INVESTIGATION OF THE BIM IMPLEMENTATION PROCESS IN THE CONSTRUCTION PHASE: CASE OF THE TURKISH COMPANIES

by

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ABSTRACT

INVESTIGATION OF THE BIM IMPLEMENTATION PROCESS IN THE CONSTRUCTION PHASE: CASE OF THE TURKISH COMPANIES

Architectural, Engineering and Construction (AEC) industries are in a transition process that deeply affects the long-established way of collaboration to complete a project. Building Information Modeling (BIM) is at the heart of this process by enabling all the data to be digitally represented. Companies have spent great efforts and resources to implement BIM. In order to achieve this transition process successfully, some critical factors must be identified. The primary objective of this study is to systematically identify the critical success factors (CSFs) of BIM implementation process in the construction phase for Turkish construction industry. In this respect, 45 Research papers have been reviewed and an initial list of CSFs have been developed. Among those, frequency was counted to reveal the significance of each factor in the literature based on how many papers have referred them. A comprehensive framework, representing the BIM implementation process, has been developed that consists of 6 components namely; drivers, inputs, enablers, barriers, benefits and impacts. CSFs have assigned under those components based on their functions. Three levels of influences namely, industry level, firm level and project level are defined. 18 Case projects have been examined via interviews with the project executives to assess the significance of identified CSFs in real construction projects. Interviewees are asked to specify the significance of the relevant CSF on a 1-5 Likert scale based on their experience in that particular project. Interviewees are also asked to share their own experiences during the BIM transition process. Comparison of the literature and the case study shows the key points that are discussed within the paper. This study is expected to identify the significance of CSFs in order to achieve the BIM implementation process successfully.

ÖZET

İNŞAAT AŞAMASINDA BIM UYGULAMA SÜRECİNİN İNCELENMESİ: TÜRK FİRMALARI VAKA ÇALIŞMASI

İnşaat sektörü, uzun zamandır süregelen iş birliği modelini derinden etkileyen bir dönüşüm süreci içerisindedir. Yapı Bilgi Modellemesi (YBM) bütün bilgilerin dijital olarak yansıtılmasına olanak sağlayarak bu dönüşüm sürecinin tam kalbinde yer almaktadır. Firmalar, YBM uygulaması için yüksek bir oranda efor ve kaynak sarf etmektedirler. Bu dönüşüm sürecinin başarılı bir şekilde tamamlanması için bazı kritik faktörlerin belirlenmesi gerekmektedir. Bu çalışmanın birincil amacı, Türk inşaat sektöründe yapım aşamasında YBM uygulamaları ile ilgili kritik başarı faktörlerinin (KBF) sistematik bir şekilde belirlenmesidir. Bu doğrultuda, 45 Farklı araştırma incelenmiş ve KBF'lerin öncül bir listesi çıkarılmıştır. Bu faktörlerin literatürde kaç farklı makalede bahsedilmiş olmasına dayanarak önemlerinin ölçülmesi için bahsedilme sıklığı kaydedilmiştir. YBM Uygulama sürecini temsil eden kapsayıcı bir sistem geliştirilmiş olup, bu sistem "itici güçler", "girdiler", "engeller", "katalizörler", "faydalar" ve "etkiler" olmak üzere 6 ayrı parametreden oluşmaktadır. Belirlenen KBF'ler fonksiyonları doğrultusunda bu parametelerin altına atanmıştır. Sektörel seviye, firmasal seviye ve projesel seviye olmak üzere 3 ayrı etki seviyesi belirlenmiştir. Belirnen KBF'lerin gerçek inşaat projelerindeki öneminin belirlenmesi amacı ile 18 ayrı proje vaka analizi olarak incelenmiş, her birinde görev alan yetkililer ile mülakatlar yapılmıştır. Görüşülen yetkililerin kendi projelerinde yaşadıkları deneyimleri baz alarak belirlenen KBF'lerin önem derecelerini 1'den 5'e kadar belirtmeleri istenmiştir. Görüşülen yetkililerin aynı zamanda YBM geçiş sürecinde yaşadıkları tecrübelerini de aktarmaları istenmiştir. Literatür ve vaka analizlerinin kıyaslanması sonucunda önemli noktalar belirlenmiş ve bu çalışma dahilinde tartışılmıştır. Bu çalışmanın, YBM uygulama sürecinin başarılı bir şekilde tamamlanması için gerekli olan KBF'lerin önemini belirlemesi beklenmektedir.

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LIST OF ACRONYMS/ABBREVIATIONS

2D	Two Dimensional
3D	Three Dimensional
4D	Four Dimensional
5D	Five Dimensional
6D	Six Dimensional
7D	Seven Dimensional
AEC	Architectural, Engineering, Construction
AGC	The Associated General Contractors of America
AIA	The American Institute of Architects
AR	Augmented Reality
AVG	Average
BCA	Business Council of Australia
BIM	Building Information Modeling
BREEAM	Building Research Establishment's Environmental Assessment Method
BS	British Standards
CAD	Computer Aided Design
CASBEE	Comprehensive Assessment System for Building Environmental Efficiency
COBIM	National Common BIM Requirement
CSFs	Critical Success Factors
ENR	Engineering News Record
ERP	Enterprise Resource Planning
FM	Facility Management
GC	General Contractor
HSE	Health, Safety and Environment
HVAC	Heating, Ventilation and Air Conditioning
IFC	Industry Foundation Class
IFD	The International Framework of Dictionaries

