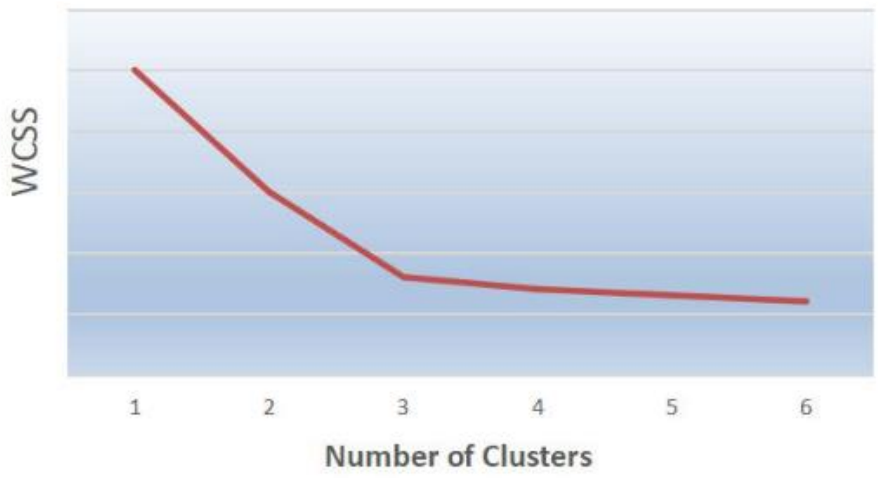


Figure 4.6. Elbow Technique (Cui, 2020)

4.2.2 Pairwise Correlations Analysis

There are some techniques to analyse and measure relation between variable in the population. The techniques that evaluate input variable without having to compare them to an output variable are to identify which pairs of variables are interrelated and which give clues for possible data analysis and objectives (Nettleton, 2014). A correlation coefficient is simple and commonly used to quantify the degree of association between two variables (Boslaugh, 2012). The Pearson correlation method is the most common method for numerical variables; the output is a value between -1 and 1, where 0 is nonexistence of correlation, 1 is total positive correlation and -1 is negative total correlation(Nettleton, 2014). There are some potential problems for Pearson correlation analysis. It is not able to present different between dependent and independent variables (Statistics, 2020). Thus, it is need to be aware of data set to be analysed. Figure 4.7 shown the meanings of correlation values that are calculated for two variables. It is considered that value more than 0.7 is existence of positive correlation, whereas value less than -0.7 is negative correlation.

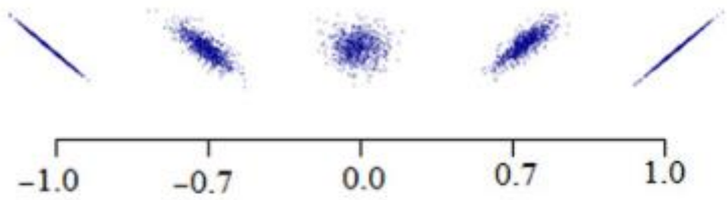


Figure 4.7. Correlation between two numerical values (Nettleton, 2014)

4.3 Material: Data Library

The proposed system aims to learn patterns and trends from data sets which can be used for space analysis for requirement processing. In this part, a completed project about space and building data library higher education is presented. The tags and ontology of this system guide with their technical capacity for the development of data-driven dynamic requirement elicitation system. The composition of any data-library can be implemented to this research study with the execution of proper machine computing methods. One of the important key to successful data driven methodology is to have easy and rapid access to accurate and multidimensional data (Power, 2008). Thus, a completed project (YMESS and MEKSIS) from Turkey, which is to collect data and design a decision support system over them, is decided as data library for the development and examining the objectives of this research study.

4.3.1 YMESS and MEKSİS

YMESS is the inventory classification system of higher education facilities which was prepared by a group of academicians and experts to collect and explore the universities spaces of Turkey at functional base as a part of MEKSİS project.(T.C. Kalkınma Bakanlığı, 2018b). Main objective of the MEKSİS project is to develop higher education facilities investment decision support system to maintain efficiency on spaces and building of public universities (T.C. Cumhurbaşkanlığı Strateji ve Bütçe Başkanlığı, 2022). Postsecondary education facilities inventory and classification manual of USA was used to develop methodology for space tags and system (National Working Group on Postsecondary Facilities, 2006).

All public universities collected and submit the data of spaces on their universities with the help of vocational education due to guidelines of the system (T.C. Kalkınma Bakanlığı, 2018a, 2018b). The space tags and codes are regulated under the main function group and sub function group which is presented at the appendix G. An example of spaces is shown in Table 4.5. The collected data of space are function, area height, level and façade. Each data group is related with the building, and buildings are related to university campus, and campus is related the university. Some additional values of spaces are also asked to measure and entry from assigned officer which are illumination value, humidity and temperature and inside CO2 levels. At the moment, the system is composed of 129 public university. The general knowledge could be examined from the web page of MEKSİS, for the contents of data library the contact with the strategy and budget department of Turkey Government.

Table 4.5 Data tags' example

Space Function	Space Code	Level	ID	Code	Main Function	Main Function Code	Area	Space Height	Number of Users
Classroom	ED	Z	1	ED-Z-1	Education	E	74,23 m²	4,34 m	48 p
Circulation	OS	K4	1000	OS-K4-1000	Others	O	798,16 m²		
Classrom(with slope)	EA	Z	11	EA-Z-11	Education	E	81,00 m²	4,97 m	70 p
Data Room	OC	Z	22	OC-Z-22	Others	O	22,81 m²		
Seminar Room	ES	Z	24	ES-Z-24	Education	E	53,76 m²	5,90 m	22 p
Restroom	OW	Z	32	OW-Z-32	Others	O	11,34 m²		
Personnel Office	MI	Z	44	MI-Z-44	Administrative	M	52,00 m²		6 p
Class Laboratory	EL	Z	57	EL-Z-57	Education	E	101,26 m²	4,23 m	45 p
Circulation	OS	Z	1000	OS-Z-1000	Others	O	2624,30 m²		
Cafeteria	GK	Z	60	GK-Z-60	Social	G	474,84 m²		
Academician Office	MA	K2	35	MA-K2-35	Administrative	M	53,00 m²	3,00 m	9 p
Personnel Office	MI	K2	36	MI-K2-36	Administrative	M	29,23 m²	2,95 m	2 p
Personnel Office	MI	K2	37	MI-K2-37	Administrative	M	29,23 m²	2,96 m	2 p
Academician Office(admin)	MY	K2	38	MY-K2-38	Administrative	M	35,43 m²	2,90 m	1 p
Research Laboratory	RM	K4	28	RM-K4-28	Research	R	41,00 m²	2,90 m	

4.3.2 Limitation of the Data Library

The data library is composed of the information which is instructed with manual of the project. It is well organized body of information for space analysis, however there may be expansion for space relational or functional analysis from the views of architecture and requirements. It is seen that the data library is expandable with the implementation of new needed values within the actual framework. For existing data library; occupancy evaluation, proximity relations of spaces, functional connections of spaces and computable 3D space knowledge is unavailable.

4.4 Software's Used for the Development

Briefing framework studies, activities and relations are examined and developed by Unified Modelling Language, for application Visual Paradigm 16.2 (Object Management Group, 2022) is used. Excel (Microsoft, 2022) is used for the data library, user activities, machine learning activities and user interface of the system. XLSTAT (Addinsoft, 2022) is used for K-Means clustering algorithm for descriptive space analysis.

CHAPTER 5

DEVELOPMENT OF THE DATA-DRIVEN REQUIREMENT ELICITATION SYSTEM

This chapter presents the developed version of data-driven requirement elicitation system due to objectives of the research. First objectives and used data library are stated, then activities that are taken part in the system are explored. The structure of the system is explored in detail with defined iterations, at the end of the chapter limitations of running system and possible remarks on expansion are given.

5.1 Objectives of Proposed System

The proposed system is developed by the methodologies and tools presented in the previous chapter. Main aim of the research to improve the requirement elicitation and validation process within the briefing framework. To develop a system by considering literature survey and survey among industry practitioners, the objectives are examined throughout the development of data-driven requirement elicitation system:

- Defining space requirements of building through dynamic iterations by user
- Capturing knowledge from data-library to direct the requirement elicitation process by recommendations and evaluations
- Implementing unsupervised machine learning activities for creating valuable knowledge over data-library
- Developing a rule-based framework to processes and represent requirements maintained by machine and the any user without experience. The tolerances and flexible choices of users should be ensured.

5.2 Used Data Library

Space information, student number and academician's number of three completed building (faculty of art and science) of different universities is used for composing data library. The values of spaces are recorded into the system due to YMESS. The number of the occupant are taken from the last released report of YOKSİS (YÖK, 2022). Table 5.2 presents a sample of data library, only shows 30 rows of one building. Approximately 250 rows are existing to define the spaces of one building in the data library. Table 5.1 shows the general information of the buildings which form the data library for the development and evaluation of proposed system of this research study.

Table 5.1 General information about data-library

University	Case 1	Students(2021-2022)		Academic Staff(2021-2022)	
Year	2010	Undergraduate	1858	Prof.	23
Building Typology:	Faculty of Art and Science			Assoc. Prof.	29
Location:	Case 1			Asst. Prof.	20
Net Area	19537,47			Instructor	4
Gross Area:	23980,48			Research Assistant	35
Gross/Net Ratio:	1,22740969	Total:	1858	Total:	111
University	Case 2	Students(2021-2022)		Academic Staff(2021-2022)	
Year	2012	Undergraduate	1694	Prof.	27
Building Typology:	Faculty of Art and Science			Assoc. Prof.	22
Location:	Case 2			Asst. Prof.	44
Net Area	13491,6			Instructor	4
Gross Area:	16092,7			Research Assistant	42
Gross/Net Ratio:	1,192794035	Total:	1694	Total:	139
University	Case 3	Students(2021-2022)		Academic Staff(2021-2022)	
Year	2013	Undergraduate	713	Prof.	13
Building Typology:	Faculty of Art and Science			Assoc. Prof.	23
Location:	Case 3			Asst. Prof.	23
Net Area	10251,31			Instructor	2
Gross Area:	11615,99			Research Assistant	14
Gross/Net Ratio:	1,133122498	Total:	713	Total:	75

Table 5.2 Sample of data-library

Space Function	Space Code	Level	ID	Code	Main Function	Main Function	Area	Space Height	Number of Users
Mechanical Room	OT	B1	1	OT-B1-1	Others	O	335,23 m²		
Classrom(with slope)	EA	B1	2	EA-B1-2	Education	E	276,23 m²	8,32 m	276 p
Classrom(with slope)	EA	B1	3	EA-B1-3	Education	E	119,36 m²	6,96 m	119 p
Class Laboratory	EL	B1	4	EL-B1-4	Education	E	85,00 m²	3,93 m	36 p
Class Laboratory	EL	B1	5	EL-B1-5	Education	E	80,00 m²	3,93 m	36 p
Class Laboratory	EL	B1	6	EL-B1-6	Education	E	82,32 m²	4,00 m	36 p
Class Laboratory	EL	B1	7	EL-B1-7	Education	E	84,32 m²	3,80 m	36 p
Class Laboratory	EL	B1	8	EL-B1-8	Education	E	82,00 m²	3,75 m	36 p
Class Laboratory	EL	B1	9	EL-B1-9	Education	E	81,00 m²	3,96 m	36 p
Circulation	OS	B1	1000	OS-B1-1000	Others	O	2196,23 m²		
Circulation	OS	Z	1000	OS-Z-1000	Others	O	1605,36 m²		
Circulation	OS	K1	1000	OS-K1-1000	Others	O	781,36 m²		
Circulation	OS	K2	1000	OS-K2-1000	Others	O	753,36 m²		
Class Laboratory	EL	B1	10	EL-B1-10	Education	E	86,00 m²	4,00 m	36 p
Class Laboratory	EL	B1	11	EL-B1-11	Education	E	81,00 m²	3,87 m	36 p
Class Laboratory	EL	B1	12	EL-B1-12	Education	E	82,32 m²	3,97 m	36 p
Restroom	OW	B1	13	OW-B1-13	Others	O	37,50 m²		
Restroom	OW	B1	14	OW-B1-14	Others	O	37,50 m²		
Restroom	OW	B1	15	OW-B1-15	Others	O	30,23 m²		
Restroom	OW	B1	16	OW-B1-16	Others	O	30,23 m²		
Meeting Room	CM	K2	72	CM-K2-72	Congress and Me	C	72,50 m²	3,90 m	50 p
Restroom	OW	B1	17	OW-B1-17	Others	O	47,23 m²		
Restroom	OW	B1	18	OW-B1-18	Others	O	45,63 m²		
Classrom(with slope)	EA	B1	19	EA-B1-19	Education	E	84,32 m²	4,65 m	64 p
Classrom(with slope)	EA	B1	20	EA-B1-20	Education	E	82,00 m²	4,50 m	64 p
Classrom(with slope)	EA	B1	21	EA-B1-21	Education	E	81,00 m²	4,30 m	64 p
Classrom(with slope)	EA	B1	22	EA-B1-22	Education	E	84,50 m²	4,56 m	64 p
Classrom(with slope)	EA	B1	23	EA-B1-23	Education	E	84,50 m²	4,32 m	64 p
Classrom(with slope)	EA	B1	24	EA-B1-24	Education	E	83,00 m²	4,44 m	64 p

5.3 Machine Learning Activities

Machine learning and computing activities are used to capture knowledge from the data-library. This knowledge is used to define the needed space for the building typology, create recommendations, and evaluate the values and present comments against user's entries to the system. The iterations which are consisted of user activities, machine learning activities and exchange nodes are presented with the structure of the system in the next section. The machine learning activities and their working principles are explored at this section. Figure 5.1 shows the machine learning activities of the system over data-library and user entries. The objectives are to explore pattern and clusters of spaces and relation of pairs. First, data rank classification for primary and additional spaces are computed to identify the spaces which take more places in quantity comparing to whole building within the typology. The lower ranked spaces as additional spaces for building spaces. Additional spaces mean that they are created due to project unique context and cannot be valid for entire building typology. Thus, they are proposed and asked to the users to examine without evaluation or recommendation. For example, a dining hall may be defined in a building, whether there is a dining facility in the campus, or not. This situation is a known situation from individuals, however machine doesn't. The machine comes up to the result by analysis the spaces which are composing the building relations and their existence ratio.

The ranked spaces as primary spaces are computed by machine via K-means clustering algorithm to describe the valuable space types within the group. For example, considering the number of building and diverse classroom spaces with different area, height and capacity, there may be thousands of classrooms with slight or big differences. The main objective of descriptive space analysis with K-means clustering algorithm to search utilized clusters or space variants within the space groups. There may be also primary spaces for which machine cannot define any cluster opportunities resulting from the data-library. Primary spaces with and without cluster opportunities and additional spaces are asked from the user and recorded by datastore nodes.

Correlation analysis is made by the machine in pairwise to find valuable relation between items. These relations and relation ratios are used to recommendations and calculational of relational spaces. Also, no correlation is possible to find by machine, and with this any recommendation and calculations cannot be done. Every building typology may result in different correlation results, and it is obvious that this knowledge come from the completed building spaces record. This system does not open the validity of data-library, it states a methodology to capture requirement knowledge from existing buildings. Besides, the value of the data-library should be evaluated, considering that they are approved, constructed and used building since various dates by public universities.

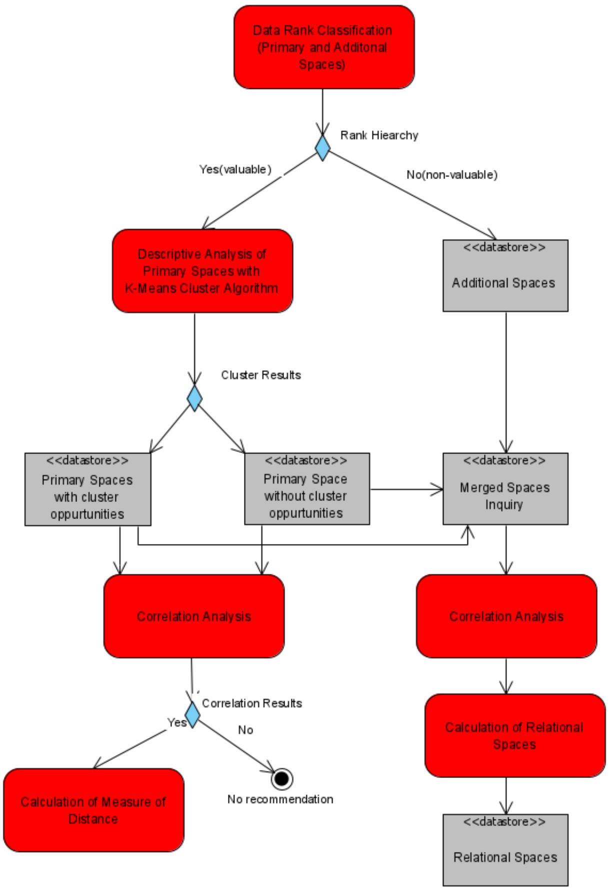


Figure 5.1. Machine learning activities due to spaces

5.3.1 Rank and Descriptive Space Analysis with K-Means Clustering

Table 5.3 shows the rank analysis's results of spaces within the building typology. All spaces under the subgroups of YMESS are calculated, and the ratios of in the whole domain is presented. At the moment, the assumption of identifying relational spaces is made considering the YMESS subgroups and general facts of architectural spaces like circulation areas. However, it is also possible to be calculated and learned by the machine with further improvement on algorithm. The primary spaces are ranked and it is decided to have descriptive space analysis up to 6 to hold the system more intelligible for users. There is no obstacle for execution of K-means clustering for all spaces of building typology. The additional spaces are left for other iterations to asked for the user and relational spaces are stated to be calculated by machine due to results of the requirement elicitation process.

Table 5.3 Rank Analysis

Space Function	Space Type	Space Code	Main Function	Total Area:	Quantity	Number users	Ratio	Rank
Class Laboratory	Primary	EL	Education	4.114 m²	48	2.081	9,47%	2
Research Laboratory	Primary	RM	Research	833 m²	21	0	1,92%	8
Classrom(with slope)	Primary	EA	Education	2.532 m²	24	2.110	5,83%	4
Others(education)	Primary	EX	Education	694 m²	8	350	1,60%	9
Academician Office	Primary	MA	Administrative	3.898 m²	216	532	8,97%	3
Personnel Office	Primary	MI	Administrative	1.139 m²	45	122	2,62%	7
Academician Office(admin)	Primary	MY	Administrative	1.391 m²	38	44	3,20%	5
Seminar Room	Primary	ES	Education	1.235 m²	20	574	2,84%	6
Classroom	Primary	ED	Education	4.280 m²	53	3.226	9,85%	1
Personnel Office (admin)	Primary	MP	Administrative	143 m²	3	3	0,33%	11
Meeting Room	Primary	CM	Congress and Meeting	196 m²	3	108	0,45%	10
Data Room	Relational	OC	Others	506 m²	26	0	1,17%	-
Restroom	Relational	OW	Others	1.497 m²	84	0	3,45%	-
Cafeteria	Relational	GK	Social	1.040 m²	12	0	2,39%	-
Mechanical Room	Relational	OT	Others	633 m²	4	0	1,46%	-
Circulation	Relational	OS	Others	16.740 m²	14	0	38,54%	-
								-
Conference Hall	Additional	CS	Congress and Meeting	348 m²	1	267	0,80%	-
Eating Area	Additional	GY	Social	401 m²	1	332	0,92%	-
Depot	Additional	OH	Others	800 m²	1	0	1,84%	-
Archive	Additional	OP	Others	267 m²	3	0	0,61%	-

Table 5.4 shows a part of classroom space's list of data-library which is composed of three completed building. There are 53 rows at the total for this space. Steps of the descriptive space analysis with K-means clustering algorithm are presented for

class space example, the results of other spaces are given at the appendices including the details of method, iterations and values.

Table 5.4 A part of classroom space's list

Space Function	Space Code	Level	Code	Main Function	Area	Space Heig	Number of Users
Classroom	ED	K3	ED-K3-3	Education	117,88 m²	3,32 m	100 p
Classroom	ED	K3	ED-K3-4	Education	119,00 m²	3,95 m	100 p
Classroom	ED	K3	ED-K3-5	Education	120,00 m²	4,00 m	100 p
Classroom	ED	Z	ED-Z-1	Education	74,23 m²	4,34 m	48 p
Classroom	ED	K2	ED-K2-9	Education	75,69 m²	4,23 m	48 p
Classroom	ED	K2	ED-K2-10	Education	75,00 m²	4,34 m	48 p
Classroom	ED	K2	ED-K2-11	Education	75,50 m²	4,32 m	48 p
Classroom	ED	K2	ED-K2-12	Education	72,32 m²	4,14 m	48 p
Classroom	ED	K2	ED-K2-13	Education	75,60 m²	4,34 m	48 p
Classroom	ED	K2	ED-K2-14	Education	75,69 m²	4,40 m	48 p
Classroom	ED	B1	ED-B1-35	Education	65,00 m²	4,00 m	52 p
Classroom	ED	B1	ED-B1-36	Education	66,50 m²	3,90 m	52 p
Classroom	ED	Z	ED-Z-15	Education	72,00 m²	3,90 m	64 p
Classroom	ED	Z	ED-Z-21	Education	72,00 m²	3,97 m	64 p
Classroom	ED	Z	ED-Z-22	Education	73,50 m²	3,93 m	64 p
Classroom	ED	Z	ED-Z-23	Education	66,50 m²	3,90 m	52 p
Classroom	ED	Z	ED-Z-24	Education	66,50 m²	3,90 m	52 p
Classroom	ED	Z	ED-Z-25	Education	66,50 m²	3,90 m	52 p
Classroom	ED	Z	ED-Z-26	Education	66,50 m²	3,75 m	52 p
Classroom	ED	Z	ED-Z-27	Education	57,23 m²	3,96 m	42 p
Classroom	ED	Z	ED-Z-43	Education	67,00 m²	3,90 m	52 p
Classroom	ED	Z	ED-Z-44	Education	66,50 m²	4,00 m	52 p
Classroom	ED	Z	ED-Z-45	Education	65,00 m²	3,90 m	52 p
Classroom	ED	Z	ED-Z-46	Education	63,00 m²	3,90 m	52 p

It is possible to explore the initial clusters by manual investigation by creating chart with values. It can be seen from the Figure 5.2, space-height density clustering and number of users-area density clustering by drawing them at X and Y axis. K-means clustering algorithm as presented at the previous chapter, is used to make descriptive analysis by seeking trends and pattern in the given data sets. The classroom spaces are executed for three variables; area, height and number of users. By exploring Figure 5.3, 4 main cluster of classroom space can be seen. The graphic including number of clusters against WCSS shown that 4 cluster definition is selected due to elbow technique, since more than 4 clusters do not result any significant change on sum of distances. The centroids of these clusters identify the features of classroom spaces that is commonly used in this building typology. This knowledge is captured and processed in the proposed system to direct users by discovering needed spaces of worked building. Table 5.5 presents the results of the descriptive space analysis via K-means algorithm for all spaces of building typology. These spaces are used in the iterations for recommendation of spaces and main body of measurement calculations.