IPD	Integrated Project Delivery
LC	Lean Construction
LCA	Life Cycle Assesment
LEED	Leadership in Energy and Environmental Design
LOD	Level of Detail / Level of Development
MAX	Maximum
MEP	Mechanical, Electrical, Plumbing
MIN	Minimum
N/A	Not Applicable
NBIMS	National BIM Standards
nD	n Dimensional
PM	Project Management
PPP	Public Private Partnership
RFI	Request for Information
S	Strength
UAVs	Unmanned Aerial Vehicles
USGBC	The United States Green Building Council
V-SAFE	Virtual Safety Analysis For Engineering Applications
VR	Virtual Reality
W	Weakness

1. INTRODUCTION

Since Building Information Modeling (BIM) has been deeply affecting the Architectural, Engineering, Construction (AEC) Industries, it became a critical research area for researchers and academicians. Building Information Modeling is one of the most fascinating improvements in the construction industry. BIM models are the digital simulations of not only the building itself but also the construction and usage process as a whole.

This research is an exploration of the BIM implementation process in construction phase with all aspects. The core objective is to identify the critical success factors (CSFs) for all components of the implementation process. Below sections briefly outline the background of the research, problem determination, problem statement, previous studies in this topic, aim and objectives of the study, research methodologies utilized, significance of the study, scope and limitations and organization of the thesis.

1.1. Research Background

Architecture, Engineering and Construction (AEC) industries have been experiencing a transition process to implement the Building Information Modeling system (McGraw-Hill Construction, 2012). The transition deeply affects the way of doing business in the industry. Professionals have been facing with different situations through the process. It is critical for the AEC companies to achieve that transition process successfully.

The construction industry is highly competitive and therefore it is essential to adopt new technologies to survive within the competition. Construction companies seek to develop BIM capabilities for competitive advantage (Eastman *et al.*, 2011). A well prepared BIM implementation plan is the key for achievement. Thus, various factors need to be considered before the implementation. First of all, those factors need to be identified.

Based on this background, this study analyzes all the components of the BIM implementation process together, investigates the critical success factors and evaluates them on real case study projects.

1.2. Determination of the Problem

BIM is a game changing development for the construction industry. Globally, BIM implementation levels indicates very high adoption rates (Ghaffarhouseini *et al.*, 2017). It is expected that BIM to be comprehensively utilized in various countries and the utilization ratio is rapidly increasing (Smart Market Report, 2014). However, the industry is very slow to adopt BIM (World Economic Forum, 2018; Smith, 2014).

One of the main reasons for the slow adoption is that there is not a clear path for the BIM implementation. AEC industry professionals are under a big pressure to find the right way for the BIM implementation. All around the world, AEC companies have been spending lots of their funds for BIM investments. In this highly competitive environment, AEC industry professionals need to be aware of the key critical success factors (CSFs) that should be considered while planning the BIM implementation process for their companies.

1.3. Statement of the Problem

Current research within the literature focused on different components of the BIM implementation process. There is only a few research investigated the process comprehensively and/or evaluate it on real case study examples.

This study investigates the BIM implementation process by using a comprehensive framework to identify the critical success factors. Identified CSFs are evaluated on real case study projects by industry experts.

1.4. Related Studies

Majority of the research in the literature tried to investigate the effectiveness of Building Information Modeling (Kareem and Fernanda, 2018; Kovacic and Filzmoser, 2014; Arayici *et al.*, 2010). In addition, there are also lots of research regarding the definition of BIM (Sullivan and Barlish, 2012; Arayici *et al.*, 2012) and some other research in the literature primarily focused on adoption of BIM in the developed countries (Ozorhon and Karahan, 2016).

In the literature, there are hundreds of papers discussed BIM from different perspectives and with different approaches. Some research focused on the implementation process, some focused on the results and others on specific cases to measure the performance.

Research that focused on the implementation process are generally discussed the risks and challenges together with the drivers for the BIM implementation. Dawood *et al.* (2012), has conducted a study to investigate barriers and drivers of BIM and collected qualitative and quantitative data through a web-based questionnaire. Research group have identified time and cost, resistance to change and lack of experience as some of the main barriers for BIM implementation. Based on the survey results, same study revealed that integrated project delivery (IPD) systems, external and internal supports are the main drivers for BIM adoption. BIM usage argued to be limited unless the technology, end users and the process combined. Based on a research questionnaire targeting the top 100 UK contractors, Eadie *et al.* (2013), demonstrated that significance of the driving factors of BIM implementation are highly correlated with the experience level of the respondent. Although non-users of BIM ranked the pressure (pressure of government, client or competition) as the top driver, users of BIM ranked the clash detection and reduced rework as the top driver based on their experience.

Research focused on the results of BIM implementation are mainly aimed to define the benefits and impacts of the implementation process. Ghaffarianhoseini *et al.* (2016), discussed the reality of BIM by reviewing the literature and grouped the clear current benefits of BIM into 9 different components as technical, knowledge management, standardization, diversity management, integration, economic, planning / scheduling, building LCA and decision support benefits. They expected BIM to have transformational impact on the AEC industry. Stanley and Thurnell (2014), designed a cross-sectional questionnaire to investigate the benefits of 5D BIM and stated BIM provides advantages for quantity surveying by improving the efficiency and visualization together with earlier risk identification. A recent study based on statistical analysis of a comprehensive questionnaire has revealed 13 different positive returns of BIM. The leading benefits has been identified as improving multiparty communication and 3D visualization by Jin *et al.* (2017).

Other research that focused on some specific cases tried to describe best practices, measure performances and identify the inputs and enablers for the BIM implementation process. Abbasnejad *et al.* (2016) tried to identify key enablers for an effective BIM implementation. Based on an extensive literature review, they identified the enablers for different tasks that need to be achieved during implementation process and conclude that BIM is an organizational innovation and therefore organizational innovation principles are essential to be considered.