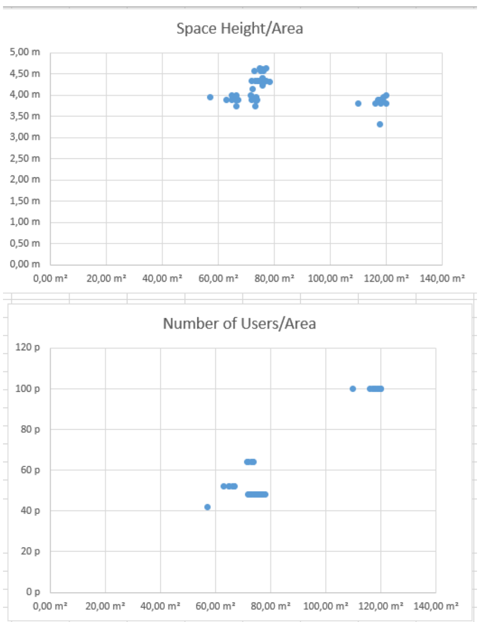
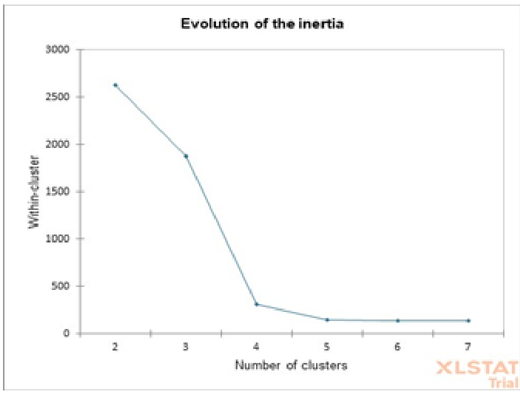


Figure 5.2. Pre investigation of classroom cluster



Cluster centroids:

Cluster	Area	Space Height	Number of Users	Sum of weights	Within-cluster variance
1	117,475	3,811	100,000	10,000	8,512
2	75,245	4,395	48,000	24,000	2,155
3	65,112	3,910	51,091	11,000	17,269
4	72,923	3,910	64,000	8,000	0,803

Figure 5.3. K-means results of classroom space

Table 5.5 Results of the descriptive space analysis

Space name	Area	Height	Number of Users	Cluster	Quantity	Ratio
Classroom	117,48	3,81	100,00	1	10	18,87%
Classroom	75,25	4,39	48,00	2	24	45,28%
Classroom	65,11	3,91	51,09	3	11	20,75%
Classroom	72,92	3,91	64,00	4	8	15,09%
Class Laboratory	82,27	3,77	54,00	1	12	25,00%
Class Laboratory	101,18	4,32	45,00	2	14	29,17%
Class Laboratory	54,27	4,29	38,75	3	4	8,33%
Class Laboratory	82,96	3,91	36,00	4	18	37,50%
Academician Office	11,70	3,02	1,00	1	36	16,67%
Academician Office	12,90	2,94	1,81	2	62	28,70%
Academician Office	51,20	2,95	7,89	3	18	8,33%
Academician Office	22,81	3,19	2,78	4	54	25,00%
Academician Office	11,37	2,92	2,00	5	46	21,30%
Classroom (with slope)	88,68	4,74	72,67	1	21	87,50%
Classroom (with slope)	196,78	6,28	154,00	2	2	8,33%
Classroom (with slope)	276,23	8,32	276,00	3	1	4,17%
Academician Office(admin)	55,51	3,04	1,00	1	11,000	28,95%
Academician Office(admin)	27,23	2,94	1,00	2	22,000	57,89%
Academician Office(admin)	36,30	2,93	1,00	3	5,000	13,16%
Personnel Office	26,84	2,93	2,93	1	15,000	33,33%
Personnel Office	13,04	3,08	1,50	2	20,000	44,44%
Personnel Office	47,57	2,99	4,80	3	10,000	22,22%
Seminar Room	(Not enough number of items for K-means clustering algorithm)					
Research Laboratory						
Others(education)						
Personnel Office (admin)						

5.3.2 Pairwise Correlation Analysis

Pairwise correlation analysis is executed by machine to find whether there is valuable relation with space in quantity, or not. For the calculations all of the items in the data library belonging the same building typology are used. Recommendation in iterations for spaces and calculations for relational spaces are done due to non-relational items resulting from pairwise correlation analysis. Table 5.6 shows the pairwise correlation results between item including spaces, totals of areas and capacities and actual occupations of student and academicians. The results are examined and decisions are taken due to person correlation approaches. Table 5.7 presents the relation decision on primary spaces and relational spaces. These selections are used for the calculation of recommendations and relational spaces. Exploring the table, it can be seen that largest value for classroom and classroom slope is existing with the total capacity, although it has relation with registered student number. For another example, no correlation is found for mechanical and data room, thus a constant quantity is selected from the calculations on data-library. All of the decisions on items through table, which will be changed when the data-library meaning the building typology is selected differently. This knowledge is captured from the completed buildings of intended typology that has quantitative and descriptive value on defining relations between spaces and occupants.

Table 5.6 Correlations of items

	Gross Are	Net Area	Gross/Ne	Student N	Academic	Classroom	Classrom(	Seminar R	Meeting R	Class Labo	Research L	Others(ed	Academic	Academic	Personne	Personne	Restroom	Cafeteria	Mechanic	Circulatio	Number s	Number s	Total capa	Number o	Number o
Gross Area:	1	0,999891	0,952276	0,85319	0,42385	0,984243	0,663062	0,877827	0,96634	0,889896	-0,62798	0,999981	0,994005	0,892779	0,974915	0,998879	0,431944	0,829378	-0,79556	0,997565	0,989827	0,629844	0,745567	0,653764	0,55853
Net Area	0,999891	1	0,947672	0,845407	0,410451	0,986743	0,651954	0,884794	0,962442	0,883074	-0,61644	0,999782	0,995509	0,88604	0,978091	0,999469	0,445194	0,837525	-0,78654	0,996428	0,987622	0,618324	0,735661	0,642536	0,54624
Gross/Net Ratio:	0,952276	0,947672	1	0,971685	0,680087	0,883299	0,859909	0,689732	0,998751	0,986665	-0,83555	0,954136	0,913196	0,98768	0,86045	0,936762	0,136035	0,619264	-0,94253	0,971245	0,986016	0,83687	0,913406	0,853537	0,78506
Student Number planned	0,85319	0,845407	0,971685	1	0,834055	0,747517	0,956169	0,499119	0,958663	0,997185	-0,94171	0,856383	0,791049	0,996688	0,715693	0,827547	-0,1019	0,416206	-0,99479	0,88749	0,918721	0,942515	0,983721	0,952479	0,90919
Academician planned	0,42385	0,410451	0,680087	0,834055	1	0,257019	0,959038	-0,06176	0,6426	0,790345	-0,97104	0,429414	0,322285	0,786433	0,211624	0,380508	-0,6338	-0,15449	-0,88596	0,485986	0,548401	0,970461	0,919616	0,962464	0,98802
Classroom	0,984243	0,986743	0,883299	0,747517	0,257019	1	0,520252	0,948689	0,905623	0,795214	-0,48048	0,983137	0,997675	0,799054	0,99891	0,991509	0,584613	0,915097	-0,67589	0,969514	0,949074	0,482579	0,615981	0,509662	0,40306
Classrom(with slope)	0,663062	0,651954	0,859909	0,956169	0,959038	0,520252	1	0,223509	0,833326	0,931524	-0,99894	0,667654	0,577246	0,929193	0,479817	0,626891	-0,38872	0,131716	-0,98104	0,713655	0,762818	0,999052	0,993223	0,999924	0,99126
Seminar Room	0,877827	0,884794	0,689732	0,499119	-0,06176	0,948689	0,223509	1	0,725053	0,562682	-0,1785	0,874864	0,924932	0,567928	0,962416	0,899513	0,811162	0,995649	-0,40817	0,842284	0,800751	0,180862	0,335274	0,21145	0,09299
Meeting Room	0,96634	0,962442	0,998751	0,958663	0,6426	0,905623	0,833326	0,725053	1	0,977299	-0,80706	0,967904	0,932419	0,978626	0,884838	0,953081	0,185373	0,657728	-0,92466	0,981929	0,993112	0,80847	0,891923	0,826433	0,75313
Class Laboratory	0,889896	0,883074	0,986665	0,997185	0,790345	0,795214	0,931524	0,562682	0,977299	1	-0,91384	0,892685	0,834688	0,99998	0,766042	0,867309	-0,02703	0,483207	-0,98434	0,919543	0,945743	0,914808	0,967479	0,92696	0,87541
Research Laboratory	-0,62798	-0,61644	-0,83555	-0,94171	-0,97104	-0,48048	-0,99894	-0,1785	-0,80706	-0,91384	1	-0,63275	-0,53913	-0,91124	-0,43901	-0,59044	0,430635	-0,08604	0,971105	-0,68073	-0,73231	-1	-0,98684	-0,99944	-0,99627
Others(education)	0,999981	0,999782	0,954136	0,856383	0,429414	0,983137	0,667654	0,874864	0,967904	0,892685	-0,63275	1	0,993314	0,895533	0,973528	0,998569	0,426388	0,825926	-0,79927	0,997975	0,990684	0,63461	0,749653	0,658406	0,56362
Academician Office(admin	0,994005	0,995509	0,913196	0,791049	0,322285	0,997675	0,577246	0,924932	0,932419	0,834688	-0,53913	0,993314	1	0,838174	0,993406	0,998066	0,52796	0,885488	-0,72455	0,98396	0,968339	0,541149	0,668236	0,567114	0,46449
Academician Office	0,892779	0,88604	0,98768	0,996688	0,786433	0,799054	0,929193	0,567928	0,978626	0,99998	-0,91124	0,895533	0,838174	1	0,770114	0,870457	-0,02067	0,488765	-0,9832	0,922023	0,94779	0,912221	0,965851	0,924556	0,87232
Personnel Office (admin)	0,974915	0,978091	0,86045	0,715693	0,211624	0,99891	0,479817	0,962416	0,884838	0,766042	-0,43901	0,973528	0,993406	0,770114	1	0,984357	0,62185	0,932924	-0,64075	0,957018	0,933331	0,441165	0,578534	0,468941	0,35989
Personnel Office	0,998879	0,999469	0,936762	0,827547	0,380508	0,991509	0,626891	0,899513	0,953081	0,867309	-0,59044	0,998569	0,998066	0,870457	0,984357	1	0,474145	0,854891	-0,76599	0,993146	0,981984	0,592377	0,713191	0,617217	0,51864
Restroom	0,431944	0,445194	0,136035	-0,1019	-0,6338	0,584613	-0,38872	0,811162	0,185373	-0,02703	0,430635	0,426388	0,52796	-0,02067	0,62185	0,474145	1	0,862125	0,202799	0,367991	0,299233	-0,42847	-0,27901	-0,40008	-0,50686
Cafeteria	0,829378	0,837525	0,619264	0,416206	-0,15449	0,915097	0,131716	0,995649	0,657728	0,483207	-0,08604	0,825926	0,885488	0,488765	0,932924	0,854891	0,862125	1	-0,32133	0,788394	0,741454	0,088434	0,246031	0,119459	-0,00019
Mechanical and Data	-0,79556	-0,78654	-0,94253	-0,99479	-0,88596	-0,67589	-0,98104	-0,40817	-0,92466	-0,98434	0,971105	-0,79927	-0,72455	-0,9832	-0,64075	-0,76599	0,202799	-0,32133	1	-0,83588	-0,87367	-0,97167	-0,99692	-0,97857	-0,94691
Circulation	0,997565	0,996428	0,971245	0,88749	0,485986	0,969514	0,713655	0,842284	0,981929	0,919543	-0,68073	0,997975	0,98396	0,922023	0,957018	0,993146	0,367991	0,788394	-0,83588	1	0,99734	0,682481	0,790231	0,704946	0,61502
Number student Capacity(	0,989827	0,987622	0,986016	0,918721	0,548401	0,949074	0,762818	0,800751	0,993112	0,945743	-0,73231	0,990684	0,968339	0,94779	0,933331	0,981984	0,299233	0,741454	-0,87367	0,99734	1	0,733944	0,832799	0,754771	0,67086
Number student Capacity(	0,629844	0,618324	0,83687	0,942515	0,970461	0,482579	0,999052	0,180862	0,80847	0,914808	-1	0,63461	0,541149	0,912221	0,441165	0,592377	-0,42847	0,088434	-0,97167	0,682481	0,733944	1	0,987222	0,999513	0,99606
Total capacity	0,745567	0,735661	0,913406	0,983721	0,919616	0,615981	0,993223	0,335274	0,891923	0,967479	-0,98684	0,749653	0,668236	0,965851	0,578534	0,713191	-0,27901	0,246031	-0,99692	0,790231	0,832799	0,987222	1	0,991712	0,96921
Number of Academician Ca	0,653764	0,642536	0,853537	0,952479	0,962464	0,509662	0,999924	0,21145	0,826433	0,92696	-0,99944	0,658406	0,567114	0,924556	0,468941	0,617217	-0,40008	0,119459	-0,97857	0,704946	0,754771	0,999513	0,991712	1	0,99282
Number of Personel Capac	0,558527	0,546237	0,785063	0,90919	0,988024	0,403056	0,991262	0,092985	0,753128	0,875413	-0,99627	0,563619	0,464491	0,872321	0,359893	0,518643	-0,50686	-0,00019	-0,94691	0,615018	0,67086	0,996065	0,969214	0,992816	1

Table 5.7 Decision via correlation analysis

Decision of Classroom and Slope Cl.				
Variant 1	Variant 2	Value		
Classroom area	Student Number	0,747517	positive	
Total Capacity	Student Number	0,918721	positive	selected
Decision of Class lab.				
Variant 1	Variant 2	Value		
Area	Student Number	0,945743	positive	selected
Decision of Academician				
Variant 1	Variant 2	Value		
Area	Number of Acade	0,962464	positive	selected
Decision of Academician admin				
Variant 1	Variant 2	Value		
Area	Net area	0,995509	positive	selected
Standart deviation is low	Constant area + percentage			
Decision of Personel office				
Variant 1	Variant 2	Value		
Area	Net area	0,999469	positive	selected
Stadart deviation is low	Constant area + percentage			
Decision of Seminar				
Variant 1	Variant 2	Value		
Area	Classroom	0,948689	positive	selected
Decision of Personel admin				
Variant 1	Variant 2	Value		
Area	personnel	0,984357	positive	selected
Decision of Circulation				
Variant 1	Variant 2	Value		
Area	Net Area	0,996428	positive	selected
Decision of restroom				
Variant 1	Variant 2	Value		
Area	Net Area	0,445194	nearest selection	
area	Capacities	negative		problem
Decision of Cafeteria				
Variant 1	Variant 2	Value		
Area	Classroom	0,915097	positive	selected
Decision of Mechanical and Data Room				
Correlation is not found A constant number from mean is inserted				
Decision of Gross Area				
Variant 1	Variant 2	Value		
Net Area	gross area	0,999891	positive	selected

5.3.3 Calculation of Recommendations and Relational Spaces

Recommendations for spaces against user entries are calculated through assumptions made by machine learning activities. The space groups and valuable correlations are stated by machine learning activities. Besides the calculations of relational spaces are done, after the elicitation of spaces requirements through system and user. The proportional relations between items are used and calculated which shown in Table 5.8. All the results came with decimals and they are converted to integers for better perception.

Table 5.8 Calculations for relations

	Ratio	**Ratio of**
Gross Area:	1,194286418	net area
Net Area		
Gross/Net Ratio:		
Student Number planned		
Academician planned		
Classroom		
Classrom(with slope)		
Seminar Room	0,288487822	Classroom Area
Meeting Room		
Class Laboratory	0,964611958	Student Number planned
Research Laboratory		
Others(education)		
Academician Office(admin)	0,032142509	net area
Academician Office	11,99335385	Academician planned
Personnel Office (admin)	0,125588173	Personnal
Personnel Office	0,026319547	net area
Restroom	0,059795828	net area
Cafeteria	0,242974125	Classroom Area
Mechanical and Data	492	
Circulation	0,630760976	net area
Number student Capacity(classroom)		
Number student Capacity(classroom with slope)		
Total capacity	1,251113716	Student Number planned
Number of Academician Capacity		
Number of Personel Capacity		
Seminer room Capacity		

5.4 Data-Driven Requirement Elicitation System

Data-driven requirement elicitation system works with machine learning activities presented at the previous section, executed by any user and utilize the data-library implemented to. Figure 5.4 present the all the activities of machine and users, iterations, data store and data library connections. The working steps of the system is presented at the below;

Pre-Iteration:

User Activity: building definition and typology selection

Machine Computing Activity: rank classification, descriptive analysis of spaces (k-means clustering) within the data library

Output: Requirement template with division ratio recommendation

1st-Iteration:

User Activity: entry of primary spaces

Machine Computing Activity in Iteration: calculation of division ratio’s (entry)

Machine Computing Activity after Iteration: correlation analysis and calculations of space relation

Output: recommendation for primary spaces

2nd-Iteration:

User Activity: change in primary spaces

Machine Computing Activity in Iteration: calculation of primary spaces situations against recommendation

Output: decided primary spaces

3rd-Iteration:

User Activity: entry of additional spaces

Machine Computing Activity after Iteration: calculation of relational spaces with correlation analysis

Output: results with relational spaces recommendation

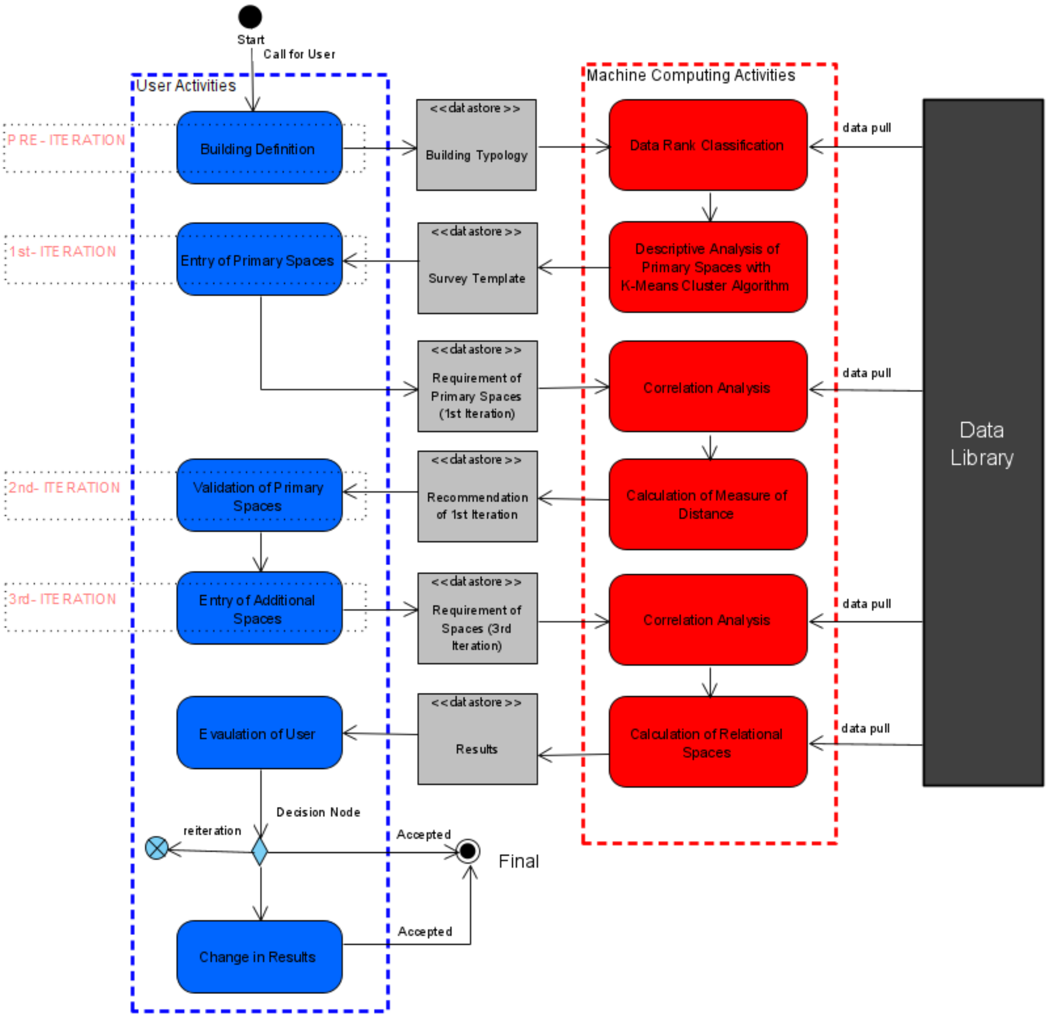


Figure 5.4. Data-driven requirement elicitation system

The user of the system could use the system forward and then go back any iteration to examine requirement decisions, recommendation and results to create different scenarios for comparison. Also, the requirement objectives coming from planned users of the building could be inserted to the system for evaluation. The system does not propose a ruled validation activity for requirements. However, it develops thought on validation with recommendations, calculations of relational spaces and analysis of different scenarios. As stated in the previous chapter, the results of the system could be used for further processes, designer refinement, project studies and transferred into BIM rules for automated rule checking for spaces.