In the literature, there are limited number of studies that tried to analyze the components of the BIM implementation process with the underlying critical success factors (Ozorhon and Karahan, 2016; Shang *et al.*, 2014).

1.5. Aim and Objectives

The primary objective of this thesis study is to investigate the critical success factors for the BIM implementation process in construction phase of the projects of Turkish AEC companies. For this purpose, CSFs are identified via an extensive literature review and rated by industry experts from different types of case projects. Findings are expected to reveal the significance of the critical success factors. Objectives of this research are listed as follows:

- To conduct an extensive literature review regarding the CSFs of BIM implementation.
- To develop a comprehensive framework for the BIM implementation process.
- To evaluate the CSFs with industry experts for real case projects.
- To shed a light on the BIM implementation process and give industry professionals a lead.

1.6. Research Methodology

First of all, the problematic process of the BIM implementation decided to be investigated. The study started with an extensive literature review and CSFs were identified and frequencies are counted based on the literature. After an initial evaluation of the literature findings, a comprehensive framework was developed. Three levels of influences namely, industry level, firm level and project level are defined. Then, case studies are performed with industry experts from 18 case study projects. During the face to face interviews, interviewees are asked to evaluate the significance of those CSFs on a 1-5 Likert scale (5 corresponds to very important) considering their experiences in the selected projects. Findings are compared according to literature frequencies, influence levels and project types.

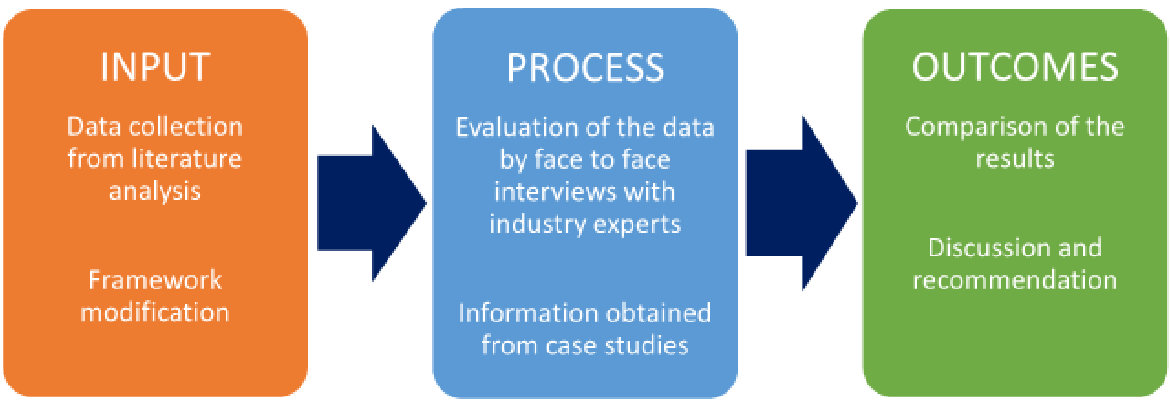

Figure 1.1. Conceptual Phases of the Research

1.7. Significance of the Study

Findings of this thesis study may provide significant information about the BIM implementation process in construction phase. A good understanding of the critical success factors may guide further researchers to investigate a certain path for BIM implementation. Beside, this thesis study may guide the industry professionals who are at the beginning of the BIM implementation for their project or company.

1.8. Scope and Limitations

This thesis study conducted only by considering the BIM implementation process in the construction phase. Thus, the scope of the study limits the outcomes for different phases such as design or facility management. In this research, all the data collected from the relevant previous studies in the literature, consequently the data collection were limited to literature. Last but not the least, the collected data evaluated by experts from medium to large size construction projects of Turkish construction companies. Thus, the outcomes are confined within their opinions and may not be applicable for construction companies outside of Turkey.

1.9. Organization of the Thesis

This thesis includes 6 chapters. In Chapter 1, introductory information was given together with the research background, methodology, objectives, significance, scope and limitation of the thesis. Chapter 2 includes detailed information about BIM concept in based on the literature. Chapter 3 describes the utilized methodologies within the context of this study. Chapter 4 outlines the findings from both literature analysis and the case studies. In Chapter 5, results are discussed and compared. Lastly, Chapter 6 includes conclusions and recommendations for further studies. Outline of the organization of this thesis is as seen in Figure 1.2.