5.4.1 Pre-Iteration- Building Definition and Typology Selection

Pre-iteration defined the user activities for building definition and typology selection, machine learning activities related to user's selection. The machine learning activities: rank classification and descriptive space analysis via k-means clustering algorithm are presented at the previous sections. The interface of this iteration is shown in Figure 5.5

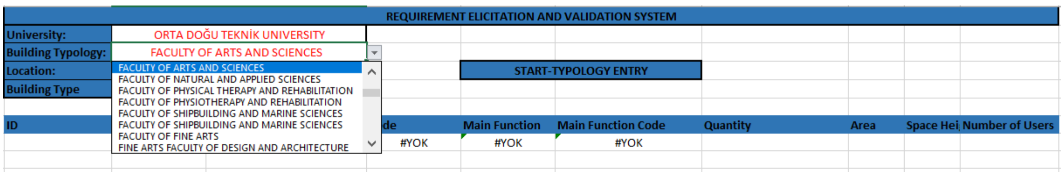


Figure 5.5. Interface of pre-iteration.

5.4.2 1st Iteration-Primary Spaces

Figure 5.6 shows the interface of the 1st iteration in which the recommended space clusters and ratios within the cluster are presented. This knowledge is captured from the data-library due to user building typology section via machine learning activities as explored in the previous sections. An example of randomly user entries is given

Figure 5.7 in order to explain feature of the system better. Light blue parts are the user entry sections for quantities that is connected to machine calculations. Planned student number and academician number should be entered definitely, since these values are vital role for the system calculations. The system prompts an explanation to users for sections for each entry. The clusters of the spaces with area and number of users' recommendation are given. It is also possible to revise the recommended area and number of user's value according to system user preferences, and not use any space group for entries. As can be seen from the interface, there is no space recommendation for some primary spaces like seminar room or research laboratory, since the machine learning activities could not find any descriptive relational over them. The system uses the space tags from the YMESS and it can be added further space explanation in unformal language by users. The space codes, main function part and codes are automatically updated from the space tags ontology whether any entry is made for any of them. New rows representing spaces could be added by users to figure out their requirement definition projects. The recommended ratio's and entry ratio's will be calculated due to space tags and presented to user dynamically. Recommended ratios are coming from the knowledge captured from the data-library as presented before. The users of the system are expected to examine these recommendations against the ratios of their entries to maintain more rational requirement entries. Although they are directed via these activities, it is free to create requirements by using space tags ontology of data-library. In Figure 5.7, the entries of the users and entry ratios are coloured in red for better understanding. For example, the classroom with slope cluster ($275m^2$-175person) has entry of zero. The recommended ratio within the cluster is 4.17% and ratio of entry is 0.00%. User could see and track these dynamic results of calculations and change, revise their requirement entries. The outcomes of 1^{st} iteration are transferred to 2^{nd} iteration. They are connected between iterations; thus, any change and revision could be done by user by considering the situation of requirement in any phase.

REQUIREMENT ELICITATION AND VALIDATION SYSTEM

University:	ORTA DOĞU TEKNİK UNIVERSITY	Student Number	
Building Typology:	FACULTY OF ARTS AND SCIENCES	Academician Number	
Location:	Ankara		
Building Type	New Building		

1st ITERATION-PRIMARY SPACES

Space Function	Space Code	Main Function	Main Function Code	Explanation	Quantity	Area	Number of Users	Recommended Ratio	Entry Ratio
Classroom	ED	Education	E			115	100	9,43%	
Classroom	ED	Education	E			75	50	22,64%	
Classroom	ED	Education	E			65	50	10,38%	
Classroom	ED	Education	E			75	65	7,55%	
Classroom(with slope)	EA	Education	E			90	75	12,50%	
Classroom(with slope)	EA	Education	E			195	155	14,58%	
Classroom(with slope)	EA	Education	E			275	275	4,17%	
Class Laboratory	EL	Education	E			80	55	25,00%	
Class Laboratory	EL	Education	E			100	45	29,17%	
Class Laboratory	EL	Education	E			55	40	8,33%	
Class Laboratory	EL	Education	E			85	35	37,50%	
Academician Office	MA	Administrative	M			10	1	16,67%	
Academician Office	MA	Administrative	M			15	2	28,70%	
Academician Office	MA	Administrative	M			50	8	8,33%	
Academician Office	MA	Administrative	M			25	3	25,00%	
Academician Office	MA	Administrative	M			10	2	21,30%	
Academician Office(admin	MY	Administrative	M			55	1	28,95%	
Academician Office(admin	MY	Administrative	M			25	1	57,89%	
Academician Office(admin	MY	Administrative	M			35	1	13,16%	
Personnel Office	MI	Administrative	M			25	3	33,33%	
Personnel Office	MI	Administrative	M			15	2	44,44%	
Personnel Office	MI	Administrative	M			50	5	22,22%	
Seminar Room	ES	Education	E			0			
Research Laboratory	RM	Research	R						
Others(education)	EX	Education	E	computer					
Personnel Office (admin)	MP	Administrative	M						

Figure 5.6. Interface of 1st iteration (blank)

REQUIREMENT ELICITATION AND VALIDATION SYSTEM

University:	ORTA DOĞU TEKNİK UNIVERSITY	Student Number	1000
Building Typology:	FACULTY OF ARTS AND SCIENCES	Academician Number	90
Location:	Ankara		
Building Type	New Building		

1st ITERATION-PRIMARY SPACES

Space Function	Space Code	Main Function	Main Function Code	Explanation	Quantity	Area	Number of Users	Recommended Ratio	Entry Ratio
Classroom	ED	Education	E		3	115	100	9,43%	8,82%
Classroom	ED	Education	E		2	75	50	22,64%	5,88%
Classroom	ED	Education	E		5	65	50	10,38%	14,71%
Classroom	ED	Education	E		7	75	65	7,55%	20,59%
Classroom(with slope)	EA	Education	E		0	90	75	12,50%	0,00%
Classroom(with slope)	EA	Education	E		4	195	155	14,58%	11,76%
Classroom(with slope)	EA	Education	E		0	275	275	4,17%	0,00%
Class Laboratory	EL	Education	E		5	80	55	25,00%	35,71%
Class Laboratory	EL	Education	E		3	100	45	29,17%	21,43%
Class Laboratory	EL	Education	E		2	55	40	8,33%	14,29%
Class Laboratory	EL	Education	E		4	85	35	37,50%	28,57%
Academician Office	MA	Administrative	M		10	10	1	16,67%	30,30%
Academician Office	MA	Administrative	M		15	15	2	28,70%	45,45%
Academician Office	MA	Administrative	M		5	50	8	8,33%	15,15%
Academician Office	MA	Administrative	M		3	25	3	25,00%	9,09%
Academician Office	MA	Administrative	M		0	10	2	21,30%	0,00%
Academician Office(admin	MY	Administrative	M		1	55	1	28,95%	9,09%
Academician Office(admin	MY	Administrative	M		8	25	1	57,89%	72,73%
Academician Office(admin	MY	Administrative	M		2	35	1	13,16%	18,18%
Personnel Office	MI	Administrative	M		2	25	3	33,33%	22,22%
Personnel Office	MI	Administrative	M		3	15	2	44,44%	33,33%
Personnel Office	MI	Administrative	M		4	50	5	22,22%	44,44%
Seminar Room	ES	Education	E		2	0	20		
Research Laboratory	RM	Research	R		5	50			
Others(education)	EX	Education	E	computer	2	100			
Personnel Office (admin)	MP	Administrative	M		2	25			

Figure 5.7. Interface of 1st iteration

5.4.3 2nd Iteration-Primary Spaces Validation

In this iteration, the system presents to the user recommendations and measure of distances due to their entries. The values for these calculations are originated from the knowledge captured via machine learning activities over data-library. Figure 5.8 presents the interface of 2nd iterations in which the recommendations due to space groups inserted and entry parts coloured in light blue explained. As stated, it is possible to change recommended area and number users per space cluster.

The recommendations over range are originated to pairwise correlation and calculation and relational value from data-library. For this running system, the values for measurement of distance are decided as; 0%-10% in range, 10%-20% nearly range, more than 20% out of range with both positive and negative direction. This system arrangement could be changed by administrator according to facts of studies. For a point of view, these recommendations reflect the trends and patterns of completed building under the processes building typology. Thus, it offers a comparison and argument medium for the user while creating the requirement of the new building in the same typology. User can examine the recommendations due to primary spaces entries, change the entries and see the update on values of distance and validate the primary space requirements by revising them. It is also possible to go backwards to 1st iteration, or come back again on 2nd iterations after executing the next iterations. The iteration is called as primary space validation although they can be revised after, since the additional spaces are asked to user and then relational spaces are calculated due to these spaces.

REQUIREMENT ELICITATION AND VALIDATION SYSTEM

University:	ORTA DOĞU TEKNİK UNIVERSITY	Student Number	1000
Building Typology:	FACULTY OF ARTS AND SCIENCES	Academician Number	90
Location:	Ankara		
Building Type	New Building		

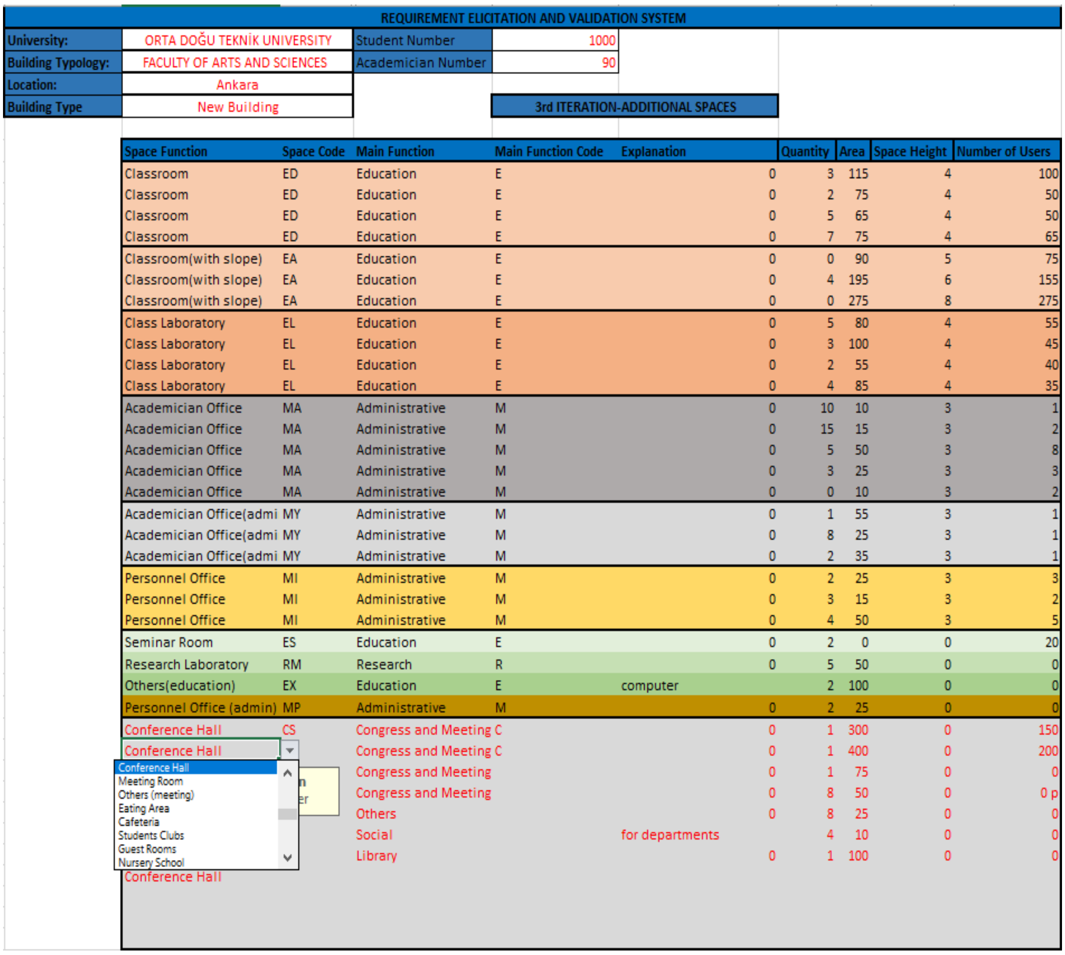
2nd ITERATION-PRIMARY SPACES' VALIDATION

Space Function	Space Code	Main Function	Main Function Code	Explanation	Quantity	Area	Space Height	Number of Users	Measure of Distance	Recommendation
Classroom	ED	Education	E	0	3	115	4	100		
Classroom	ED	Education	E	0	2	75	4	50		
Classroom	ED	Education	E	0	5	65	4	50		
Classroom	ED	Education	E	0	7	75	4	65		
Classroom(with slope)	EA	Education	E	0	0	90	5	75		
Classroom(with slope)	EA	Education	E	0	4	195	6	155		
Classroom(with slope)	EA	Education	E	0	0	275	8	275	128,06%	Out of Range, Decrease
Class Laboratory	EL	Education	E	0	5	80	4	55		
Class Laboratory	EL	Education	E	0	3	100	4	45		
Class Laboratory	EL	Education	E	0	2	55	4	40		
Class Laboratory	EL	Education	E	0	4	85	4	35	19,22%	Nearly Range, Decrease
Academician Office	MA	Administrative	M	0	10	10	3	1		
Academician Office	MA	Administrative	M	0	15	15	3	2		
Academician Office	MA	Administrative	M	0	5	50	3	8		
Academician Office	MA	Administrative	M	0	3	25	3	3		
Academician Office	MA	Administrative	M	0	0	10	3	2	-39,78%	Out out Range, Increase
Academician Office(admin	MY	Administrative	M	0	1	55	3	1		
Academician Office(admin	MY	Administrative	M	0	8	25	3	1		
Academician Office(admin	MY	Administrative	M	0	2	35	3	1	5,79%	In Range, May Decrease
Personnel Office	MI	Administrative	M	0	2	25	3	3		
Personnel Office	MI	Administrative	M	0	3	15	3	2		
Personnel Office	MI	Administrative	M	0	4	50	3	5	22,15%	Out of Range, Decrease
Seminar Room	ES	Education	E	0	2	0	0	20	-100,00%	Out out Range, Increase
Research Laboratory	RM	Research	R	0	5	50	0	0		
Others(education)	EX	Education	E	computer	2	100	0	0		
Personnel Office (admin)	MP	Administrative	M	0	2	25	0	0	-25,90%	Out out Range, Increase

Figure 5.8. Interface of 2nd iteration

5.4.4 3rd Iteration-Additional Spaces

Figure 5.9 shows the interface of 3rd iteration which for entering the additional spaces. The user can add and define space due to space tags from the YMESS.



REQUIREMENT ELICITATION AND VALIDATION SYSTEM

University:	ORTA DOĞU TEKNİK UNIVERSITY	Student Number	1000
Building Typology:	FACULTY OF ARTS AND SCIENCES	Academician Number	90
Location:	Ankara		
Building Type	New Building		

3rd ITERATION-ADDITIONAL SPACES

Space Function	Space Code	Main Function	Main Function Code	Explanation		Quantity	Area	Space Height	Number of Users
Classroom	ED	Education	E		0	3	115	4	100
Classroom	ED	Education	E		0	2	75	4	50
Classroom	ED	Education	E		0	5	65	4	50
Classroom	ED	Education	E		0	7	75	4	65
Classroom(with slope)	EA	Education	E		0	0	90	5	75
Classroom(with slope)	EA	Education	E		0	4	195	6	155
Classroom(with slope)	EA	Education	E		0	0	275	8	275
Class Laboratory	EL	Education	E		0	5	80	4	55
Class Laboratory	EL	Education	E		0	3	100	4	45
Class Laboratory	EL	Education	E		0	2	55	4	40
Class Laboratory	EL	Education	E		0	4	85	4	35
Academician Office	MA	Administrative	M		0	10	10	3	1
Academician Office	MA	Administrative	M		0	15	15	3	2
Academician Office	MA	Administrative	M		0	5	50	3	8
Academician Office	MA	Administrative	M		0	3	25	3	3
Academician Office	MA	Administrative	M		0	0	10	3	2
Academician Office(admi	MY	Administrative	M		0	1	55	3	1
Academician Office(admi	MY	Administrative	M		0	8	25	3	1
Academician Office(admi	MY	Administrative	M		0	2	35	3	1
Personnel Office	MI	Administrative	M		0	2	25	3	3
Personnel Office	MI	Administrative	M		0	3	15	3	2
Personnel Office	MI	Administrative	M		0	4	50	3	5
Seminar Room	ES	Education	E		0	2	0	0	20
Research Laboratory	RM	Research	R		0	5	50	0	0
Others(education)	EX	Education	E	computer		2	100	0	0
Personnel Office (admin)	MP	Administrative	M		0	2	25	0	0
Conference Hall	CS	Congress and Meeting C			0	1	300	0	150
Conference Hall		Congress and Meeting C			0	1	400	0	200
		Congress and Meeting			0	1	75	0	0
		Congress and Meeting			0	8	50	0	0 p
		Others			0	8	25	0	0
		Social		for departments		4	10	0	0
		Library			0	1	100	0	0
Conference Hall									

Figure 5.9. Interface of 3rd iteration

5.4.5 Results and Relational Spaces

At the end of the execution of all iterations, relational spaces and calculations of gross are, net area, total student seat and total academician seat are presented to the user. These results are dynamically updated from the system, if the user goes backwards and do any iterations. Also, it is possible to revise the relational spaces due to user's choices or approaches. Relational spaces are calculated due to proportional relations. As it is presented earlies, the decisions on relations are made by machine via pairwise correlation analysis over the data-library. Gross area is calculated according to net area by using mean of gross/net area ratios of building typology in the data-library. The spaces which are resulting from the legislations and design choices cannot be calculated, thus a prompt is given for these space group as they should be added by user. If there is a space tag for this space is exited in the data-library, machine learning activities could have found the relation to any items and propose some value.

As stated earlier, these results of the system could be used and completed via some processes with the involvement of client and designer for refinement, improvement in detail level for project studies. Requirement of any project is not a fixed document; it should be dynamic and developing knowledge throughout the project stages. However, the system makes possible to figure out main framework of requirement by capturing the knowledge from data library via machine learning activities. The systematic approach to spaces including space tags and values make possible both to execute activities in the system and to convert and transfer the knowledge easily to BIM environment for automated rule checking over requirements.

REQUIREMENT ELICITATION AND VALIDATION SYSTEM					
University:	ORTA DOĞU TEKNİK UNIVERSITY	Student Number	1000	Gross Area	15621,41954
Building Typology:	FACULTY OF ARTS AND SCIENCES	Academician Number	90	Net Area	13080,13 m^2
Location:	Ankara			Total Student Seat	1725 p
Building Type	New Building		RESULTS	Total Academic Seat	89 p

Space Function	Space Code	Code	Main Function	Code	Explanation	Quantity	Area	Space Heigh	Number of Users
Classroom	ED	ED-#-#	Education	E		3	115 m^2	4	100
Classroom	ED	ED-#-#	Education	E		2	75 m^2	4	50
Classroom	ED	ED-#-#	Education	E		5	65 m^2	4	50
Classroom	ED	ED-#-#	Education	E		7	75 m^2	4	65
Classroom(with slope)	EA	EA-#-#	Education	E		0	90 m^2	5	75
Classroom(with slope)	EA	EA-#-#	Education	E		4	195 m^2	6	155
Classroom(with slope)	EA	EA-#-#	Education	E		0	275 m^2	8	275
Class Laboratory	EL	EL-#-#	Education	E		5	80 m^2	4	55
Class Laboratory	EL	EL-#-#	Education	E		3	100 m^2	4	45
Class Laboratory	EL	EL-#-#	Education	E		2	55 m^2	4	40
Class Laboratory	EL	EL-#-#	Education	E		4	85 m^2	4	35
Academician Office	MA	MA-#-#	Administrative	M		10	10 m^2	3	1
Academician Office	MA	MA-#-#	Administrative	M		15	15 m^2	3	2
Academician Office	MA	MA-#-#	Administrative	M		5	50 m^2	3	8
Academician Office	MA	MA-#-#	Administrative	M		3	25 m^2	3	3
Academician Office	MA	MA-#-#	Administrative	M		0	10 m^2	3	2
Academician Office(admin	MY	MY-#-#	Administrative	M		1	55 m^2	3	1
Academician Office(admin	MY	MY-#-#	Administrative	M		8	25 m^2	3	1
Academician Office(admin	MY	MY-#-#	Administrative	M		2	35 m^2	3	1
Personnel Office	MI	MI-#-#	Administrative	M		2	25 m^2	3	3
Personnel Office	MI	MI-#-#	Administrative	M		3	15 m^2	3	2
Personnel Office	MI	MI-#-#	Administrative	M		4	50 m^2	3	5
Seminar Room	ES	ES-#-#	Education	E		2	m^2	0	20
Research Laboratory	RM	RM-#-#	Research	R		5	50 m^2	0	0
Others(education)	EX	EX-#-#	Education	E	computer	2	100 m^2	0	0
Personnel Office (admin)	MP	MP-#-#	Administrative	M	0	2	25 m^2	0	0
Conference Hall	CS	CS-#-#	Congress and Meeting	C		1	300 m^2	0	150
Conference Hall						1	400 m^2	0	200
Meeting Room						1	75 m^2	0	0
Meeting Room						8	50 m^2	0	0
Archive						8	25 m^2	0	0
Cafeteria					for departments	4	10 m^2	0	0
Working Space(silent)						1	100 m^2	0	0
Data Room	OC	OC-#-#	Others	O			492 m^2		
Mechanical Room	OT	OT-#-#	Others	O					
Cafeteria	GK	GK-#-#	Social	G			516 m^2		
Restroom	OW	OW-#-#	Others	O			453 m^2		
Circulation	OS	OS-#-#	Others	O			5.059 m^2		
Spaces resulting from regulations and legislation in the region should be added.									

Figure 5.10. Interface of results

5.5 Limitations of the Running System

In this section, the limitations of running proposed system are explored. Limitation of the research is conducted at the conclusion chapter. The limitations stated are:

- Data library is composed of three completed building cases of one building typology, there is no connection to MEKSİS data library
- The space tags and features are used from YMESS

- The system is planned to work in automated and unsupervised version. The running system is trial version, so activity connections are done manually with sustaining the unsupervised activity' conditions.
- Space and technology change due time is ignored
- Occupancy and satisfaction evaluation of space is not existed
- Records of iterations and logs of session are taken manually

5.6 Possible Expansions' Remarks

The possible expansions and improvement areas are thought to be stated after the test and validation of the system via expert case studies. In this section some remarks about the expansions are explored which are also searched and examined during the development of the system. System can be expanded and developed by some other approaches and improvements. Various statistical calculations or machine learning algorithm can be added and implemented to the system, by some examination on different and expanded data library sets. Instead of pairwise correlations, analysis over more dependent and independent values may be developed over the system. For another example; frequencies or distributions of spaces with the interrelation of other building typologies may be studies for seeking some general statements over relational spaces. Quantitative limits or ranges of spaces may be inserted to the system according released specifications and standards of building typologies.