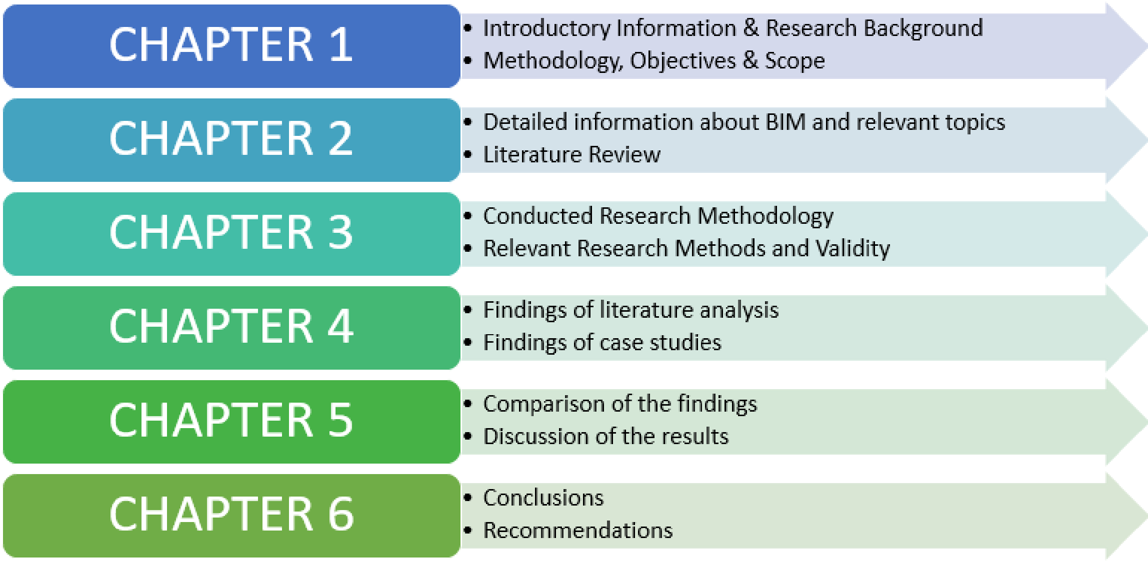

Figure 1.2. Organization of the Thesis

2. INVESTIGATION OF THE BIM IMPLEMENTATION PROCESS IN CONSTRUCTION PHASE

In the previous chapter, introductory information for the thesis study was given. This chapter aims to give detailed information about BIM and related concepts based on the relevant literature sources.

2.1. Introduction

The AEC industries have unique product/process/group characteristics that create a need for an effective information flow management. This need was first fulfilled by the computer aided design (CAD) applications. However, the need has grown up as the projects got larger and the technology gone further. Traditional design communication tools are the project specifications and the two dimension (2D) layouts, however those tools create ambiguities within project parties (Chelson, 2010). Especially recent construction projects have a wide range of information that needs to be managed properly by fluent communication. This traditional method of collaboration is inefficient. It brings lot of clarifications, change orders and re-works that consequently results in time and resource waste. At this point, BIM enables the AEC companies to manage all the project information via a single model. A well-developed BIM model provides many types of information (technical, schedule, cost, procurement, energy analysis, maintenance schedule etc.) regarding the project.

Labor productivity of the AEC industries have been decreasing gradually since the early 1960s (Hergunsel, 2011). One of the main reasons for this decreasing trend is the lack of communication among the project parties. The labor productivity index for U.S. construction industry versus all non-farm industries between 1964 and 2001 can be seen in the Figure 2.1.

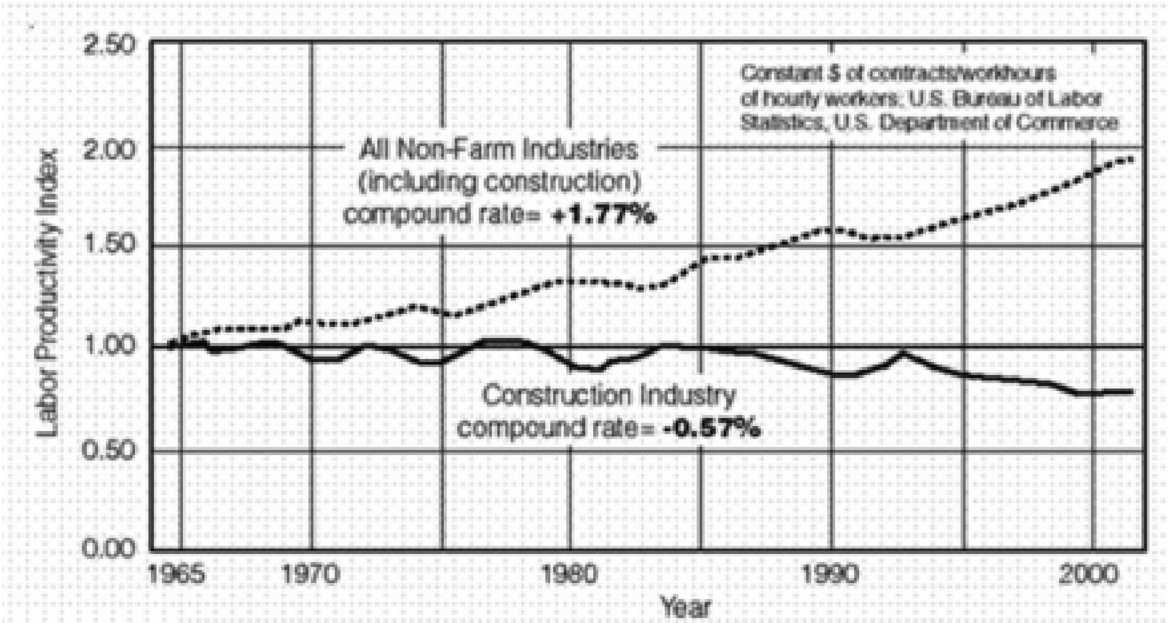

Figure 2.1. Labor Productivity Index For U.S. Construction Industry vs All Non-farm Industries from 1964 to 2001 (McGraw Hill Construction, 2008)

BIM has been considered as a solution to facilitate the continuous productivity improvement in AEC industries (Qian, 2012). It allows industry professionals to collaborate in a better way. In this way, the job that needs to be done can be completed correctly, accurately and timely. BIM implementation rate has been increasing in AEC industries (McGraw-Hill Construction, 2012). Since the BIM usage rate increase, there are lots of issues to be identified in order to ensure a smooth implementation process.