Requirement elicitation system can work online by cloud with implementation of connection on online data-library connection and user interface attachment. The knowledge created via iterations in the system has contribution to data-library after approval and completion of the building. With the integration of BIM rule converting and transferring feature, the results of process can be used for automated rule checking of spaces over designed projects. These expansions could be possible to integrate system, since the belonging data of all processes computed in a ruled framework and space ontology.

CHAPTER 6

TESTING AND VALIDATION

In this chapter, the testing and validation of the developed data-driven dynamic requirement elicitation system is explained in detail. In the first section, the material and method used for the process are elaborated, and in the second section the case studies and results gathered through procedure are presented.

6.1 Material and Method

Seven separate case studies and evaluation of experts for the testing and validation of the proposed system were held. Information about the experts, sessions, cases and evaluation method are presented with the description of procedure.

6.1.1 Information about the Experts

The proposed system is presenting a guidance and method for the users who are to works on requirements before the designer assignment. It is thought that the system may have outcomes for designers to evaluate, track and compare their studies throughout the project process by requirements quantitative data and relations. However, as stated at the previous chapters, the potential user group is consisted of individuals that are assigned to figure out requirement of the building and create main body of architectural programme. Thus, the experts from public officers whose work experience are directly related to this situation and data library typology are selected. Seven experts from diverse public universities of Turkey approve the case study work and evaluation after execution of process. All are engineers or architects from different 'Directorate of Construction and Technical Works Departments' of various universities, various cities. They have work experience from 8-25 years, and work as project controller, construction controller and project engineer/architect of small size/renovation project.

6.1.2 Information about the Sessions

The sessions were held through online meeting. They are informed about the system and session. The interface of system is controlled by the author for preventing confliction or misunderstanding. However, author did not have any comments and entries during the session and it is stated clearly at the beginning. Table 6.1 shows the date and duration of the sessions.

Table 6.1 Information about the sessions

	ID	Date	Duration (m)
Expert	1	16.May 2022	80
Expert	2	18.May 2022	45
Expert	3	18.May 2022	70
Expert	4	20.May 2022	50
Expert	5	20.May 2022	50
Expert	6	23.May 2022	45
Expert	7	23.May 2022	40

6.1.3 Description of the Case Study

Case study topic and features are selected related to data library building typology. All experts were informed to execute requirement elicitation system for a given building objective shown in Table 6.2. The undergraduate student number and distributed number of academicians are selected from a sample of same building typology from YÖK reports (YÖK, 2022). Experts were expected to elicit requirements of selected typology through proposed system with given qualitative objectives and considering their university location and condition.

Table 6.2 Case study information

Case Assumptions		Academic Staff Planned	
University	**Expert Case**	Prof.	15
Year	New	Assoc. Prof.	25
Building Typology	Faculty of Art and Science	Asst. Prof.	30
Location:	**Expert Case**	Instructor	5
Department Number	8	Research Assistant	25
Undergraduate Student Planned	1250	Total:	100

6.1.4 Procedure and Method

Delphi technique is outcome of the "Project Delphi" which was an Air Force sponsored Rand Corporation study in USA (Dalkey & Helmer, 1963a). It is used to present and future scenarios focused on specific issues with the help of experts (Renzi & Freitas, 2015). Technique is widely used and accepted method since 1960s to gather data from domain of expertise to evaluate, create or validate the knowledge from different experience and points of view by building a common scenario (Renzi & Freitas, 2015; Şahin, 2001; Turoff & Linstone, 2002). The strengths of Delphi technique are to allow for creating opinions from participants against research problem, link together existing knowledge and areas of agreement, not to demand proximity or face to face meeting, reduces effect of noise in communication, take feedback from individuals and evaluate them by experts of groups (Fink-Hafner, Dagen, Dousak, Novak, & Hafner-Fink, 2019). Delphi steps are; (1) define the problems or research questions, (2) identify and invite experts, (3) capture the comments to solicit ideas, (4) organize them and take rates from same group and (5) re-rate ideas from same group by presenting rank results of previous iteration. The rating procedure rounds are decided to group reaction on gathered knowledge. At least round 3 is needed, however more rounds is also applicable according research problem (Şahin, 2001). Important necessities of process are stated as; experts should be agreed to complete process, the results and identities of individuals should not be shared to express thought freely, all ideas should be organized and presented after capturing from at round 1 for objectivity and the descriptive statistical results of previous round should be presented by explanation to experts (Dalkey & Helmer, 1963b; Fink-Hafner et al., 2019; Okoli & Pawlowski, 2004; Şahin, 2001).

Delphi steps for this research is figured out at Figure 6.1. The objective of procedure is to evaluate the proposed system by experts with the usage experience on requirement elicitation, as it is definition of the problem. Seven experts as presented at the previous section were invited to execute process. They were informed about the case study, research objective and testing procedure at the start of the process. All steps were executed individually without knowing each other. After the case study execution, first the results of requirement elicitation process are recorded. Secondly, the unstructured interviews were handled with all experts. Five main questions were asked them to increase communication value; general comments on usage, comments and thoughts on recommendation property of system, possible benefits or problems on practice, properties and deficiencies to be improved and comments on developments. Also, they were asked to state thoughts of any kind about the research and proposed system. Then, the ideas and comments were listed and organized under the sub-groups and sent to experts to collect rates on items. The response scale is organized in likert scale which is commonly used in questionnaires between 1-7 (1-definitely disagree, 2- disagree, 3- partial disagree, 4-indecisive, 5- partial agree, 6- agree, 7- definitely agree). The collected responds were examined through statistical calculations commonly used for descriptive evaluation in Delphi technique. Median (MD) is value that shows average of responses, quarter 1(Q1) is value that takes the 25% of responses at the left and 75% of responses, quarter 3(Q3) is value that takes the 75% of responses at the left and 25% of responses the right, and range (R) is the distance between quarters (Şahin, 2001). Smaller range value shows the consensus of respondents on objected items, higher values of range show the opposite.

At the last round, experts were informed about the common results of rates including the explanation about MD, Q1, Q3 and R. They were asked to examine the results and do revision on their previous rating if they want. Three rounds are decided to be adequate for this research, however the possibility of other rounds stands if revision of rating is high.

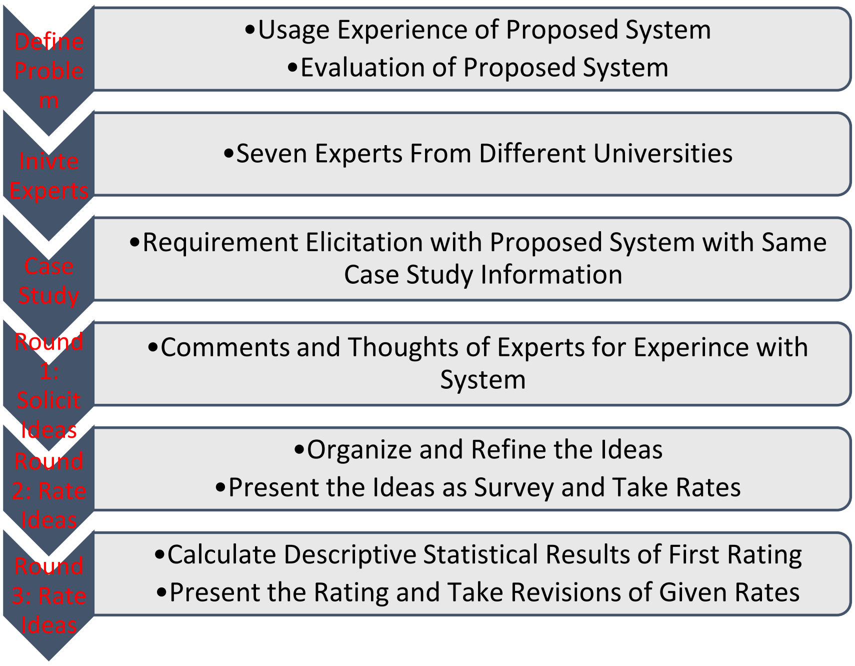


Figure 6.1. Testing procedure of research via Delphi technique

6.2 Case Studies

The case studies were held online by experts between 16.05.2022 and 23.05.2022, and all iterations were executed and recorded. The first round including the interview to solicit ideas were made after the case study at same dates.

6.2.1 Results of Requirement Elicitation

The results of the requirements due to experts are presented at the appendices. The brief result for objected building is explored in Table 6.3. Exploring the requirement results for experts' case studies, it is seen there are differences between quantities of spaces, although the instructed case study information is same. The reason of this situation is originated from varying space organization thoughts due to experience and managers approach on buildings. This issue is discussed with experts independent from the testing procedure. As an example; there is absence of classroom with slope for Expert 4. Expert 4 stated that actual board of university has a decision of using flat classroom for education and organizing additional conference room for high occupation. Thus, in the requirement session expert decided to use the flat classroom and examine the recommendation coming from the total capacity of educational areas. Another example is about the research laboratory. Expert 4 and 7 stated that theses spaces should be organized in the different building for research purpose, so they eliminated them. Expert 3 offers 2835 m² of additional spaces including meeting room, conference room and eating area which are more than other experts. He stated that the building needs these spaces and better way is to add these requirements and see the results. He also asked 'If the result is not good, can I go back to related iteration to revise?'. This is an important comment on the opportunity of the proposed system. The iterations can be executed in many times to evaluate the results for getting more optimum requirements considering conditions of objected case. The different scenarios can be studies in shorter time and it is possible to see the outcomes of requirements which is presenting total quantities of building. It is so important for this building typology of public investment, since the budget of construction is crucial for decisions on space requirements.

It can be seen from results table and appendices in detail there are more or less numbers of academician seat, although the planned number is 100. Some experts thought possible expansion, some planned the rooms bigger in area, less in seat to increase capacity after completion if needed. The approach of experts differs according to their experience and vision of their institutions. It can be stated that system gives opportunity to users to reflect their thought on space resulting from background within a ruled framework.

Table 6.3 Results of case studies

Space-Item	Expert Case 1	Expert Case 2	Expert Case 3	Expert Case 4	Expert Case 5	Expert Case 6	Expert Case 7
Registered-Planned Student	1250 p	1250 p	1250 p	1250 p	1250 p	1250 p	1250 p
Registered-Planned Acedemician	100 p	100 p	100 p	100 p	100 p	100 p	100 p
Total Student Seat	1370 p	1170 p	1335 p	1190 p	1490 p	1625 p	1545 p
Total Academic Seat	120 p	140 p	110 p	75 p	95 p	125 p	101 p
Net Area:	12.068 m^2	15.207 m^2	13.887 m^2	9.468 m^2	13.460 m^2	12.693 m^2	13.892 m^2
Gross Area:	14.412 m^2	18.162 m^2	16.585 m^2	11.307 m^2	16.075 m^2	15.159 m^2	16.591 m^2
Classroom	454 m^2	775 m^2	1.240 m^2	1.570 m^2	1.040 m^2	890 m^2	900 m^2
Classrom(with slope)	1.215 m^2	675 m^2	585 m^2	m^2	755 m^2	1.055 m^2	825 m^2
Class Laboratory	1.030 m^2	880 m^2	1.040 m^2	730 m^2	1.160 m^2	700 m^2	1.200 m^2
Academician Office	910 m^2	1.175 m^2	1.345 m^2	1.125 m^2	1.275 m^2	1.850 m^2	1.450 m^2
Academician Office(admin)	325 m^2	160 m^2	100 m^2	335 m^2	365 m^2	360 m^2	360 m^2
Personnel Office	380 m^2	335 m^2	290 m^2	105 m^2	280 m^2	250 m^2	195 m^2
Seminar Room	440 m^2	375 m^2	330 m^2	340 m^2	440 m^2	45 m^2	540 m^2
Research Laboratory	100 m^2	240 m^2	210 m^2	m^2	100 m^2	m^2	450 m^2
Others(education)	300 m^2	480 m^2	420 m^2	m^2	100 m^2	100 m^2	150 m^2
Personnel Office (admin)	50 m^2	25 m^2	25 m^2	25 m^2	25 m^2	25 m^2	35 m^2
Additional Spaces Total	880 m^2	2.835 m^2	1.515 m^2	375 m^2	1.320 m^2	1.105 m^2	1.022 m^2
Mechanical and Data	492 m^2	492 m^2	492 m^2	492 m^2	492 m^2	492 m^2	492 m^2
Cafeteria	406 m^2	352 m^2	443 m^2	381 m^2	436 m^2	473 m^2	419 m^2
Restroom	418 m^2	526 m^2	480 m^2	328 m^2	466 m^2	439 m^2	481 m^2
Circulation	4.668 m^2	5.882 m^2	5.372 m^2	3.662 m^2	5.206 m^2	4.910 m^2	5.373 m^2

6.2.2 Experts Evaluation

The testing procedure includes round 1 to solicit ideas, round 2 to rate and round 3 to re-rate for validating the consensus of ideas. As it is stated in the previous sections, procedure of Delphi technique is executed. The results and discussion are explored in the sub sections due to groups. All results are in number showing agreement degree in likert scale:

[1-definitely disagree], [2-disagree], [3-partial disagree], [4-indecisive],

[5-partial agree], [6-agree], [7-definitely agree].

Round 2 and round 3 were held between 27.05.2022 and 13.05.2022 and details of rounds are presented in Table 6.4.

Table 6.4 Round details

		2nd round		3rd round	
	ID	submission	date	submission	date
Expert	1	x	30 May 2022	same	2 June 2022
Expert	2	x	27 May 2022	same	2 June 2022
Expert	3	x	1 June 2022	Revision	13 June 2022
Expert	4	x	31 May 2022	Revision	3 June 2022
Expert	5	x	30 May 2022	Revision	2 June 2022
Expert	6	x	27 May 2022	same	2 June 2022
Expert	7	x	1 June 2022	Revision	9 June 2022

6.2.2.1 General Usage

The statements and results under the general usage group are presented at Table 6.5. From 1.1 and 1.2 items, it is seen that the system is stated as useful and beneficial for requirement elicitation via space opportunity property, since the needed spaces of all building typology cannot be known by users. The knowledge about spaces is coming from experience or documents, however the system offers space types which is captured from machine learning activities on data-library of completed buildings.

The results are seen as coherent with standards and their experience which also give opportunity the examine the building at the final. The system gives (1.6) optimized results for space dimension and student numbers that can be used for defining space parameters. Item 1.7, beside duration of session shows that the time and workload needed for requirement elicitation is dramatically decreased. It gives opportunity to users to examine and compare different scenarios to reach optimum results. It is understood from item 1.5 that there is positive thought of removing the project stakeholders from the requirement elicitation resulted decreased workload and time, however there is no consensus of this statement. Some expert(s)' opinion is that involvement of project stakeholders to process should be maintained somehow.

Table 6.5 Results of general usage

ID	Statement	Md	Q1	Q3	R
1.1	Space opportunity template is very important. The needed spaces of building type are not known	6	6	7	1
1.2	Useful and beneficial for requirement elicitation	7	6	7	1
1.3	The results are coherent with standards and experience	6	6	7	1
1.4	The results at the final are valuable to examine the building	7	6	7	1
1.5	Collecting and understanding the knowledge from project stakeholders are removed from the process. It gives advantages in time, workload and accuracy	7	3	7	4
1.6	It gives optimized results considering space dimension, student number and investment trends	6	6	7	1
1.7	Time and workload of requirement elicitation is dramatically decreased	7	6	7	1

6.2.2.2 Recommendation Property

The statements and results under the recommendation property group are presented at Table 6.6. Content of the recommendations was found logical and dynamic update of the recommendation against users' input was beneficial. There is a constant consensus on dynamic update of recommendation and opportunity to review and revise entries by examining recommendations. These comments are very crucial to evaluate the methodology that make inferences from data library by machine learning activities. There are two important comments on recommendation parts; one is to relate recommendation with region and other is to related them with land issues and estimated budget. The system's computations on data-library can be activated due to region of building, since MEKSİS entries inquire location, and budget can be related to recommendation with the approved and accepted budget estimations. However, land issues hard to implement, because they are more related to designer contribution on requirements and project. There is a statement about coherency of academician office recommendation, that shows cases of data-library do not reflect of approaches of experts well.

Table 6.6 Results of recommendation property

ID	Statement	Md	Q1	Q3	R
2.1	Dynamic update of recommendation is beneficial	7	7	7	0
2.2	Recommendations are logical	7	6	7	1
2.3	Recommendations give opportunity to review and revise the entries	7	7	7	0
2.4	Recommendation may be calculated due to selected region	7	5	7	2
2.5	Recommendation may be calculated due to land issues and estimated budget	6	6	6	0
2.6	Academician admin office recommendation should be examined	5	5	6	1

6.2.2.3 Benefits on Practice

The statements and results under the benefits on practice group are presented at Table 6.7. It is important to evaluate benefits on practice of proposed system. Items 3.1, 3.2 and 3.3 shows the important role system over managing the knowledge of other project stakeholders like users or decision makers. First, it gives opportunity to examine and evaluate requirements which prepared by individual with other session and procedures. Since the time and workload are low, needs and objectives coming from outside can be imported in the system and evaluated. Secondly, the requirements coming from users who are not experienced in practice can be computed and the results can be verification base with the acceptance of the system. Experts stated that one of the important problems is to tell to users or decision makers causes and reasons of accepting and refusing the wished. Since they are unexperienced in architectural programming and spaces, system may be used validation. Router feature and self-control mechanism are stated as other benefits of the system. For the users who have knowledge on spaces and need space groups for any building typology can handle the requirement elicitation process with recommendations and ruled framework of proposed system.

Table 6.7 Results of benefits on practice

ID	Statement	Md	Q1	Q3	R
3.1	The results and computations give opportunity to evaluate requirements came from possible users	7	6	7	1
3.2	It can be possible to examine numbers of opportunities in a short time	7	6	7	1
3.3	System presents a statement to explain reasons of requirements to inexperienced project stakeholders	7	6	7	1
3.4	System offers a self-control mechanism to user	7	6	7	1
3.5	System directs to user who has no knowledge on spaces	7	6	7	1

6.2.2.4 Properties to Be Improved

The statements and results under the benefits on practice group are presented at Table 6.8. Generally, it can be seen from the values of range(R), the consensus level on items is lower than previous group. It underlines that the improvement areas are more related to experts' own situation of studies. However, they should be examined and evaluated for the research contribution. Indoor car parking is recommended to improved. Reason of the ignorance in the system is to be directly related to decision of authority, not to have relational correlation between closed space in university campuses. Generally, car parking is sustained in open car parking areas. Detailed name tags for spaces, especially for office spaces with re- examination was stated. It is crucial property to be improved, however space tags are directly related to data-library space ontology. In the present database, subdivision of office space due to roles of personnel is not recorded. By more detailed data-library, it can be improved and added within the context of methodology. Requirements may change according to time and region; it is also stated by experts. However, the system captured the knowledge from actual completed building data-base. Change of requirement due to time or region can be only implemented to the system by update of data-library. Rest is out of the limitation of the system. Item 4.5 and 4.9 show comments of recommendation related to space/person standard coming from the specification or legislation documents. It is easy to implement and may be added for further development, however objective of the research is to inference this knowledge from data-base with machine learning activities. Items 4.6 and 4.7 are related to guidance for usage which are valuable. For future released version of system, wider research and surveys should be handled with potential users. Also, there is significance comments about the system to give recommendation about additional space which is known at the development space. Reason of it is simple and clear, machine learning activities were not able to find correlation between additional spaces and other spaces in this building typology. If there is existence of relation, it will be implemented automatically within the framework of the system.

Table 6.8 Results of properties to be improved

ID	Statement	Md	Q1	Q3	R
4.1	Indoor car parking should be enabled	6	4	6	2
4.2	Office spaces' opportunities should be examined	4	2	5	3
4.3	Name tags due to space type recommendation should be given	6	4	6	2
4.4	Requirements changes due to time and region should be examined	6	4	7	3
4.5	Area/User recommendation or limits for other spaces should be added	5	4	6	2
4.6	Some explanations to users whether they can or can't may be added	4	2	6	4
4.7	Relational spaces that are not entered by users should be shown	6	5	7	2
4.8	Recommendation for additional spaces may be added	7	5	7	2
4.9	System should not be allowed to enter out of range	2	1	3	2

6.2.2.5 Future Development Comments

Future development comments are presented at Table 6.9. All comments are valuable for the improvement of data-driven dynamic. requirement elicitation system, whether they are decided to implement or not, are able to implement, or not. Shelter space calculation is made according to legislation and it is directly related to design of projects, using the results of spaces is not enough to estimate. Another way is to capture relation knowledge from data-library; however, shelter space tag is not inquired in the MEKSİS space ontology. Limiting the queries due to space standard is possible, but there is not consensus on this comment. Item 5.4 and 5.6 are directly related to division of education departments in a building typology. The student number distributed due to the department is available in the system (YÖK, 2022). However, the usage of spaces is not available in the actual data-library. The update of data-library according to this kind of sub-division make possible to develop further machine learning activities within the proposed methodology. Budget estimation considering building typology and total areas is very uncomplicated action for the system with the implementation of approved and accepted unit prices. Item 5.5 is related to space dimension and, item 5.8 is about the recommendation of number and area of levels. It is obvious that these are directly related to designer's project studies. System only may offer some limits of space dimension coming from the standards, but it is impossible to have activities on levels without the involvement of the designers to the design processes. Knowledge of experts (expert on architectural programming) may be inserted to the system is one of the important comments. The dimension of knowledge is hard to be formalized, converted and transferred in to the system to be computed, since it comes from the experience and tacit level is high. It can be added to system by unformal entries like explanation parts, and these experts (designers) can use the system for helping their judgement against requirements. System may offer an evaluation report of requirements at the end; however, the value of this report is limited to completed cases included in the data-library. It is not decided to develop this feature for the system, since there is absence of any evaluation of completed building like post occupancy evaluation.