2.1.1. Definition of BIM

The acronym “BIM” has been widely used for “Building Information Modeling”. It has a meaning of creating a model that contains all types of necessary information for a structure. Many people from construction industry misunderstood the concept of BIM and confused about the difference between three dimensional (3D) modeling and BIM. Using 3D models does not mean utilizing BIM. In order to clarify this confusion, understanding the definitions is crucial. In the literature, there are lots of research that defined BIM. Some of those definitions are as follows:

- National BIM Standards Committee of USA defined BIM as, "a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle; defined as existing from earliest conception to demolition. A basic premise of BIM is collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or modify information in the BIM to support and reflect the roles of that stakeholder." (NBIMS, 2007).
- Another definition by The American Institute of Architects is as, "a model-based technology linked with a database of project information, and this reflects the general reliance on database technology as the foundation. It is identified as one of the most powerful tools to support Integrated Project Database. Because BIM can combine, among other things, the design, fabrication information, erection instructions, and project management logistics in one database, it provides a platform for collaboration throughout the project's design and construction phase" (AIA National, 2007).
- The Associated General Contractors of America defined BIM as, "the process of generating and managing building information model through the use of three dimensional, intelligent design information" (The Associated General Contractors (AGC) of America, 2014).
- Chuck Eastman explains that "BIM is not a thing or a type of software but a human activity that ultimately involves broad process changes in construction." (Eastman *et al.*, 2008)
- "The information management process throughout the lifecycle of a building which mainly focuses on enabling and facilitating the integrated way of project flow and delivery, by the collaborative use of semantically rich 3-D digital building models in all stages of the, project and building lifecycle." (Underwood and Isikdag, 2011)

2.1.2. History of Building Information Modeling

As being one of the oldest industries, The Construction Industry, has evolved too much especially in the last 50 years. The two dimensional hand drawings are the father of the current design systems. The natural need for a systematic and solid modeling tool emerged back in 1970s. BIM has been conceptually utilized in those years as CAD-Aided design via ArchiCAD which was first developed in 1980s. The BIM term with its actual definition was first appeared in 1990s. BIM is an evolution of traditional CAD system and it is more intelligent, user-friendly and inter-operable. With the development of Revit software in 2000s, BIM become more popular and adoption have been continuously increasing all around the world. The AEC industry actually started to utilize BIM in mid 2000s (Azhar *et al.*, 2012). In the last decade, BIM adoption was increased with an acceleration since the governments and clients are getting aware of its benefits. A research conducted by McGraw Hill Construction (2012) stated that BIM adoption in North America had grown 17% in 2007 and 71% in 2012.

2.2. Understanding the Concept of BIM

BIM is one of the most fascinating improvements in the AEC industries (Eastman *et al.*, 2011; Stanley and Thurnell, 2014). BIM is currently considered as the ultimate for project delivery (Azhar, 2008). BIM is an innovative approach for designing, constructing and managing a structure by providing consistent, accurate and reliable information. BIM helps industry professionals to model the physical and functional characteristics of a structure in three dimension.

2.2.1. Applications of BIM

BIM has various applications within the construction industry. Users can use it for different purposes through all stages of the construction process. BIM also named as “nD Modeling Tool” because it allows modeling a project with more than 3 dimensions. The term ’nD’ actually comes from the number of dimensions that the project represented digitally (Bryde *et al.*, 2013). 3D are the regular three dimensions and it can increase up to seven dimensions (7D) depends on the usage purpose of BIM. Definitions of the dimensions are as followed; 4D representation is for planning and scheduling (time component), 5D representation is for cost controlling and estimating (cost component), 6D representation is for green building designs and energy analysis (sustainability component) and 7D representation is for facility management purposes (World Economic Forum, 2018). A graphical representation of the nD modeling can be seen in Figure 2.2.

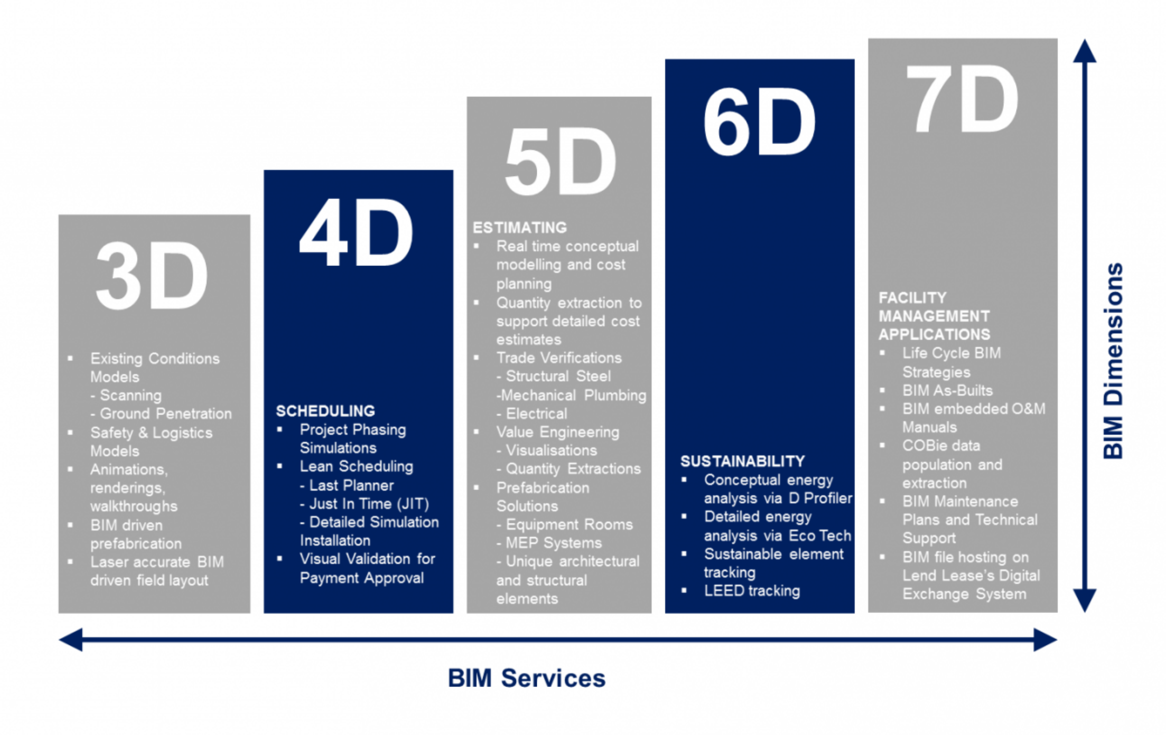

Figure 2.2. Graphical Representation of n-D BIM Application

2.2.1.1. 3D BIM Application. 3D Models are digital representations of physical body of the building by collection of points with the drawings. BIM provides an integrated 3D model in a collaborative BIM environment from which all stakeholders can access and manage the data and information according to their special needs (Alazmeh *et al.*, 2017). 3D Representation of the building in a model enables the project parties to review the building in three dimensions digitally, and to easily revise throughout the project life cycle, from preliminary designing stage, to construction, to facility operation and then to demolition. 3D visualization on BIM helps the project parties to manage their interdisciplinary collaboration more effectively in modeling and analyzing processes (Kovacic *et al.*, 2015). In addition, the accurate data that collected and stored throughout the project life cycle enables users to add new value to the predictive models. 3D models increase the visualization of the building and improve the communication of parties. It also improves the collaboration and reduces the reworks. Improving multiparty communication and understanding from 3D visualization are the most recognized returns from BIM investment (Jin *et al.*, 2017)

2.2.1.2. 4D BIM Application. The term 4D refers to the 3D plus the fourth dimension: 'time'. 4D Models are graphical perspectives of a model representing the time dimension (Kunz and Fischer, 2011) Time component indicates scheduling and planning works of the construction activities. 4D Planning is among the major drivers for innovation in the construction industry (Kassem *et al.*, 2012). 4D BIM models are used for the purpose of construction site planning and scheduling. The fourth dimension of the BIM model allows the project parties to view and manage the progress of the construction activities throughout the project life cycle. 4D Models can be used for constructability analysis, project delivery schedules and procurement planning (Sun *et al.*, 2015) Application of 4D BIM models can improve the control over conflicts during the construction process (Kassem *et al.*, 2012). 4D Models also allow the participants to handle with the complexity of change orders that occurs during the construction process. Using BIM with 4D models provide project stakeholders optimization of activities, planning and coordination.

2.2.1.3. 5D BIM Application. The term 5D refers to the 4D plus the fifth dimension: 'cost'. Cost component of BIM indicates estimating and cost analysis works for the construction projects. A schematic 5D model provides quantities and as the detail level increases, even the cost effect of design changes can be calculated from the model (McGraw Hill Construction, 2008). 5D BIM models are mainly used for budget tracking and cost analysis works. "Performing value engineering and cost estimation from the beginning of the design process would potentially enable a faster and more cost-effective project delivery process, higher quality buildings, and increased control and predictability for the owner" (Forgues *et al.*, 2012). As it is understandable from that statement, application of 5D BIM models improves the accuracy and predictability construction project cost estimations, scope changes and materials. 5D BIM models allow project parties to discuss over different scenarios for the process. 5D Modeling is essential for an effective change management. It also enables to develop a cost effective construction that decrease the amount of wastes. 5D Modeling provides advantages for quantity surveying by increasing efficiency, visualization of construction details, and earlier risk identification (Stanley and Thurnell, 2014)

2.2.1.4. 6D BIM Application. The term 6D refers to the 5D plus the sixth dimension: 'sustainability'. Sustainability component of BIM indicates green building design works for the energy consumption calculations. 6D BIM models help to conduct energy consumption analyses for the designers. Application of 6D BIM models allows designers to perform more comprehensive and accurate energy consumption estimates at the preliminary designing stage. In addition, usage of 6D models also allows measurement and verification during the operational phase of the building. In order to make service providers (facility managers) fully benefited from the BIM, 6D BIM application is needed. Analyzing 6D BIM information may reveal options to reduce a structure's consumption (World Economic Forum, 2018). Leadership in Energy and Environmental Design (LEED) certificate qualifications can be tracked from the model. From a general perspective, the sustainability component also beneficial for the humanity as it is decreasing the total energy consumption of all the implemented buildings in the world.

2.2.1.5. 7D BIM Application. The term 7D refers to the 6D plus the seventh dimension: 'facility management'. Facility Management component of BIM indicates modeling for the operation and maintenance of the building for the whole life cycle. 7D BIM models includes resource with warranties information, specifications, maintenance schedules and any other necessary information. 7D models allow the project parties to view and manage related asset data for example the unit status, maintenance or operation manuals etc. "The integration of BIM into the Facility Management (FM) stage of a building's lifecycle portends a significant boost to maintenance and operations procedures." (Tereno *et al.*, 2016). Utilization of 7D BIM models enables easier and faster unit replacements, optimized convenience and a favorable building life cycle management. It also makes the management of subcontractor or supplier data easier for facility component. A 7D model can be utilized as an as-built of the structure.

2.2.2. BIM Implementation Maturity Stages

Within the management related disciplines, maturity models are getting popular. A maturity model helps companies in managing change processes. As the maturity improves, the unpredictability of the results decreases. In order to complete a successful BIM implementation in a construction project, all project parties must have a certain level of BIM capability to utilize BIM effectively (Giel and Issa, 2013).