The experts have consensus on offering quantities of spaces at the start of the first iteration. This feature can be developed by some additional machine learning and computing activities on data-library; however, it should be stated that the space quantities and distributions in groups differ due to different approach of experts due to location, institute and managing issues. The bill of quantities is calculated during and after the project design process. It directly originated from project itself. However, there may be some calculation by machine, if there is existence of data-library including bill of quantities according to building and space typology. Finally, item 5.9 states that the system can work a requirement elicitation and validation reference base, if the decision makers accept the accuracy of the system. This is also one of the objectives of proposed system which need further feedback, development and validation of framework through case studies in scientific way.

Table 6.9 Future development comments

ID	Statement	Md	Q1	Q3	R
5.1	Shelter space should be recommended	6	5	6	1
5.2	Space standard may limit the queries	4	3	6	3
5.3	Budget calculations of building may be added	7	6	7	1
5.4	Number of students due to departments may be added to improve accuracy	6	5	6	1
5.5	Space dimension recommendation may be given	6	4	7	3
5.6	System may calculate quantities of classroom due to department student number	5	4	6	2
5.7	Knowledge of experts may be inserted to the system	6	4	6	2
5.8	Is it possible for system to offer number of levels and ground floor area?	4	3	4	1
5.9	If decision makers accept accuracy of system, it can work as a requirement elicitation and validation reference	6	6	7	1
5.10	The bill of quantities due construction sub-group may be calculated	5	2	6	4
5.11	An evaluation report of results may be beneficial	6	6	6	0
5.12	System may offer number of quantities at start	6	5	6	1

CHAPTER 7

CONCLUSIONS

In the final chapter; brief outline of the study, major findings and contributions, limitations of research and recommendation on further works are presented.

7.1 Summary of the Research

The briefing in the construction industry is a process that can be executed all over the project life cycle for maintaining informative and collaborative working situations. It is used for understanding organization's needs and resources and matching these to its objectives (Blyth & Worthigton, 2010). In the design and pre-design phase, briefing with the involvement of project stakeholders is one of the ensuring activities for the project's requirement elicitation. The success of this process and planning have important impacts on the total construction cost; it costs about 1.5%, however this relatively small amount influences up to 80% of the total life cycle cost of a construction project (Faatz, 2009).

Briefing frameworks are used to manage the knowledge of construction and project stakeholders in parallel with construction processes. It starts long before the project execution for identifying requirements and continues after the completion of project for connect the learned knowledge to new projects. The main contributions to construct project are requirement management, communication and success as an important knowledge source. Knowledge is a greater understanding of a given domain or problem., while made up of data and information (Firestone & McElroy, 2012). Requirement knowledge of buildings takes wider place in construction domain to be processed and managed. From knowledge point of view, it is important that construction industry realizes the benefits and necessities of knowledge management approach as other sectors, implements and develops the processes and cycles of knowledge like capturing, refining, archiving and reusing. Some barriers and factors for briefing and knowledge management have similar trends considering they are dealing with knowledge. The knowledge of space requirements should be examined in accordance with knowledge dimensions and processes. Communication gaps, misunderstanding, inadequate identification of requirements, time, experience level of project stakeholders and lack of comprehensive frameworks are important issues that affect requirement elicitation in briefing process. Considering the knowledge dimension of requirements there are important improvements and research studies like Clientpro (J. M. Kamara & Anumba, 2001), CAPRIKON (Koskela, L., Owen, 2006), KPfC (Kivrak et al., 2008) and automated update of space requirements (Kim et al., 2015) which examined methodologies and frameworks for knowledge. Also, with the developments on technology like BIM, requirements or requirement-based activities are examined in virtual environment for improvement of project execution.

There are existing several gaps, lack or problem on requirement elicitation in briefing process, since the human dimension is great to deal with and the context of project uniqueness is presence. The issues searched and learned from the survey were used to develop a questionnaire survey and connected interview which was held with the architect as industry experts. The results and findings of the survey are given in the research, which objective is to attain knowledge about the approaches, methods, problem areas and procedures that are part of the vocational practice. It could be stated that industry practitioners are aware of scientific research and vocational improvements for briefing, requirement capturing and knowledge process, while they are suffering from some issues like; lack and admission of frameworks, experience level of project stakeholders and to be obliged to define requirement from the scratch without proper involvement of users. In this situation, all work and evaluation are loaded to architect in project proposal stage. At least it can be said that architect has to accept undefined work in which time, scale and budget cannot be examined. It is obvious that the experience and thoughts of designer are indispensable facts for requirement elicitation and validation before and during the project execution. However, there should be methods, frameworks or procedures that project initiator can use to create requirements of projects in a level by assuring the accuracy with connecting to knowledge source or base.

The architectural design is a process which affected by the experience and thoughts of architects, socio-economic and cultural aspects, environmental sustainability issues and intentions. The knowledge of space requirements, functional relations and layouts and conceptual body of projects are valuable and indispensable parts of any building design process. Moreover, these have significant contributions to the success of project considering the utilization and evaluation of spaces. However, the sustainability reflections and integration of components differ due to project typology and designers' approach. Obtaining the requirement data and how they are used are governed by the architects, who can find the rule-based frameworks for the requirement elicitation beneficial, irrelevant, or restraining creative capability. Even though it may be hard to communicate with this formulated knowledge by designers, elicitation of requirements for any building project is vital and rule-based system for creation of knowledge corresponds in private practice.

This research explores the definition, fact and problem areas of briefing and knowledge processes within the scope of requirement elicitation. Then the issues are investigated with contemporary strategies and research projects, and are conducted with survey and interview with industry experts. The underlined objectives are capturing knowledge from the data-library of completed project via machine learning activities to make requirement elicitation process independent from individual's experience and defining space requirement of building through dynamic iterations within the rule-based framework which make possible to process and represent the requirement maintained by machine and user. Machine learning activities and data-library space tags are explored and used to develop system by examining the system with UML. The developed data-driven requirement elicitation system was tested on seven case studies by experts through the conducted Delphi technique and discussions. The results were found satisfactory and contribution of the research is underlined. Recommendations and properties to be improved to increase the practical benefits and methodical value of the system are stated.

7.2 Major Findings and Contribution

In this study, the system is proposed for the projects that their examples in the same typology were kept systematically in a data library. The method is defining and examining the knowledge capturing procedure via machine learning activities which direct the user by dynamic recommendations and calculated proportional relations. A trial running system is developed and examined by seven experts to evaluate requirement elicitation system for diverse building typologies which works with the direction of data-library. As it is stated throughout the research, the system does not offer creation, definition and validation of all types of requirements, while they should be studied by designer and other project stakeholders with other knowledge capturing and briefing techniques and approaches. However, it presents a way to capture and create knowledge from completed cases within the ruled framework which can be also used as initiation point and comparison base for requirement. Other contributions of the study and major findings can be given as follows:

- With the extensive literature review, the briefing issues, knowledge management in the construction, and dimension of knowledge and requirements were explored.
- Contemporary strategies, frameworks, research projects and commercial software are investigated due to knowledge cycle and processes. The features, contributions and knowledge dimension of these are categorically analysed.
- Throughout the survey with the industry experts, the position and approaches of designers who are part of Turkey’s architectural vocational practice are investigated. Their thought and comments on briefing issues, briefing techniques, and important items affecting success and knowledge process are evaluated. Besides, the profile and organizational information in relation to

technology usage and executing knowledge capturing techniques are investigated.

- By interview with industry experts, approaches and the applications on the requirement elicitation process before and during the project execution are determined, the recommendations and comments of the group representing vocational practice are stated for research on requirement process in the construction industry. Feedback from the experts is crucial for the improvements on requirement elicitation and validation framework, thus the research presents important contribution to define possible areas to develop, problem to deal with
- As explored in the material and method chapter, machine learning activities are explored to seek and define the possible trends and approaches from case studies implementing data-library systematic working principles to the framework.
- As to obtained results of the evaluation by experts, the space opportunities recommended by system via machine learning activities are coherent with standards and experience, valuable and optimized which make user without knowledge on building typology possible to handle requirement elicitation process. The time and workload for requirement elicitations decreased dramatically, so this gives opportunity to examine different scenarios of spaces for reaching optimum and successful results.
- The knowledge captured from the data-library is stated valuable and proper which is inferenced from the comments on recommendations and calculations of proportional relations. This means that it is possible to attain some other knowledge from the data libraries of completed building by diverse machine learning activities due to objected needs and missions. Having greater data sets as a sample or population of domain stands an important necessity.
- According to the results, recommendations of the system give the opportunity to user review and revise their choices by comparing position of their results.

Thus, they can define logical space requirements with reflecting their thought and comments. Also, recommendations of experts to improve the system for benefits on practice are stated.

- The proposed system presents statement to explain reason of requirements to inexperienced project stakeholders with iterative framework-based knowledge on spaces. The direction and guidance of requirement elicitation offers a self-control mechanism to user with examining recommendations and results dynamically.
- System works as another knowledge source for requirement elicitation and validation which based on machine learning from data-libraries. The process should be completed with conventional or preferred activities by architects for refinement and utilization of requirements. The approach of architects for using the captured knowledge affects the value and integration into the design. However, the captured and refined knowledge along and after the process could be converted and transferred to BIM environment for automated rule checking on spaces.

7.3 Limitations of the Study

One of the bottlenecks of the study lies in the unique context of building projects. The requirements of any project are affected and examined according to project typology and scale, regional conditions, client business environment and objectives, and designer experience and contribution to requirement refinement and development. Thus, the research proposed a system to improvement of requirement elicitation via computable activities in objectively examining environment within the awareness of value-added evaluation and knowledge creation of designers. As stages of any building design, requirement elicitation is a process that project stakeholders should work on much to achieve success approved by community or consensus of participants. With design proposal and other activities as explored in the literature survey and survey among industry practitioners, requirements of project evolve and change along the project execution, thus the outcome of proposed system is to be further examined considering its contribution. The utilization of the knowledge created as a result of developed system could be possible by the involvement of architects. The requirements could only take responses by implementing them into design process. Though the outcomes of this rule-based approach will be valuable on practice of design, whether architects have tendency to use these frameworks.

Machine learning and computing activities have great potential to create knowledge from data and information sets and library. The methods' domain is wide and offers diverse techniques and algorithms that can be implement in to proposed system. K-means clustering algorithm to define space groups of building typology, rank analysis for decisions on hierarchy and pairwise correlation analysis to search for trends and approaches on relations are integrated to the system. Considering that case studies uncover the contribution of them for capturing the knowledge from data libraries, other relational calculations and algorithms could be implemented within the similar objectives. Another significant subject which is out of the limits of the study, the knowledge that created and processes by machine learning activities has overlapping or differing projection with the conventional methods. These are being discussed by researchers considering continuity and accuracy of the knowledge.

The system provides an initiation framework and comparison base with its captured knowledge and working iteration including recommendations and calculations of relational proportions. The development and improvements of the system are done considering the usage of DBB project whereas the involvement of designer and user clients cannot be provided. On the other hand, within the surveys and development, it is evaluated that the system can also offer a comparison and validation base with adding the judgment of project stakeholders. Since the system present recommendations and calculations of measures related to worked building typology.

The data-library space ontology and tags are imported from the YMESS. The features of the spaces related to requirements are limited to actualize the objections of MEKSİS project. It takes an important role while developing trial of proposed system and testing, however there is need of information expansions due to spaces to capture more requirement knowledge of buildings. The space tags are searched from the public published web sites and reports and implement in to the research. The set of three completed building due to space tags is used a data-library of system. The contents of MEKSİS show all the building of public universities of Turkey. Since the value of machine learning activities over data set increases with relation of amount of the data, the proposed system could be further developed and examined with getting permission to integrate contents of MEKSİS. Besides, the framework is to be examined and developed for other building typologies, if the data-library of them could be provided. Although the sample of data-library is limited, the proposed system and evaluation show the potential for the knowledge creation from datasets of existing buildings.

The test of proposed system was held through seven experts via case study execution and Delphi method which are presented in the testing validation chapter. The results and discussion among evaluations are given. The cases are defined according to hypothetical condition for sampling building typology. The given information is decided due to values from the YOKSİS, and experts asked to execute the requirement elicitation due to their conditions and approaches. The assessed cases, given same conditions and information to experts, executing the session and selection of experts can be regarded as satisfactory which is minimizing the inherent subjectivity. Further examination on actual cases with other experts can provide additional comments and contributing evaluations for the improvement and development of proposed system.

The performance of data-driven requirement elicitation system was tested via seven case studies, assed by experts of different universities. For the development of running system activity connections are done manually with sustaining the unsupervised activity' conditions, although it is planned to work in automated and unsupervised version. The major aim to provide in-depth commentaries of experts on usage of the system and its potential contribution to requirement elicitation practice. In order to make the system more comprehensive for the objectives and vocational practice, it is needed to improve the system and assure the worth via more examining through cases and connections to approval mechanism. However, the results state the important potential of proposed system on capturing the knowledge from data libraries via rule-based framework.

7.4 Recommendations for Further Work

In the data-driven requirement elicitation system, the knowledge is captured from the data library and processes by user in ruled framework with recommendations. The data library is composed of completed project cases. Via some techniques and hierarchical analysis, the designer's knowledge and experience can be implemented into the system. Since the success of requirement elicitation and validation in briefing process is affected from involvement of stakeholders.

The usage of machine learning activities provides capturing valuable knowledge, trend and approaches that make user possible to execute requirement elicitation without specifying experience in building typology. These activities are developed and expanded via some other machine learning techniques and algorithms to find out additional knowledge which can be utilized in the system. The framework of the data library is important for machine computing activities. There can be development ontology of data library focusing on space requirements, or the conversion techniques can be handled for making the system workable on different data-set. Another subject for further work is the application of the proposed system over diverse building typologies. As it was mentioned among the limitations of the study, the data-library was created with cases from same typology, the experiments and development on different typologies can bring stimulating results.

Through the evaluation with experts, important statements, presented in the test and validation chapter, are underlined for the improvement and further work. Limiting the entries according to standards, space dimension recommendations, quantity proposal for spaces, using the system as validation reference with authority approvals and distributing the spaces due to department of buildings are valuable comments for further work. Since the example of running system is developed on the existing building data library of university buildings, the case studies and evaluation were done with experts (engineers/architects) from ‘Directorate of Construction and Technical Works Departments’ of universities. By executing further sessions and discussing with other experts, especially architects in private practice, the thoughts on development and usage of created knowledge on design process could be evolved better.

The proposed data-driven requirement elicitation system offers a framework for initiation of requirement capturing and base for comparison with knowledge captured from data libraries via machine learning activities. The components of system; recommendations, calculations of relational proportions, user involvements, iterations and relational space calculations provide an accurate and ruled framework to be executed in shorter time and less workload. This brings also scenario generation work requirements of same building, by providing more examinations system can evaluate the outcomes both for results and process on a more objective basis. The comparison of the architectural space list of completed projects by designer and the space requirements created with the proposed system for same projects by designer or any user will bring important criticism for further work.

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APPENDICES

A. Ethical Committee Approval

B. Survey Questions

Dear Sir or Madam,

This survey is conducted as a part of the PhD thesis study, "Knowledge Capturing in Design Briefing Process for Requirement Elicitation and Validation", conducted at the Building Science Program in the Middle East Technical University by Ekrem Bahadır Çalışkan under the supervision of Assist. Prof. Dr. Mehmet Koray Pekeriçli. The survey is prepared for the architects and architectural companies in Turkey and all the information gathered is going the to be kept confidential. Results and analysis of the survey will be used for the research, where personal and company information will not be shared, used, or published.

The objective of this study is to improve the briefing process that is used to capture and evaluate the requirement knowledge from the client. Important issues, factors, advantages, difficulties and problems of requirement elicitation and validating methods and processes in client briefing process by architectural practitioners among construction projects are going to be explored by the respondents. The information gathered by your participation in this survey is going to be informative on the management of requirements. The use of Building Information Modelling is also enquired from the participants to investigate the contribution/relation of BIM in practice regarding the management of requirement knowledge.

The survey consists of a multiple-choice questionnaire and open-ended survey questions for both gathering the information of choices and progress, and for enlarging the research by the involvement and expression of the contemporary practices of the participants. The survey is divided into three themes. First theme is related to organizational information, the second is for knowledge capturing in client briefing process and the last theme is related to the process for requirement elicitation and validation.

The survey is expected to be filled out by those who participate in the architectural design process and manage the knowledge coming from client briefing process. Please mark the “N.A.” if you are not clearly familiar with any statement.

Ekrem Bahadır Çalışkan

M.S. Architect / Metu Department of Architecture PhD Student

A-Organizational Information

1-Please answer the questions about yourself and the company

Name:

Position and Occupation:

Company Name and City:

Email address:

2-Number of Employees:

- 0-5
- 6-10
- 11-15
- 16-20
- Over 20

3-What is the total area of the building projects that you/your company have/has finished in the last five years?

- 0-25.000 m^2
- 25.001-50.000 m^2
- 50.001-100.000 m^2
- 100.001-250.000 m^2
- Over 250.000 m^2

4-Please select the project categories that your company is involved with.

- Residential Buildings
- Education Buildings
- Office Buildings
- Public Buildings
- Service Buildings
- Sport Facilities
- Hotels and Accommodation
- Health Care Buildings
- Conservation

- Environmental Design
- Interior Design
- Other:

5-Which project stakeholders below does your company have communication at pre-design and design stages?

	Never	Rarely	Sometimes	Often	Always
Client (Investor)					
Client (User)					
Consultants					
Project Engineers					
Construction Team					
Facility Management Team					

6-In which category below does your company use Building Information Modelling (BIM)?

	Never	Rarely	Sometimes	Often	Always	N.A.
Design						
Simulations (life cycle cost, environment, energy, *etc.*)						
Document management						
Procurement						
Facility Management						
Specifications						
Construction management (scheduling, logistics, *etc.*)						
Collaboration						
Automated Rule Checking						
Client Briefing						
Other:						

B-Knowledge Capturing at Client Briefing Process

Briefing is needed to manage the requirements by communication between paying client, user client and the designer. It is possible to understand the user needs better by using Knowledge Capturing tools in efficient way. In the light of your experience, please answer the questions below about the client briefing process.

7-Please evaluate the technique(s) in terms of their efficiency during the client briefing process.

	Not effective	Somewhat effective	Neutral	Effective	Very Effective	N.A.
Interviews						
Questionnaires						
Observation						
Storytelling						
Brainstorming						
Scenario Analysis						
Workshops						
Request for Proposals						
Sketches and Diagrams						
BIM environment						
Other:						

8-In which category below does your company keep the records of the client briefing? Please select the importance level of category for the success of project.

	Never	Rarely	Sometimes	Often	Always	Importance	N.A.
Paper based							
Digital text based							
Digital text based and shared with client							
*In computer processable format							

In structured database							

*Data format that can be processed and analysed by software applications

9- Please evaluate the items below for their importance for the success of capturing the requirement knowledge during the client briefing process.

	Not important	Somewhat important	Neutral	Important	Very Important	N.A.
Open and effective communication						
Defining the objectives of project						
Involvement of user client						
Evaluation of requirements during the briefing process						
Use of comprehensive frameworks/methods						
Approval of the outputs of client briefing process						
Recording the outputs of client briefing process						

10- In the light of your experience, what are the problems in gathering requirement knowledge from the client?

11- Please evaluate the importance of the cases below on the success of briefing process in relation to project performance and client satisfaction.

	Not important	Somewhat important	Neutral	Important	Very Important	N.A.
Inexperienced client						

Inadequate identification and representation of requirements during the briefing process						
Misunderstanding of client's needs						
Designer experience						
Insufficient time given to the briefing process						
Proper updating of requirements and change orders.						
Time needed for repeating works						

C-Processes for Requirement Elicitation and Validation

Knowledge cycle defines the processes for creating, capturing, archiving, understanding and reusing knowledge. Presentation of the cycle and processes differ among researchers; however, they are thought as a continuous loop for the knowledge gathering and refinement. In the light of your experience, please answer the questions below about the knowledge processes for the management of client's needs and requirements.

12- What do you think about the impact of storing, finding and reusing of knowledge during the client briefing process on the requirement gathering process?

13- Please evaluate the importance of actions about client requirements below on the project performance and success.

	Not important	Somewhat important	Neutral	Important	Very Important	N.A.
Clear statements						
Validation before design phase						

Validation with design proposals						
Usage of specification's libraries for the evaluations						
Usage of designer experience for the evaluations						
*Evaluation with structured knowledge bases						

*Analysis and association of output data with pre-recorded data in computer processable format and non-computer medium.

14-In which category below does your company use the process for knowledge management of requirements during/after the client briefing process? Please select the importance level of category for the success of project.

	Never	Rarely	Sometimes	Often	Always	Importance
Indexing and archiving of requirements						
Use-reuse of knowledge from records						
Use-reuse of knowledge from records for other projects						
Continuous update and report to client						
Use of processable techniques(computer) for requirements evaluation						

*BIM automated rule checking						
Validation of requirements with design proposals						

*Analysis of data by computer with rules sets automatically

15- Please evaluate the success of briefing process on the following issues.

	Not effective	Somewhat effective	Neutral	Effective	Very Effective	N.A.
Design success						
Time and budget of design phase						
Reduction of re-work in design phase						
Better decision making						
Increased productivity and profit in design phase						
Time and budget of construction						
Client satisfaction						
Other:						

- For 8 and 14 questions, the importance levels are not important, somewhat important, neutral, important and very important.

C. Survey Questions (Turkish)

Sayın Katılımcı,

Bu anket Dr. Öğr. Üyesi Mehmet Koray Pekeriçli danışmanlığında Orta Doğu Teknik Üniversitesi Yapı Bilimleri programında hazırlanmakta olan "Gereksinimleri Meydana Çıkarma ve Onaylama için Dizayn Brifingdeki Bilgileri Yakalamak" başlıklı doktora tezi çalışması için yapılmaktadır. Anket, Türkiye'deki mimarlar ve mimarlık firmaları için hazırlanmıştır ve elde edilen tüm bilgiler kesinlikle gizli tutulacaktır. Çalışmanın analizleri ve sonuçları araştırma için kullanılacak, kişisel ve firmalara ait bilgiler paylaşılmayacak, kullanılmayacak ve yayınlanmayacaktır.