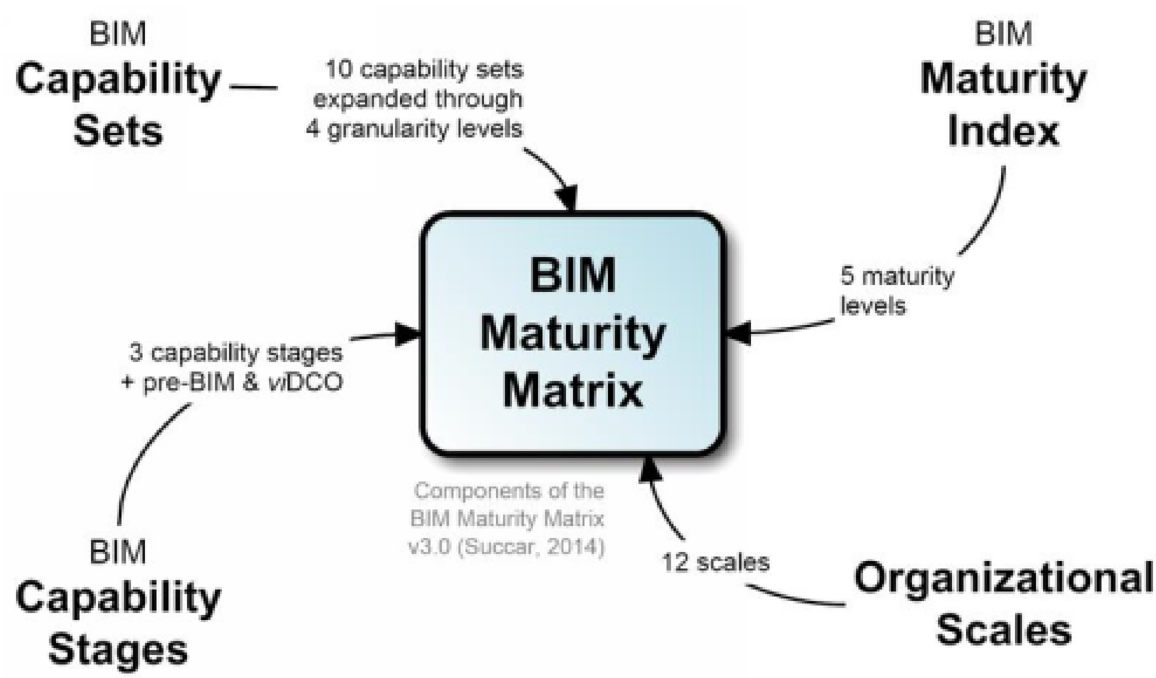

Figure 2.3. Components of BIM Maturity Matrix (Succar, 2015)

BIM maturity assessment models have been developed to assess project stakeholders' the BIM capabilities as well as the self-assessment (Giel and Issa, 2013). BIM maturity represents the quality, sustainability and level of excellence in delivering a BIM model (Succar, 2010). A BIM Maturity Matrix, developed by (Succar, 2015), which shows a comprehensive evaluation the framework based on technology, process, and policy can be found in Figure 2.3.

Furthermore, public sector defines implementation levels and publishes policies. The UK Government, as an example, made it mandatory for all public funded projects to utilize BIM in at least Level 2 since 2016. Definition of the BIM levels in the UK by the BIM Industry Working Group is as (Eadie *et al.*, 2013);

- Level 0: Unmanaged 2D CAD drawings (paper or electronic) are the most likely exchange mechanism.
- Level 1: Managed 2D or 3D CAD drawings formatted according to BS1192:2007 with a collaboration tool providing a common data environment by standard data structures and formats. Commercial data managed by standalone finance and cost management packages with no integration.
- Level 2: Managed 3D environment held in separate discipline BIM tools with attached data. Commercial data managed by an ERP system. Integration of the basis of proprietary interfaces middleware cloud regarded as "pBIM". The approach may utilize 4D program data and 5D cost elements as well as feed operational systems.
- Level 3: Fully open process and data integration enabled by web services compliant with emerging IFC / IFD standards, managed by a collaborative model server. Could be regarded as iBIM or integrated BIM potentially employing concurrent engineering processes.

2.2.3. Detail Levels of BIM Applications - LOD

In order to clearly define the BIM deliverables, each deliverable need to be assigned a specific level of detail (LOD). Information exchange and collaboration should be on the same LOD (Jin *et al.*, 2017). LOD, also called as level of development / detail, defines the content and reliability of BIM elements at different stages or milestones. The LOD classes help project parties to understand the usability and limitations of the modelled elements. Gives information about the quality and trustworthiness of the information that can be extracted from the models. With the help of consistent information, LOD makes the communication, interoperability and coordination easier. Moreover, LOD defines the requirements. Most common LOD classes are described below.

<u>2.2.3.1. LOD 100.</u> Concept Design. In this level, there are no geometric information within the model. Only symbols are used with some attached information. The 3D model of the structure is developed to show the information at the basic level. Thus, only conceptual model is created. Only the parameters such as area, height, volume, location and orientation are defined.

<u>2.2.3.2. LOD 200.</u> Schematic Design. In this detail, the model elements are generic and recognisable objects or space allocations for coordination among the disciplines. A general model produced in which elements are modeled with approximate quantities, size, shape, location and orientation together with some attached information.