Bu çalışma proje tasarım sürecindeki müşteriden gereksinimlere dair bilgileri toplamak ve değerlendirmek için kullanılmakta olan brifing süreçlerini geliştirmeyi hedeflemektedir. Mimarların inşaat projelerindeki müşteri brifingi sürecindeki gereksinimleri meydana çıkarma ve onaylama yöntem ve süreçlerindeki önemli konular, faktörler, avantajlar, zorluklar ve problemler ortaya çıkarılmaya çalışılacaktır. Katılımınız ile elde edilecek bilgiler gereksinim bilgileri yönetimi açısından aydınlatıcı olacaktır. Ayrıca, katılımcılara Yapı Bilgi Modellemesi (BIM) kullanımı, bunun gereksinim bilgileri yönetimine katkısını ve bununla ilişkisini incelemek amacıyla sorulacaktır.

Anket, hem katılımcıların süreç hakkındaki tercihlerini elde etmek hem de güncel uygulamalar hakkında katılımcıların düşüncelerini öğrenmek amacıyla çoktan seçmeli ve açık uçlu sorulardan oluşmaktadır. Üç ana tema altında organize edilen anket içinde, birinci temada organizasyon bilgileri, ikinci temada müşteri brifing sürecindeki bilgi yakalama konuları ve üçüncü temada gereksinimleri/ihtiyaçları meydana çıkarma ve onaylama süreçleri hakkında sorular vardır.

Anket çalışmasının mimari tasarım süreçlerinde yer alan ve müşteri brifing sürecinden gelen bilgilerin yönetimi konusuna katılım sağlayan kişiler tarafından doldurulması beklenmektedir. Eğer anket içindeki herhangi bir sorudaki tanım üzerinde emin değilseniz lütfen "G.D." (geçerli değil) bölümünü işaretleyiniz.

Ekrem Bahadır Çalışkan

Y. Mimar/ ODTÜ Mimarlık Bölümü Doktora Öğrencisi

A-Organizasyon Bilgileri

1-Lütfen kendiniz ve firmanız hakkındaki soruları cevaplayınız.

İsim:

Pozisyon ve Meslek:

Firma Adı ve Şehir:

Elektronik posta adresi:

2-Firmanızda çalışan sayısı:

- 0-5
- 6-10
- 11-15
- 16-20
- 20’den fazla

3-Son beş yılda tamamladığınız toplam bina projesi alanı nedir?

- 0-25.000 m^2
- 25.001-50.000 m^2
- 50.001-100.000 m^2
- 100.001-250.000 m^2
- 250.000 m^2 ‘den fazla

4-Firmanızın üstlendiği proje kategorilerinden seçim yapınız.

- Konut Binaları
- Eğitim Binaları
- Ofis Binaları
- Kamu Binaları
- Hizmet Binaları
- Spor Tesisleri
- Otel ve Konaklama
- Sağlık Yapıları
- Restorasyon ve Koruma
- Çevre Tasarımı
- İç Mimarlık
- Diğer:

5- Firmanızın tasarım öncesinde ve tasarım aşamasında aşağıdaki proje taraflarından hangileri ile iletişimi vardır?

	Hiçbir zaman	Nadiren	Bazen	Sıklıkla	Her zaman
Müşteri (Yatırımcı)					

Müşteri (Kullanıcı)					
Proje Danışmanları					
Proje Mühendisleri					
İnşaat ekibi					
Tesis İşletme Ekibi					

6- Firmanız aşağıdaki kategorilerden hangisinde Yapı Bilgi Modellemesi (BIM) kullanmaktadır?

	Hiçbir zaman	Nadiren	Bazen	Sıklıkla	Her zaman	G.D.
Tasarım						
Simülasyonlar (yaşa döngüsü maliyeti, çevre, enerji ve bunun gibi)						
Doküman yönetimi						
Tedarik ve Temin						
Tesis Yönetimi						
Şartnameler						
İnşaat yönetimi (planlama, lojistik ve bunun gibi)						
İş birliği/birlikte çalışma						
Otomatik kural denetimi (BIM)						
Müşteri Brifingi						
Diğer:						

B-Müşteri Brifing Sürecinde Bilgi Yakalamak

Yatırımcı müşteri, kullanıcı müşteri ve tasarımcı arasındaki iletişim ile gereksinimleri yönetmek için brifing süreçleri kullanılmaktadır. Bilgi yakalama araçları ile kullanıcının isteklerini daha iyi anlamak mümkün olabilir. Tecrübeleriniz ışığında müşteri brifing süreçleri hakkındaki aşağıdaki soruları cevaplayınız.

7- Lütfen aşağıda sunulan müşteri brifingi sürecinde kullanılan teknikleri etki derecesine göre değerlendiriniz.

	Etkili Değil	Biraz Etkili	Nötr	Etkili	Çok Etkili	G.D.
Mülakat						
Anketler						
Gözlem						
Hikâye Anlatımı						
Beyin Fırtınası						
Senaryo Analizi						
Atölye çalışmaları						
Öneri çalışmaları						
Skeç ve Diyagramlar						
BIM modelleri veya unsurları						
Diğer:						

8-Firmanız aşağıdaki kategorilerden hangisi ile müşteri brifingi kayıtlarını tutmaktadır? Lütfen kategorilerin projesi başarısı için önem derecesini seçiniz.

	Hiçbir zaman	Nadiren	Bazen	Sıklıkla	Her zaman	Önem Derecesi	G.D.
Basılı doküman							
Dijital doküman							
Müşteri ile paylaşılan dijital metin							

*Bilgisayarın işleyebildiği formatlar							
Sistematik veri-tabanı							

*Bilgisayar programları tarafında üzerinde işlem ve analiz yapılabilen veriler

9- Lütfen müşteri brifingi sürecinde gereksinim/ihtiyaç bilgisini yakalamak/elde etmek için kullanılan aşağıdaki unsurları önem derecesine göre işaretleyiniz.

	Önemli Değil	Biraz Önemli	Nötr	Önemli	Çok Önemli	G.D.
Açık ve etkili iletişim						
Proje amaçlarını belirleme						
Müşteri (bina kullanıcısı) katılımı						
İhtiyaçların brifing sırasında değerlendirilmesi						
Kapsamlı prosedür ve metotların kullanılması						
Brifing çıktılarının müşteri tarafından onaylanması						
Brifing çıktılarının kayıt edilmesi						

10- Tecrübeleriniz ışığında, müşteriden gereksinim/ihtiyaç bilgisinin alınmasındaki problemler nelerdir?

11- Aşağıdaki durumların projenin performansı ve müşteri tatmini de düşünüldüğünde brifing süreci başarısı açısından önemini değerlendiriniz.

	Önemli Değil	Biraz Önemli	Nötr	Önemli	Çok Önemli	G.D.
Tecrübesiz müşteri						
Gereksinimlerin uygun olmayan/yetersiz bir şekilde belirlenmesi ve gösterimi						

Müşteri isteklerini yanlış veya eksik anlama						
Tasarımcının tecrübesi						
Brifing sürecine verilen yetersiz zaman						
İhtiyaçların ve değişiklerin düzenlenmesi ve güncellenmesi						
Tekrar eden işler için ihtiyaç duyulan zaman						

C-Gereksinimleri Meydana Çıkarma ve Onaylama için Kullanılan Süreç ve İşlemler

Bilgi döngüsü, bilginin yaratılması, bilginin yakalanması, arşivlenmesi, anlaşılması ve yeniden kullanılması ile ilgili süreçleri tanımlamaktadır. Bu döngünün ve alt işlemlerinin ortaya konulmasında araştırmacılara göre farklılıklar olmasına rağmen bilginin elde edilmesi ve rafine edilmesi için kesintisiz bir döngü olması gerektiği düşünülmektedir. Tecrübeleriniz ışığında, müşteri istek ve gereksinimlerinin yönetimi için bilgi işlemleri hakkındaki soruları cevaplayınız.

12- Müşteri brifingi sürecindeki bilgilerin saklanması, taranması ve yeniden kullanılmasının, gereksinim bilgilerinin yönetimine etkisi hakkında düşünceleriniz nedir?

13- Müşteri gereksinimleri hakkında aşağıda verilen eylemlerin proje performansı ve başarısı açısından önemini değerlendiriniz.

	Önemli Değil	Biraz Önemli	Nötr	Önemli	Çok Önemli	G.D.
Net açıklamalar						
Tasarım çalışmaları öncesi gereksinimlerin değerlendirilmesi ve onaylanması						
Gereksinimlerin tasarım önerileri ile onaylanması						

Gereksinimlerin değerlendirilmesi için mevzuatın ve bilgi kütüphanelerinin kullanılması						
Gereksinimlerin değerlendirilmesi için tasarımcının tecrübelerinin kullanılması						
*Gereksinim değerlendirilmesinde yapılandırılmış bilgi kaynaklarının kullanılması						

*Elde edilen verilerin, kayıtlı diğer bilgi kaynakları ile bilgisayar veya bilgisayar dışı formatlarda analizlerinin ve ilişkilendirilmelerinin yapılması

14- Firmanız, aşağıdaki işlemlerden hangilerini müşteri brifingi sürecinde ve sonrasında gereksinimler ile ilgili bilgileri yönetmek için kullanmaktadır? Lütfen kategorilerin projesi başarısı için önem derecesini seçiniz.

	Hiçbir zaman	Nadiren	Bazen	Sıklıkla	Her zaman	Önem Derecesi
Gereksinimleri indeksleme ve arşivleme						
Kayıtlardaki bilgilerin yeniden kullanılması						
Kayıtlardaki bilgilerin başka projeler için yeniden kullanılması						
Sürekli güncelleme ve müşteriye raporlama						
Gereksinim değerlendirmesi için bilgisayar tarafından işlenebilen						

yöntemlerin kullanılması						
*BIM kural denetimi						
Gereksinimlerin proje önerileri ile onaylanması						

*BIM ortamında kullanılan kural setleri ile proje verilerinin bilgisayar tarafından otomatik olarak analiz edilmesi

15- Brifing süreci başarısının aşağıdakiler üzerindeki etkisini değerlendiriniz.

	Etkili Değil	Biraz Etkili	Nötr	Etkili	Çok Etkili	G.D.
Tasarım projesi başarısı						
Tasarım aşamasının süresi ve bütçesi						
Tasarım aşamasındaki tekrar eden işlerin azalması						
Daha iyi karar verme durumu						
Tasarım aşamasındaki üretkenlik ve karlılığın artması						
İnşaat sürecinin zamanı ve bütçesi						
Müşteri tatmini						
Diğer:						

- 8 ve 14 numaralı sorular için önem dereceleri; önemli değil, biraz önemli, nötr, önemli ve çok önemlidir.

D. Approval of Interview

Dear Sir or Madam,

This interview is conducted as a part of the PhD thesis study, "Knowledge Capturing in Design Briefing Process for Requirement Elicitation and Validation", conducted at the Building Science Program in the Middle East Technical University by Ekrem Bahadır Çalışkan under the supervision of Asst. Prof. Dr. Mehmet Koray Pekeriçli. Notes will be taken during to interviews about your comments and answers. Analysis of interviews will be used for the research, where personal and company information will not be shared, used, or published

The objective of this study is to improve the briefing process that is used to capture and evaluate the requirement knowledge from the client. Important issues, factors, advantages, difficulties and problems of requirement elicitation and validating methods and processes in client briefing process by architectural practitioners among construction projects are going to be explored by the interviewees. For these objectives, the methods and problems about elicitation, validation or getting approval of project requirements will be asked.

Interview Date: Interview Place:

Duration of Interview:

Interviewer: Ekrem Bahadır Çalışkan

M.S. Architect / Metu Department of Architecture PhD Student

bahadir.caliskan@gmail.com

Interviewee:

Company:

"I allowed to be taken noted about interview."

Signature:

E. Requirement Results of Case Studies

REQUIREMENT ELICITATION AND VALIDATION SYSTEM						
University:	EXPERT 1 CASE	Student Number	1250		Gross Area	14412,80619
Building Typology:	FACULTY OF ARTS AND SCIENCES	Academician Number	100		Net Area	12068,13 m²
Location:	EXPERT 1 CASE				Total Student Seat	1370 p
Building Type	New Building		RESULTS		Total Academic Seat	120 p

Space Function	Space Code	Code	Main Function	Main Function Code	Explanation		Quantity	Area	Space Height	Number of Users
Classroom	ED	ED-#-#	Education	E		0	2	115 m²	4	100
Classroom	ED	ED-#-#	Education	E		0	1	75 m²	4	50
Classroom	ED	ED-#-#	Education	E		0	0	65 m²	4	50
Classroom	ED	ED-#-#	Education	E		0	2	75 m²	4	65
Classrom(with slope)	EA	EA-#-#	Education	E		0	7	90 m²	5	75
Classrom(with slope)	EA	EA-#-#	Education	E		0	3	195 m²	6	155
Classrom(with slope)	EA	EA-#-#	Education	E		0	0	275 m²	8	275
Class Laboratory	EL	EL-#-#	Education	E		0	4	80 m²	4	55
Class Laboratory	EL	EL-#-#	Education	E		0	2	100 m²	4	45
Class Laboratory	EL	EL-#-#	Education	E		0	0	55 m²	4	40
Class Laboratory	EL	EL-#-#	Education	E		0	6	85 m²	4	35
Academician Office	MA	MA-#-#	Administrative	M		0	18	10 m²	3	1
Academician Office	MA	MA-#-#	Administrative	M		0	30	15 m²	3	2
Academician Office	MA	MA-#-#	Administrative	M		0	1	50 m²	3	8
Academician Office	MA	MA-#-#	Administrative	M		0	6	25 m²	3	3
Academician Office	MA	MA-#-#	Administrative	M		0	8	10 m²	3	2
Academician Office(admin)	MY	MY-#-#	Administrative	M		0	1	55 m²	3	1
Academician Office(admin)	MY	MY-#-#	Administrative	M		0	8	25 m²	3	1
Academician Office(admin)	MY	MY-#-#	Administrative	M		0	2	35 m²	3	1
Personnel Office	MI	MI-#-#	Administrative	M		0	4	25 m²	3	3
Personnel Office	MI	MI-#-#	Administrative	M		0	8	15 m²	3	1
Personnel Office	MI	MI-#-#	Administrative	M		0	8	20 m²	3	2
Seminar Room	ES	ES-#-#	Education	E		0	8	55 m²	0	25
Research Laboratory	RM	RM-#-#	Research	R		0	2	50 m²	0	0
Others(education)	EX	EX-#-#	Education	E		0	2	150 m²	0	80
Personnel Office (admin)	MP	MP-#-#	Administrative	M		0	1	50 m²	0	0
Cafeteria	GK	GK-#-#	Social	G	for academics		8	30 m²	3	10
Others	OX	OX-#-#	Others	O	prayers room		2	50 m²	0	0
Archive	OP	OP-#-#	Others	O	for faculty		1	30 m²	0	0
Storage Room	OD	OD-#-#	Others	O	for faculty		2	30 m²	0	0
Meeting Room	CM	CM-#-#	Congress and Meeting	C	for faculty		9	50 m²	0	0
0						0	0	m²	0	0
0						0	0	m²	0	0
0						0	0	m²	0	0
0						0	0	m²	0	0
0						0	0	m²	0	0
Data Room	OC	OC-#-#	Others	O				492 m²		
Mechanical Room	OT	OT-#-#	Others	O						
Cafeteria	GK	GK-#-#	Social	G				406 m²		
Restroom	OW	OW-#-#	Others	O				418 m²		
Circulation	OS	OS-#-#	Others	O				4.668 m²		

Spaces resulting from regulations and legislation in the region should be added.

REQUIREMENT ELICITATION AND VALIDATION SYSTEM

University:	EXPERT 2 CASE	Student Number	1250	Gross Area	18162,25419
Building Typology:	FACULTY OF ARTS AND SCIENCES	Academician Number	100	Net Area	15207,62 m²
Location:	EXPERT 2 CASE			Total Student Seat	1170 p
Building Type	New Building		RESULTS	Total Academic Seat	140 p

Space Function	Space Code	Code	Main Function	Main Function Code	Explanation		Quantity	Area	Space Height	Number of Users
Classroom	ED	ED-#-#	Education	E		0	3	115 m²	4	100
Classroom	ED	ED-#-#	Education	E		0	2	75 m²	4	50
Classroom	ED	ED-#-#	Education	E		0	2	65 m²	4	50
Classroom	ED	ED-#-#	Education	E		0	2	75 m²	4	65
Classrom(with slope)	EA	EA-#-#	Education	E		0	1	90 m²	5	75
Classrom(with slope)	EA	EA-#-#	Education	E		0	3	195 m²	6	155
Classrom(with slope)	EA	EA-#-#	Education	E		0	0	275 m²	8	275
Class Laboratory	EL	EL-#-#	Education	E		0	2	80 m²	4	55
Class Laboratory	EL	EL-#-#	Education	E		0	3	100 m²	4	45
Class Laboratory	EL	EL-#-#	Education	E		0	3	55 m²	4	40
Class Laboratory	EL	EL-#-#	Education	E		0	3	85 m²	4	35
Academician Office	MA	MA-#-#	Administrative	M		0	40	10 m²	3	1
Academician Office	MA	MA-#-#	Administrative	M		0	35	15 m²	3	2
Academician Office	MA	MA-#-#	Administrative	M		0	0	50 m²	3	8
Academician Office	MA	MA-#-#	Administrative	M		0	10	25 m²	3	3
Academician Office	MA	MA-#-#	Administrative	M		0	0	10 m²	3	2
Academician Office(admin)	MY	MY-#-#	Administrative	M		0	1	55 m²	3	1
Academician Office(admin)	MY	MY-#-#	Administrative	M		0	0	25 m²	3	1
Academician Office(admin)	MY	MY-#-#	Administrative	M		0	3	35 m²	3	1
Personnel Office	MI	MI-#-#	Administrative	M		0	3	25 m²	3	3
Personnel Office	MI	MI-#-#	Administrative	M		0	14	15 m²	3	2
Personnel Office	MI	MI-#-#	Administrative	M		0	1	50 m²	3	5
Seminar Room	ES	ES-#-#	Education	E		0	15	25 m²	0	10
Research Laboratory	RM	RM-#-#	Research	R		0	8	30 m²	0	3
Others(education)	EX	EX-#-#	Education	E	computer lab		2	240 m²	0	100
Personnel Office (admin)	MP	MP-#-#	Administrative	M		0	1	25 m²	0	1
Meeting Room	CM	CM-#-#	Congress and Meeting	C		0	6	50 m²	0	0
Conference Hall	CS	CS-#-#	Congress and Meeting	C		0	1	1.100 m²	0	550
Eating Area	GY	GY-#-#	Social	G		0	1	500 m²	0	300
Storage Room	OD	OD-#-#	Others	O		0	4	20 m²	0	0
Storage Room	OD	OD-#-#	Others	O		0	1	120 m²	0	0
Archive	OP	OP-#-#	Others	O		0	11	20 m²	0	0
Atelier	OR	OR-#-#	Others	O		0	1	15 m²	0	0
Others(library)						0	1	500 m²	0	0
	0					0	0	m²	0	0
	0					0	0	m²	0	0
	0					0	0	m²	0	0
Data Room	OC	OC-#-#	Others	O				492 m²		
Mechanical Room	OT	OT-#-#	Others	O						
Cafeteria	GK	GK-#-#	Social	G				352 m²		
Restroom	OW	OW-#-#	Others	O				526 m²		
Circulation	OS	OS-#-#	Others	O				5.882 m²		

Spaces resulting from regulations and legislation in the region should be added.

REQUIREMENT ELICITATION AND VALIDATION SYSTEM

University:	EXPERT 3 CASE	Student Number	1250	Gross Area	16585,55508
Building Typology:	FACULTY OF ARTS AND SCIENCES	Academician Number	100	Net Area	13887,42 m²
Location:	EXPERT 3 CASE			Total Student Seat	1335 p
Building Type	New Building		RESULTS	Total Academic Seat	110 p

Space Function	Space Code	Code	Main Function	Main Function Code	Explanation	Quantity	Area	Space Height	Number of Users
Classroom	ED	ED-#-#	Education	E	0	0	115 m²	4	100
Classroom	ED	ED-#-#	Education	E	0	10	75 m²	4	50
Classroom	ED	ED-#-#	Education	E	0	4	85 m²	4	60
Classroom	ED	ED-#-#	Education	E	0	2	75 m²	4	65
Classrom(with slope)	EA	EA-#-#	Education	E	0	0	90 m²	5	75
Classrom(with slope)	EA	EA-#-#	Education	E	0	3	195 m²	6	155
Classrom(with slope)	EA	EA-#-#	Education	E	0	0	275 m²	8	275
Class Laboratory	EL	EL-#-#	Education	E	0	5	80 m²	4	55
Class Laboratory	EL	EL-#-#	Education	E	0	3	100 m²	4	45
Class Laboratory	EL	EL-#-#	Education	E	0	0	55 m²	4	40
Class Laboratory	EL	EL-#-#	Education	E	0	4	85 m²	4	35
Academician Office	MA	MA-#-#	Administrative	M	0	15	18 m²	3	1
Academician Office	MA	MA-#-#	Administrative	M	0	25	15 m²	3	1
Academician Office	MA	MA-#-#	Administrative	M	0	5	50 m²	3	8
Academician Office	MA	MA-#-#	Administrative	M	0	15	30 m²	3	2
Academician Office	MA	MA-#-#	Administrative	M	0	0	10 m²	3	2
Academician Office(admin)	MY	MY-#-#	Administrative	M	deans office	1	50 m²	3	1
Academician Office(admin)	MY	MY-#-#	Administrative	M	0	0	25 m²	3	1
Academician Office(admin)	MY	MY-#-#	Administrative	M	deputy dean	2	25 m²	3	1
Personnel Office	MI	MI-#-#	Administrative	M	0	4	30 m²	3	4
Personnel Office	MI	MI-#-#	Administrative	M	deparment secretary	8	15 m²	3	2
Personnel Office	MI	MI-#-#	Administrative	M	0	1	50 m²	3	5
Seminar Room	ES	ES-#-#	Education	E	graduate	6	55 m²	0	25
Research Laboratory	RM	RM-#-#	Research	R	0	6	35 m²	0	0
Others(education)	EX	EX-#-#	Education	E	computer room	3	140 m²	0	60
Personnel Office (admin)	MP	MP-#-#	Administrative	M	0	1	25 m²	0	1
Conference Hall	CS	CS-#-#	Congress and Meeting	C	0	1	300 m²	0	150
Conference Hall	CS	CS-#-#	Congress and Meeting	C	0	1	400 m²	0	200
Meeting Room	CM	CM-#-#	Congress and Meeting		0	1	75 m²	0	0
Meeting Room	CM	CM-#-#	Congress and Meeting		0	8	50 m²	0	0
Archive	OP	OP-#-#	Others		0	8	25 m²	0	0
Cafeteria	GK	GK-#-#	Social		for departments	4	10 m²	0	0
Working Space(silent)	LZ	LZ-#-#	Library		0	1	100 m²	0	0
	0				0	0	m²	0	0
	0				0	0	m²	0	0
	0				0	0	m²	0	0
	0				0	0	m²	0	0
Data Room	OC	OC-#-#	Others	O			492 m²		
Mechanical Room	OT	OT-#-#	Others	O					
Cafeteria	GK	GK-#-#	Social	G			443 m²		
Restroom	OW	OW-#-#	Others	O			480 m²		
Circulation	OS	OS-#-#	Others	O			5.372 m²		

Spaces resulting from regulations and legislation in the region should be added.

REQUIREMENT ELICITATION AND VALIDATION SYSTEM					
University:	EXPERT CASE 4	Student Number	1250	Gross Area	11307,85543
Building Typology:	FACULTY OF ARTS AND SCIENCES	Academician Number	100	Net Area	9468,29 m²
Location:	EXPERT CASE 4			Total Student Seat	1190 p
Building Type	New Building	RESULTS		Total Academic Seat	75 p

Space Function	Space Code	Code	Main Function	Main Function Code	Explanation	Quantity	Area	Space Height	Number of Users
Classroom	ED	ED-#-#	Education	E	0	0	115 m²	4	100
Classroom	ED	ED-#-#	Education	E	0	8	75 m²	4	50
Classroom	ED	ED-#-#	Education	E	0	8	65 m²	4	50
Classroom	ED	ED-#-#	Education	E	0	6	75 m²	4	65
Classrom(with slope)	EA	EA-#-#	Education	E	0	0	90 m²	5	75
Classrom(with slope)	EA	EA-#-#	Education	E	0	0	195 m²	6	155
Classrom(with slope)	EA	EA-#-#	Education	E	0	0	275 m²	8	275
Class Laboratory	EL	EL-#-#	Education	E	0	0	80 m²	4	55
Class Laboratory	EL	EL-#-#	Education	E	0	4	100 m²	4	45
Class Laboratory	EL	EL-#-#	Education	E	0	6	55 m²	4	40
Class Laboratory	EL	EL-#-#	Education	E	0	0	85 m²	4	35
Academician Office	MA	MA-#-#	Administrative	M	0	0	10 m²	3	1
Academician Office	MA	MA-#-#	Administrative	M	0	0	15 m²	3	2
Academician Office	MA	MA-#-#	Administrative	M	0	30	25 m²	3	2
Academician Office	MA	MA-#-#	Administrative	M	0	15	25 m²	3	1
Academician Office	MA	MA-#-#	Administrative	M	0	0	10 m²	3	2
Academician Office(admin)	MY	MY-#-#	Administrative	M	0	1	65 m²	3	1
Academician Office(admin)	MY	MY-#-#	Administrative	M	0	8	25 m²	3	1
Academician Office(admin)	MY	MY-#-#	Administrative	M	0	2	45 m²	3	1
Personnel Office	MI	MI-#-#	Administrative	M	0	3	25 m²	3	2
Personnel Office	MI	MI-#-#	Administrative	M	0	2	15 m²	3	2
Personnel Office	MI	MI-#-#	Administrative	M	0	0	50 m²	3	5
Seminar Room	ES	ES-#-#	Education	E	0	4	85 m²	0	40
Research Laboratory	RM	RM-#-#	Research	R	0	0	m²	0	0
Others(education)	EX	EX-#-#	Education	E	computer lab	0	m²	0	0
Personnel Office (admin)	MP	MP-#-#	Administrative	M	0	1	25 m²	0	1
Conference Hall	CS	CS-#-#	Congress and Meeting	C	0	1	100 m²	0	50
Working Space(silent)					0	2	65 m²	0	0
Archive					0	1	80 m²	0	0
Storage Room					0	3	15 m²	0	0
	0				0	0	m²	0	0
	0				0	0	m²	0	0
	0				0	0	m²	0	0
	0				0	0	m²	0	0
	0				0	0	m²	0	0
	0				0	0	m²	0	0
	0				0	0	m²	0	0
Data Room	OC	OC-#-#	Others	O			492 m²		
Mechanical Room	OT	OT-#-#	Others	O					
Cafeteria	GK	GK-#-#	Social	G			381 m²		
Restroom	OW	OW-#-#	Others	O			328 m²		
Circulation	OS	OS-#-#	Others	O			3.662 m²		

Spaces resulting from regulations and legislation in the region should be added.

REQUIREMENT ELICITATION AND VALIDATION SYSTEM

University:	EXPERT CASE 5	Student Number	1250		Gross Area	16075,13683
Building Typology:	FACULTY OF ARTS AND SCIENCES	Academician Number	100		Net Area	13460,03 m²
Location:	EXPERT CASE 5				Total Student Seat	1490 p
Building Type	New Building		RESULTS		Total Academic Seat	95 p

Space Function	Space Code	Code	Main Function	Main Function Code	Explanation	Quantity	Area	Space Height	Number of Users
Classroom	ED	ED-#-#	Education	E	0	4	115 m²	4	100
Classroom	ED	ED-#-#	Education	E	0	4	75 m²	4	50
Classroom	ED	ED-#-#	Education	E	0	2	65 m²	4	50
Classroom	ED	ED-#-#	Education	E	0	2	75 m²	4	65
Classrom(with slope)	EA	EA-#-#	Education	E	0	1	90 m²	5	75
Classrom(with slope)	EA	EA-#-#	Education	E	0	2	195 m²	6	155
Classrom(with slope)	EA	EA-#-#	Education	E	0	1	275 m²	8	275
Class Laboratory	EL	EL-#-#	Education	E	0	0	80 m²	4	55
Class Laboratory	EL	EL-#-#	Education	E	0	6	100 m²	4	45
Class Laboratory	EL	EL-#-#	Education	E	0	4	55 m²	4	40
Class Laboratory	EL	EL-#-#	Education	E	0	4	85 m²	4	35
Academician Office	MA	MA-#-#	Administrative	M	0	15	20 m²	3	1
Academician Office	MA	MA-#-#	Administrative	M	0	20	15 m²	3	1
Academician Office	MA	MA-#-#	Administrative	M	0	10	30 m²	3	3
Academician Office	MA	MA-#-#	Administrative	M	0	15	25 m²	3	2
Academician Office	MA	MA-#-#	Administrative	M	0	0	10 m²	3	2
Academician Office(admin)	MY	MY-#-#	Administrative	M	0	1	55 m²	3	1
Academician Office(admin)	MY	MY-#-#	Administrative	M	0	10	25 m²	3	1
Academician Office(admin)	MY	MY-#-#	Administrative	M	0	2	30 m²	3	1
Personnel Office	MI	MI-#-#	Administrative	M	0	3	40 m²	3	3
Personnel Office	MI	MI-#-#	Administrative	M	0	8	20 m²	3	2
Personnel Office	MI	MI-#-#	Administrative	M	0	0	50 m²	3	5
Seminar Room	ES	ES-#-#	Education	E	0	8	55 m²	0	25
Research Laboratory	RM	RM-#-#	Research	R	0	1	100 m²	0	0
Others(education)	EX	EX-#-#	Education	E	computer lab	1	100 m²	0	60
Personnel Office (admin)	MP	MP-#-#	Administrative	M	0	1	25 m²	0	1
Conference Hall	CS	CS-#-#	Congress and Meeting	C	0	1	400 m²	0	250
Working Space(silent)					0	1	300 m²	0	150
Archive					0	1	200 m²	0	0
Storage Room					0	2	50 m²	0	0
Atelier					0	4	80 m²	0	60
	0				0	0	m²	0	0
	0				0	0	m²	0	0
	0				0	0	m²	0	0
	0				0	0	m²	0	0
	0				0	0	m²	0	0
	0				0	0	m²	0	0
Data Room	OC	OC-#-#	Others	O			492 m²		
Mechanical Room	OT	OT-#-#	Others	O					
Cafeteria	GK	GK-#-#	Social	G			436 m²		
Restroom	OW	OW-#-#	Others	O			466 m²		
Circulation	OS	OS-#-#	Others	O			5.206 m²		

Spaces resulting from regulations and legislation in the region should be added.

REQUIREMENT ELICITATION AND VALIDATION SYSTEM

University:	EXPERT CASE 6	Student Number	1250	Gross Area	15159,61776
Building Typology:	FACULTY OF ARTS AND SCIENCES	Academician Number	100	Net Area	12693,45 m²
Location:	EXPERT CASE 6			Total Student Seat	1625 p
Building Type	New Building		RESULTS	Total Academic Seat	125 p

Space Function	Space Code	Code	Main Function	Main Function Code	Explanation	Quantity	Area	Space Height	Number of Users
Classroom	ED	ED-#-#	Education	E	0	4	115 m²	4	100
Classroom	ED	ED-#-#	Education	E	0	2	75 m²	4	50
Classroom	ED	ED-#-#	Education	E	0	2	65 m²	4	50
Classroom	ED	ED-#-#	Education	E	0	2	75 m²	4	65
Classrom(with slope)	EA	EA-#-#	Education	E	0	0	90 m²	5	75
Classrom(with slope)	EA	EA-#-#	Education	E	0	4	195 m²	6	155
Classrom(with slope)	EA	EA-#-#	Education	E	0	1	275 m²	8	275
Class Laboratory	EL	EL-#-#	Education	E	0	6	80 m²	4	55
Class Laboratory	EL	EL-#-#	Education	E	0	0	100 m²	4	45
Class Laboratory	EL	EL-#-#	Education	E	0	4	55 m²	4	40
Class Laboratory	EL	EL-#-#	Education	E	0	0	85 m²	4	35
Academician Office	MA	MA-#-#	Administrative	M	0	15	20 m²	3	1
Academician Office	MA	MA-#-#	Administrative	M	0	0	15 m²	3	2
Academician Office	MA	MA-#-#	Administrative	M	0	10	50 m²	3	4
Academician Office	MA	MA-#-#	Administrative	M	0	35	30 m²	3	2
Academician Office	MA	MA-#-#	Administrative	M	0	0	10 m²	3	2
Academician Office(admin)	MY	MY-#-#	Administrative	M	0	1	55 m²	3	1
Academician Office(admin)	MY	MY-#-#	Administrative	M	0	8	25 m²	3	1
Academician Office(admin)	MY	MY-#-#	Administrative	M	0	3	35 m²	3	1
Personnel Office	MI	MI-#-#	Administrative	M	0	7	25 m²	3	2
Personnel Office	MI	MI-#-#	Administrative	M	0	5	15 m²	3	1
Personnel Office	MI	MI-#-#	Administrative	M	0	0	50 m²	3	5
Seminar Room	ES	ES-#-#	Education	E	0	1	45 m²	0	20
Research Laboratory	RM	RM-#-#	Research	R	0	0	m²	0	0
Others(education)	EX	EX-#-#	Education	E	computer lab	1	100 m²	0	50
Personnel Office (admin)	MP	MP-#-#	Administrative	M	0	1	25 m²	0	1
Working Space(silent)	LZ	LZ-#-#	Library	L	0	4	100 m²	0	0
Storage Room					0	24	20 m²	0	0
Archive					0	9	25 m²	0	0
0					0	0	m²	0	0
0					0	0	m²	0	0
0					0	0	m²	0	0
0					0	0	m²	0	0
0					0	0	m²	0	0
0					0	0	m²	0	0
0					0	0	m²	0	0
0					0	0	m²	0	0
Data Room	OC	OC-#-#	Others	O			492 m²		
Mechanical Room	OT	OT-#-#	Others	O					
Cafeteria	GK	GK-#-#	Social	G			473 m²		
Restroom	OW	OW-#-#	Others	O			439 m²		
Circulation	OS	OS-#-#	Others	O			4.910 m²		

Spaces resulting from regulations and legislation in the region should be added.

REQUIREMENT ELICITATION AND VALIDATION SYSTEM

University:	EXPERT CASE 7	Student Number	1250	Gross Area	16591,13337
Building Typology:	FACULTY OF ARTS AND SCIENCES	Academician Number	100	Net Area	13892,09 m²
Location:	EXPERT CASE 7			Total Student Seat	1545 p
Building Type	New Building		RESULTS	Total Academic Seat	101 p

Space Function	Space Code	Code	Main Function	Main Function Code	Explanation	Quantity	Area	Space Height	Number of Users
Classroom	ED	ED-#-#	Education	E	0	6	150 m²	4	120
Classroom	ED	ED-#-#	Education	E	0	0	75 m²	4	50
Classroom	ED	ED-#-#	Education	E	0	0	65 m²	4	50
Classroom	ED	ED-#-#	Education	E	0	0	75 m²	4	65
Classrom(with slope)	EA	EA-#-#	Education	E	0	0	90 m²	5	75
Classrom(with slope)	EA	EA-#-#	Education	E	0	0	195 m²	6	155
Classrom(with slope)	EA	EA-#-#	Education	E	0	3	275 m²	8	275
Class Laboratory	EL	EL-#-#	Education	E	0	0	80 m²	4	55
Class Laboratory	EL	EL-#-#	Education	E	0	8	150 m²	4	100
Class Laboratory	EL	EL-#-#	Education	E	0	0	55 m²	4	40
Class Laboratory	EL	EL-#-#	Education	E	0	0	85 m²	4	35
Academician Office	MA	MA-#-#	Administrative	M	0	0	10 m²	3	1
Academician Office	MA	MA-#-#	Administrative	M	0	75	15 m²	3	1
Academician Office	MA	MA-#-#	Administrative	M	0	13	25 m²	3	2
Academician Office	MA	MA-#-#	Administrative	M	0	0	25 m²	3	3
Academician Office	MA	MA-#-#	Administrative	M	0	0	10 m²	3	2
Academician Office(admin)	MY	MY-#-#	Administrative	M	0	1	55 m²	3	1
Academician Office(admin)	MY	MY-#-#	Administrative	M	0	8	25 m²	3	1
Academician Office(admin)	MY	MY-#-#	Administrative	M	0	3	35 m²	3	1
Personnel Office	MI	MI-#-#	Administrative	M	0	3	25 m²	3	2
Personnel Office	MI	MI-#-#	Administrative	M	0	8	15 m²	3	2
Personnel Office	MI	MI-#-#	Administrative	M	0	0	50 m²	3	5
Seminar Room	ES	ES-#-#	Education	E	0	12	45 m²	0	20
Research Laboratory	RM	RM-#-#	Research	R	0	6	75 m²	0	0
Others(education)	EX	EX-#-#	Education	E	computer lab	1	150 m²	0	0
Personnel Office (admin)	MP	MP-#-#	Administrative	M	0	1	35 m²	0	0
Working Space(silent)	LZ	LZ-#-#	Library	L	0	3	100 m²	0	0
Archive					0	1	200 m²	0	0
Archive					0	3	30 m²	0	0
Storage Room					0	2	200 m²	0	0
Cafeteria					for academician	4	8 m²	0	0
	0				0	0	m²	0	0
	0				0	0	m²	0	0
	0				0	0	m²	0	0
	0				0	0	m²	0	0
	0				0	0	m²	0	0
	0				0	0	m²	0	0
Data Room	OC	OC-#-#	Others	O			492 m²		
Mechanical Room	OT	OT-#-#	Others	O					
Cafeteria	GK	GK-#-#	Social	G			419 m²		
Restroom	OW	OW-#-#	Others	O			481 m²		
Circulation	OS	OS-#-#	Others	O			5.373 m²		

Spaces resulting from regulations and legislation in the region should be added.

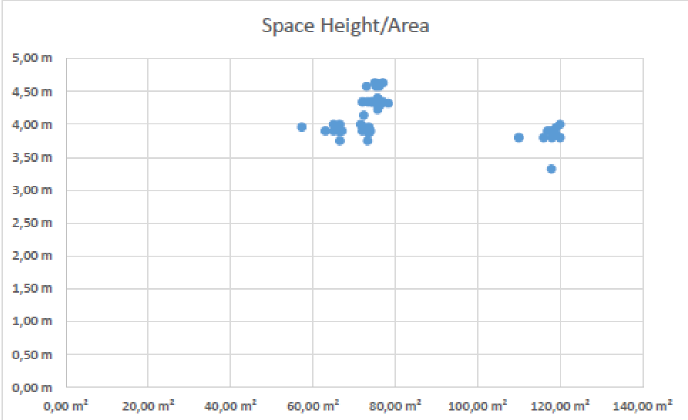
F. K-Means Clustering Algorithm Results for Spaces

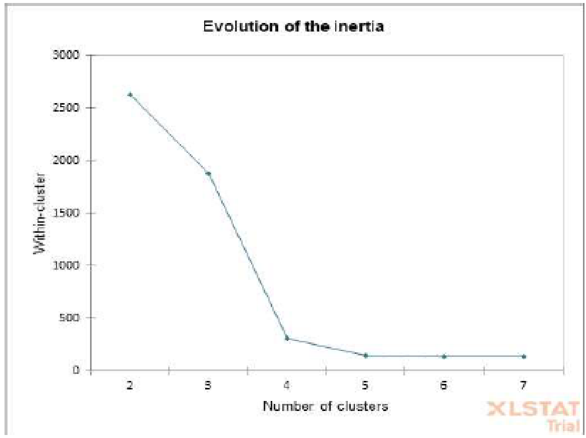
Classroom

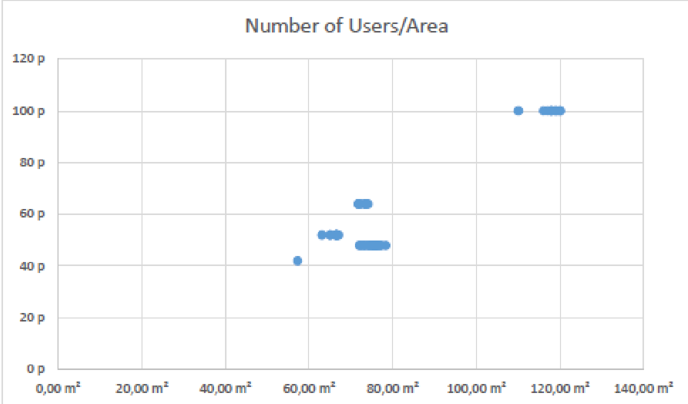
Method: Euclidean distance
Clustering criterion: Determinant(W)
Stop conditions: Iterations = 500 / Convergence = 0,00001
Number of clusters: from 2 to 7
Center: No / Reduce: No
Initial partition: Random
Repetitions: 1
Seed (random numbers): 2123055187

Summary statistics:

Variable	Observat	Obs. with missing data	Obs. without	Minimum	Maximum	Mean	Std.
Area	53	0	53	57,230	120,000	80,759	18,401
Space Height	53	0	53	3,320	4,630	4,111	0,291
Number of Users	53	0	53	42,000	100,000	60,868	19,859







Cluster centroids:

Cluster	Area	Space Height	Number of Users	Sum of weights	Within-cluster variance
1	117,475	3,811	100,000	10,000	8,512
2	75,245	4,395	48,000	24,000	2,155
3	65,112	3,910	51,091	11,000	17,269
4	72,923	3,910	64,000	8,000	0,803

Results by cluster:

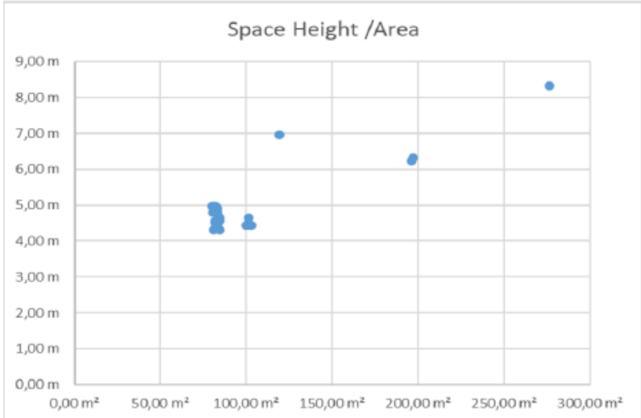
Cluster	1	2	3	4
Number of objects by cluster	10	24	11	8
Sum of weights	10	24	11	8
Within-cluster variance	8,512	2,155	17,269	0,803
Minimum distance to centroid	0,415	0,200	0,916	0,347
Average distance to centroid	1,913	1,092	2,566	0,785
Maximum distance to centroid	7,475	3,246	12,032	1,276

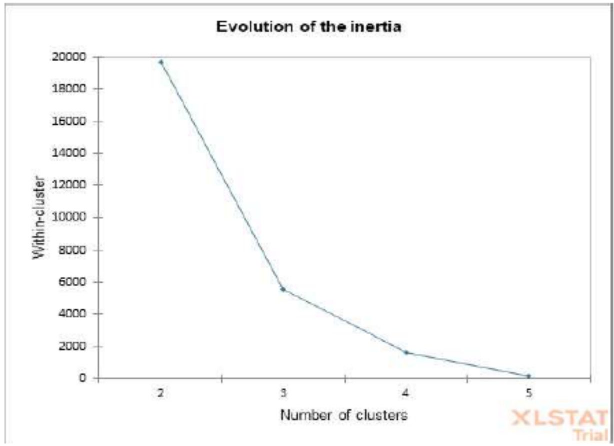
Classroom(with slope)

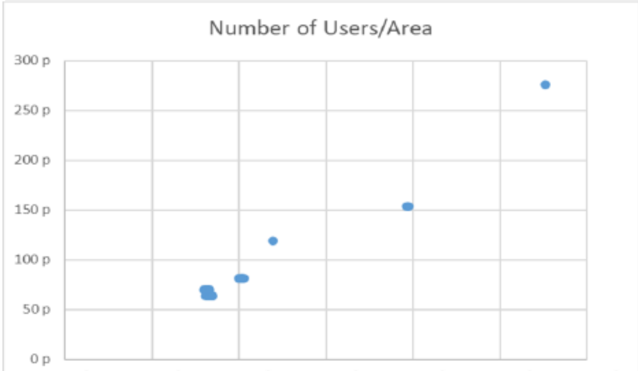
Method: Euclidean distance
Clustering criterion: Determinant(W)
Stop conditions: Iterations = 500 / Convergence = 0,00001
Number of clusters: from 2 to 5
Center: No / Reduce: No
Initial partition: Random
Repetitions: 100
Seed (random numbers): 602355881

Summary statistics:

Variable	Observa	Obs. with missing data	Obs. without	Minimum	Maximum	Mean	Std.
Area	24	0	24	80,000	276,230	105,505	48,522
Space Height	24	0	24	4,300	8,320	5,017	0,973
Number of Users	24	0	24	64,000	276,000	87,917	47,612







Cluster centroids:

Cluster	Area	Space Height	Number of Users	Sum of weights	Within-cluster variance
1	88,683	4,740	72,667	21,000	277,597
2	196,775	6,275	154,000	2,000	0,418
3	276,230	8,320	276,000	1,000	0,000

Results by cluster:

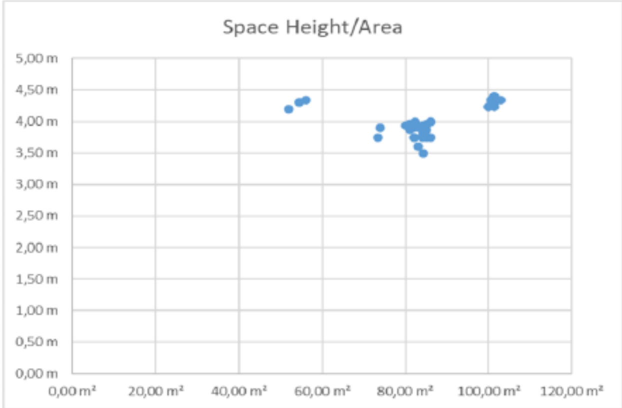
Cluster	1	2	3
Number of objects by cluster	21	2	1
Sum of weights	21	2	1
Within-cluster variance	277,597	0,418	0,000
Minimum distance to centroid	6,460	0,457	0,000
Average distance to centroid	12,804	0,457	0,000
Maximum distance to centroid	55,613	0,457	0,000

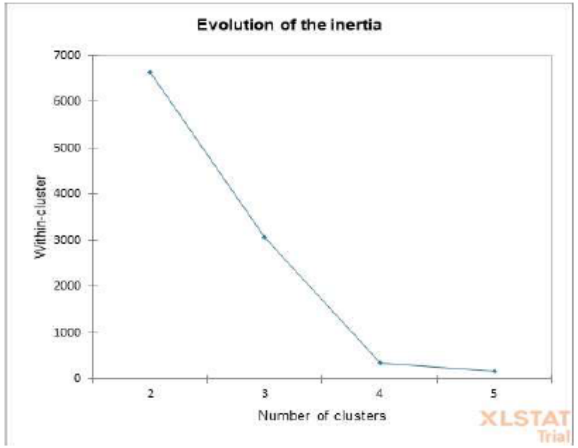
Class Laboratory

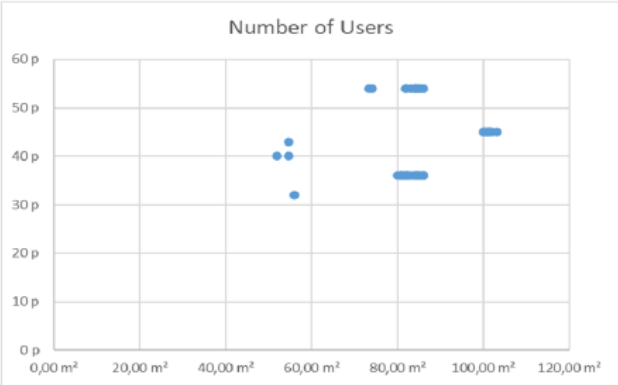
Method: Euclidean distance
Clustering criterion: Determinant(W)
Stop conditions: Iterations = 500 / Convergence = 0,00001
Number of clusters: from 2 to 5
Center: No / Reduce: No
Initial partition: Random
Repetitions: 100
Seed (random numbers): 760621891

Summary statistics:

Variable	Observa	Obs. with missing data	Obs. without	Minimum	Maximum	Mean	Std.
Area	48	0	48	52,000	103,000	85,710	12,924
Space Height	48	0	48	3,500	4,400	4,024	0,245
Number of Users	48	0	48	32,000	54,000	43,354	7,327







Cluster centroids:

Cluster	Area	Space Height	Number of Users	Sum of weights	Within-cluster variance
1	82,273	3,768	54,000	12,000	17,615
2	101,176	4,316	45,000	14,000	0,592
3	54,270	4,285	38,750	4,000	25,017
4	82,958	3,910	36,000	18,000	3,517

Results by cluster:

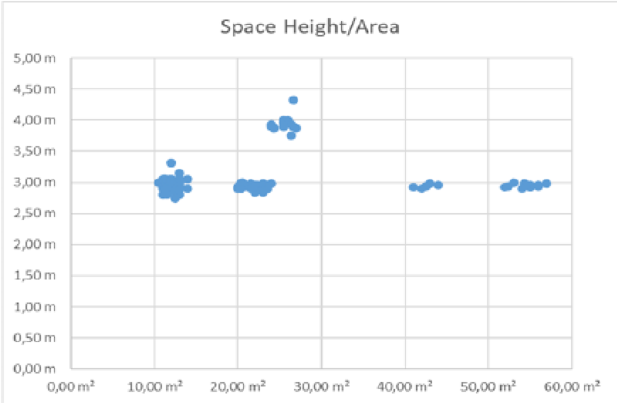
Cluster	1	2	3	4
Number of objects by cluster	12	14	4	18
Sum of weights	12	14	4	18
Within-cluster variance	17,615	0,592	25,017	3,517
Minimum distance to centroid	0,274	0,084	1,279	0,362
Average distance to centroid	2,969	0,519	3,775	1,627
Maximum distance to centroid	8,953	1,824	6,968	3,044

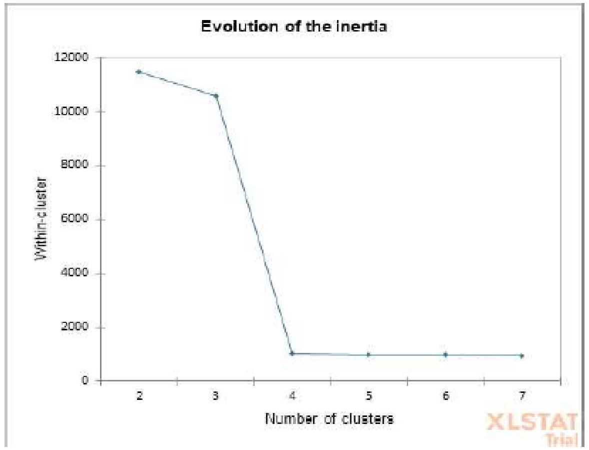
Academician Office

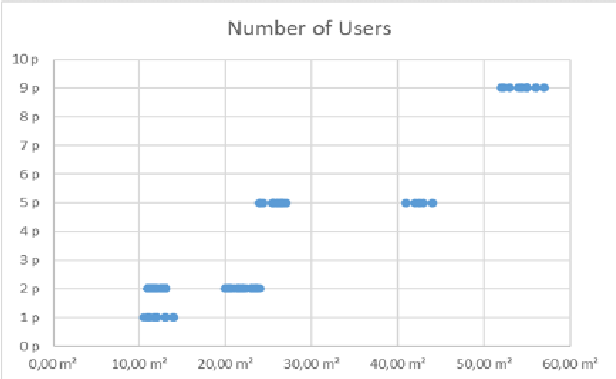
Method: Euclidean distance
Clustering criterion: Determinant(W)
Stop conditions: Iterations = 500 / Convergence = 0,00001
Number of clusters: from 2 to 7
Center: No / Reduce: No
Initial partition: Random
Repetitions: 1
Seed (random numbers): 1849623604

Summary statistics:

Variable	Observat	Obs. with missing data	Obs. without	Minimum	Maximum	Mean	Std.
Area	216	0	216	10,500	57,000	18,046	11,197
Space Height	216	0	216	2,750	4,320	3,011	0,260
Number of Users	216	0	216	1,000	9,000	2,463	1,941







Cluster centroids:

Cluster	Area	Space Height	Number of Users	Sum of weights	Within-cluster variance
1	11,702	3,017	1,000	36,000	0,213
2	12,901	2,939	1,806	62,000	0,275
3	51,199	2,945	7,889	18,000	36,028
4	22,814	3,195	2,778	54,000	6,357
5	11,373	2,916	2,000	46,000	0,086

Results by cluster:

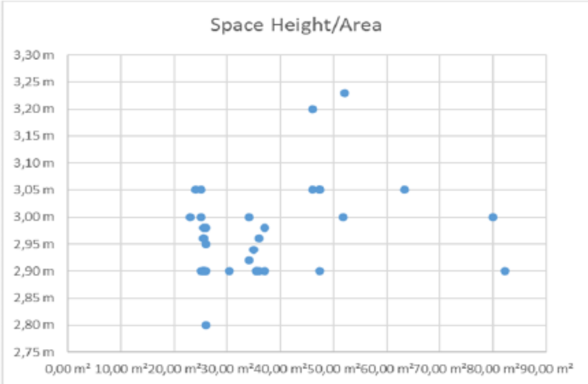
Cluster	1	2	3	4
Number of objects by cluster	36	62	18	54
Sum of weights	36	62	18	54
Within-cluster variance	0,213	0,275	36,028	6,357
Minimum distance to centroid	0,104	0,217	1,370	0,828
Average distance to centroid	0,395	0,429	5,129	2,220
Maximum distance to centroid	1,202	1,367	10,601	4,788

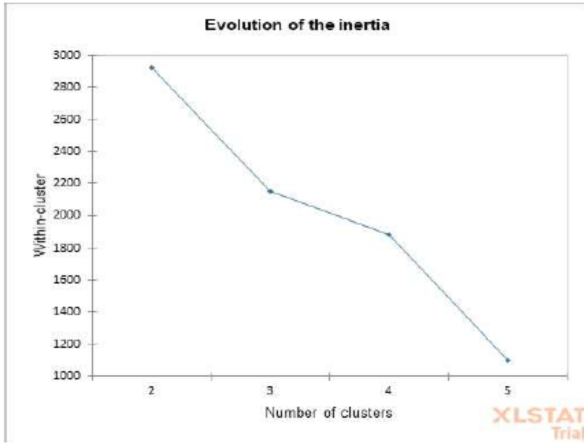
Academician Admin Office

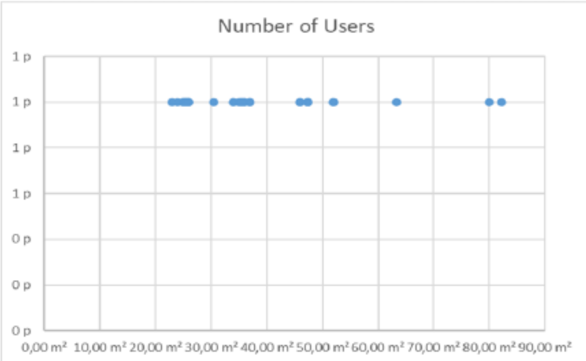
Method: Euclidean distance
Clustering criterion: Determinant(W)
Stop conditions: Iterations = 500 / Convergence = 0,00001
Number of clusters: from 2 to 5
Center: No / Reduce: No
Initial partition: Random
Repetitions: 100
Seed (random numbers): 1588894835

Summary statistics:

Variable	Observa	Obs. with missing data	Obs. without	Minimum	Maximum	Mean	Std.
Area	38	0	38	23,000	82,200	36,609	14,718
Space Height	38	0	38	2,800	3,230	2,969	0,086
Number of Users	38	0	38	1,000	1,000	1,000	0,000







Cluster centroids:

Cluster	Area	Space Height	Number of Users	Sum of weights	Within-cluster variance
1	55,506	3,044	1,000	11,000	184,710
2	27,230	2,940	1,000	22,000	14,384
3	36,300	2,928	1,000	5,000	0,452

Results by cluster:

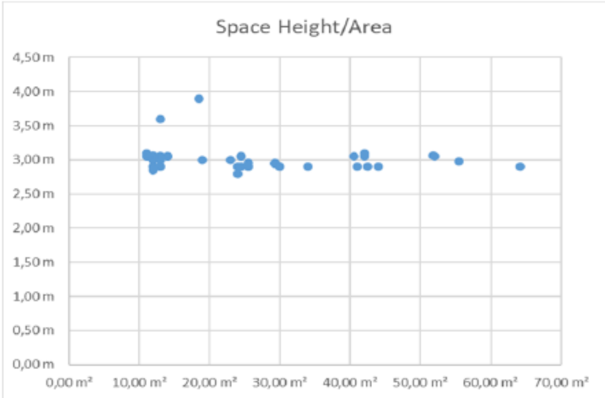
Cluster	1	2	3
Number of objects by cluster	11	22	5
Sum of weights	11	22	5
Within-cluster variance	184,710	14,384	0,452
Minimum distance to centroid	3,511	1,230	0,301
Average distance to centroid	10,715	2,974	0,561
Maximum distance to centroid	26,694	8,200	0,800

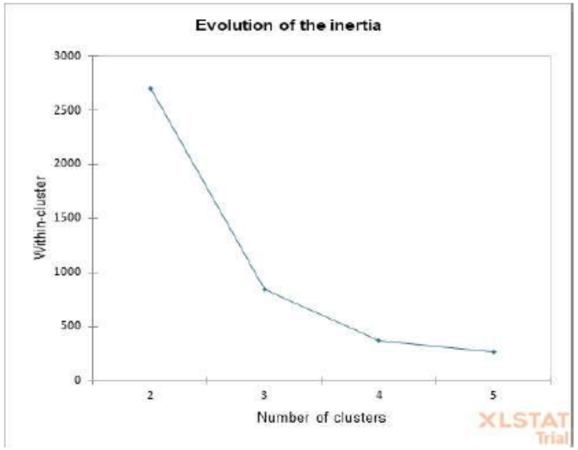
Personnel Office

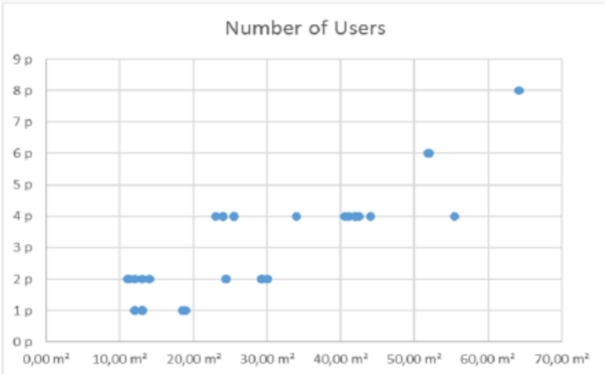
Method: Euclidean distance
Clustering criterion: Determinant(W)
Stop conditions: Iterations = 500 / Convergence = 0,00001
Number of clusters: from 2 to 5
Center: No / Reduce: No
Initial partition: Random
Repetitions: 100
Seed (random numbers): 340970876

Summary statistics:

Variable	Observa	Obs. with missing data	Obs. without	Minimum	Maximum	Mean	Std.
Area	45	0	45	11,000	64,230	25,314	14,141
Space Height	45	0	45	2,800	3,900	3,009	0,181
Number of Users	45	0	45	1,000	8,000	2,711	1,590







Cluster centroids:

Cluster	Area	Space Height	Number of Users	Sum of weights	Within-cluster variance
1	26,840	2,934	2,933	15,000	11,177
2	13,043	3,076	1,500	20,000	4,923
3	47,567	2,988	4,800	10,000	65,360

Results by cluster:

Cluster	1	2	3
Number of objects by cluster	15	20	10
Sum of weights	15	20	10
Within-cluster variance	11,177	4,923	65,360
Minimum distance to centroid	1,713	0,502	3,657
Average distance to centroid	2,958	1,565	6,764
Maximum distance to centroid	7,239	5,969	16,968

G. Space Tags from YMESS AND MEKSIS

Space Function				Main Function		
TR	EN	Meksis Code		TR	En	Meksis Code
Derslik	Classroom	ED		Eğitim	Education	E
Amfi	Classroom (with slope)	EA		Eğitim	Education	E
Seminer Odaları	Seminar Room	ES		Eğitim	Education	E
Özel Amaçlı Eğitim Alanları	Education Area for Special Scope	EO		Eğitim	Education	E
Eğitim Amaçlı Laboratuvar	Class Laboratory	EL		Eğitim	Education	E
Diğer	Others(education)	EX		Eğitim	Education	E
Merkezi Araştırma Laboratuvarı	Research Laboratory	RM		Araştırma	Research	R
Tematik Araştırma Laboratuvarı	Laboratory for Themes	RT		Araştırma	Research	R
Teknoloji Transfer Ofisleri	Office for Technology Transfer	RO		Araştırma	Research	R
Diğer	Others(research)	RX		Araştırma	Research	R
Akademik Yönetici Ofisleri	Academician Office(admin)	MY		Yönetim	Administrative	M
Akademik Personel Ofisleri	Academician Office	MA		Yönetim	Administrative	M
İdari Personel Ofisleri	Personnel Office (admin)	MP		Yönetim	Administrative	M
İdari Yönetici Ofisleri	Personnel Office	MI		Yönetim	Administrative	M
Diğer	Others(admin)	MX		Yönetim	Administrative	M
Tıp Fakültesi Hastanesi	Medical Faculty Hospital	HT		Sağlık Hizmeti	Health Services	H
İhtisas Hastanesi	Hospital	HI		Sağlık Hizmeti	Health Services	H
Diş Hastanesi / Diş Hekimliği Fakültesi Eğitim ve Uygulama Merkezi	Dental Hospital	HD		Sağlık Hizmeti	Health Services	H
Hayvan Hastanesi	Animal Hospital	HH		Sağlık Hizmeti	Health Services	H
Mediko - Sosyal	Health Center	HM		Sağlık Hizmeti	Health Services	H
Diğer	Others(health)	HX		Sağlık Hizmeti	Health Services	H
Sesli Alanlar	Working Space(quite)	LS		Kütüphane	Library	L
Sessiz Alanlar	Working Space(silent)	LZ		Kütüphane	Library	L
Özel Çalışma Alanı	Working Space(individual)	LO		Kütüphane	Library	L
Diğer	Others(library)	LX		Kütüphane	Library	L
Kongre ve Kültür Merkezi/Kongre Salonu/kültür Merkezi/Oditoryum	Auditorium	CC		Toplantı ve Konferans	Congress and Meeting	C
Konferans Salonu	Conference Hall	CS		Toplantı ve Konferans	Congress and Meeting	C

Toplantı Salonu	Meeting Room	CM		Toplantı ve Konferans	Congress and Meeting	C
Diğer	Others (meeting)	CX		Toplantı ve Konferans	Congress and Meeting	C
Yemekhane / Menza	Eating Area	GY		Sosyal Alan	Social	G
Kafeterya / Kantin	Cafeteria	GK		Sosyal Alan	Social	G
Öğrenci Kulüpleri	Students Clubs	GC		Sosyal Alan	Social	G
Uygulama Oteli / Konukevi /Misafirhane	Guest Rooms	GO		Sosyal Alan	Social	G
Anaokulu / Kreş / Gündüz Bakımevi	Nursery School	GA		Sosyal Alan	Social	G
Diğer	Others(Social)	GX		Sosyal Alan	Social	G
Kapalı Spor Salonu	Sports Hall	SS		Spor Alanı	Sport	S
Yüzme Havuzu	Swimming Pool	SY		Spor Alanı	Sport	S
Basketbol Sahası	Basketball	SB		Spor Alanı	Sport	S
Voleybol Sahası	Voleyball	SV		Spor Alanı	Sport	S
Teniz Kortu	Tennis Court	ST		Spor Alanı	Sport	S
Futbol Sahası	Football	SF		Spor Alanı	Sport	S
Diğer	Others(sport)	SX		Spor Alanı	Sport	S
Öğrenci Yurtları	Student Dormitory	AY		Barınma	Accomodation	A
Lojmanlar	Personnel House	AL		Barınma	Accomodation	A
Ticari	Commercial Space	OK		Diğer	Others	O
Hangar	Depot	OH		Diğer	Others	O
Otopark	Car Parking	OZ		Diğer	Others	O
Garaj	Garage	OG		Diğer	Others	O
Islak Hacimler	Wet Area	OI		Diğer	Others	O
Tuvalet	Restroom	OW		Diğer	Others	O
Banyo/Duş	Bathroom	OB		Diğer	Others	O
Hava Sirkülasyonu (Galeri Boşluğu)	Atrium	OA		Diğer	Others	O
Kullanıcı Sirkülasyonu	Circulation	OS		Diğer	Others	O
Bilgi İşlem Odası	Data Room	OC		Diğer	Others	O
Tesisat Odası	Mechanical Room	OT		Diğer	Others	O
Atölye	Atelier	OR		Diğer	Others	O
Arşiv	Archive	OP		Diğer	Others	O
Depo	Storage Room	OD		Diğer	Others	O
Matbaa	Press Room	OM		Diğer	Others	O
Diğer	Others	OX		Diğer	Others	O

CURRICULUM VITAE

Surname, Name: Çalışkan, Ekrem Bahadır
Nationality: Turkish

EDUCATION

Degree	Institution	Year of Graduation
MS	METU Building Science of Architecture	2010
BS	METU Architecture	2005
High School	Samsun Anadolu High School, Samsun	2000

WORK EXPERIENCE

Enrolment	Place	Year
Instructor	AYBU Architecture	2021-Present
Founder	Ebc Architecture Company	2016-2021
Founder	Atus Architecture Company	2007-2016

PUBLICATIONS

1. Çalışkan, E. B., & Pekeriçli, M. K. (2020). Knowledge Capturing in Design Briefing Process for Requirement Elicitation and Validation. *6th international Project and Construction Management Conference (e-IPCMC2020)* (pp. 215–224). ITÜ.

2. Çalışkan, E. B., & Karakuş, F. (2021). Titanium-Zinc as an Architectural Material: ETU Campus Gate Project. *1st International Conference on Advances in Engineering, Architecture, Science and Technology, Erzurum Technical University,* 522–530

3. Karakuş, F., & Çalışkan, E. B. (2021). Use of Adobe Material in Religious Architecture: 14-15. Century Mosques in Ankara. *1st International Architectural Sciences and Applications Symposium*, 369–381.

4. Sarı, R., & Çalışkan, B. E. (2021). Impact of Remote Working Upon User's Well-Beings. *4th International Symposium on Art and Design Education: Art and Design during and after the Covid-19 Period*, 488–496