<u>2.2.3.3. LOD 300.</u> Detailed Design. This level is suitable for design intent to support quantity take offs, cost estimations bidding etc. Construction layouts and shop drawings can be produced from this level models. Drawings are measurable and locations are accurate. Assemblies, precise quantity, size, shape, location and orientation are defined to an accurate model together with some attached information.

<u>2.2.3.4. LOD 350.</u> Construction Documentation. This level of detail defines cross trade coordination. This level models contains information that represent how building elements interface with various systems and other building elements with graphics and written definitions.

2.2.3.5. LOD 400. Fabrication and Assembly. This level supports detailing, fabrication and installation. Model elements carries information about specific assemblies, with complete fabrication, assembly, and detailing in addition to precise quantity, size, shape, location and orientation. This level models enable the general contractor to split construction requirements and assign to subcontractors.

2.2.3.6. LOD 500. As-Built. In this level, the model has enough geometry and information to support operations and maintenance. Geometry and data can be defined as, as-built. Elements are modeled as constructed in order to ease the maintenance and operations. Together with the actual size, shape, location, quantity, and orientation information, non-geometric information is also attached to modeled elements.

The Level of Development (LOD) specification enables industry professionals to specify and articulate with a high level of clarity, the content and reliability of the models at any stage of the process. The LOD classes specifies various issues faced by industry professionals by providing an industry-developed standard to describe the state of development of various systems within a BIM. This standard enables consistency in communication and execution by facilitating the detailed definition of BIM milestones and deliverables. An example for the LOD classes can be seen in the Figure 2.4.

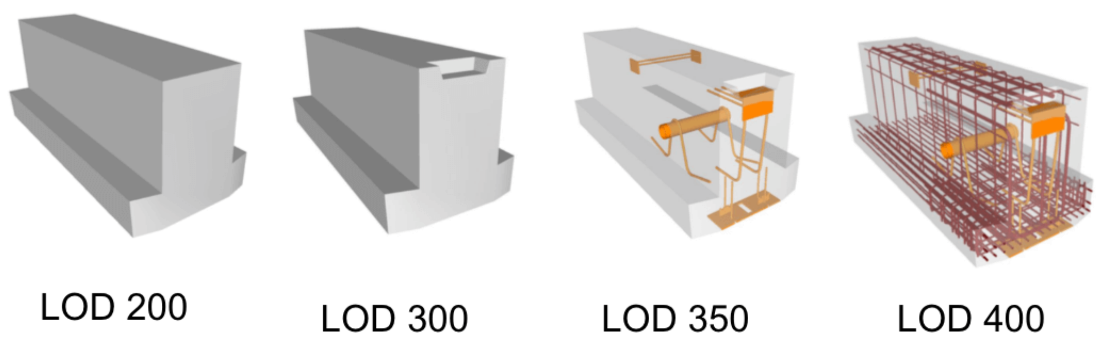

Figure 2.4. An Example For LOD Classes

2.3. BIM For Different Project Parties

Building Information Modeling is an emerging tool or process in order to manage the information flow during the life cycle of a project. Construction industry has wide range of business groups which involve to the construction process. According to Ozorhon *et al.* (2016), coordination among project parties is the most important critical success factor for the BIM implementation. Coordination and collaboration among different project parties help to avoid misunderstandings and prevent potential conflicts during the implementation process (Ozorhon and Cinar, 2015). 4 main parties that run the construction process can be described as;

- Owner - The client who makes the order and pay the money. Owner will use or benefit from the end product.
- Project Manager - The company who is responsible for managing the construction process and reports to the client.
- Designer - The team that mainly consists of engineers and architects to develop the project and deliver the blueprints. They do the initial work.
- Contractor - The group that implements the project and manage the activities. Contractor builds the project.

As the BIM adoption accelerates, collaboration among the project parties should also be increased, that results in improved profitability, reduced costs, better time management, and improved customer-client relationships (Azhar, 2011). Each one of the project parties that involved to the process can benefit from the BIM implementation. It is important to understand the BIM and maintain collaboration.

2.3.1. BIM for the Owner

A research about the project delivery method selection process for the owners shows that "the owners give their decision in order to shorten duration, establish cost earlier, reduce costs, and reduce claims" (Songer *et al.*, 1997). It is obvious that utilizing BIM makes improvements for all the criteria of the owners. Implementing

BIM to the projects is beneficial for the owners not only for the mentioned criteria but also for the facility management.

For a successful BIM implementation, it is critical for owners to be aware of BIM concept so that they can correctly select and manage the stakeholders to contract with (Mayo *et al.*, 2012). Since owners are the decision makers, they should be informed and even educated about the BIM process in order to increase the efficiency. Owners take the financial risks of BIM implementation. Thus, they will be the one who mostly benefits from it. On the other hand, owners are one of the main drivers of BIM implementation process. A previous study indicates that “Clients have the ability to foster innovation by increasing the demand for high standards of work and they adopt a role as a leader in bringing up new ideas for a supportive work environment” (Ozorhon and Oral, 2014). For the public projects, Governments are the owners. Thus, a requirement for BIM implementation in public projects will increase the country’s level of BIM adoption as well as the knowledge of the involved parties.

2.3.2. BIM for the Project Management

Project management companies responsible for initiating, planning, executing, controlling, and closing out the project by achieving previously set goals with a pre-defined quality, within budget and in a certain amount of time. They achieve this by coordinating all the project parties and therefore, project management companies are at the heart of the collaboration. BIM helps project manager to organize the project schedule and budget, to coordinate with the design team, to hire and control subcontractors, to manage RFIs (Request for Information) and change orders, to optimize client satisfaction, to manage cost issues and to close out the project (Bryde *et al.*, 2013).

2.3.3. BIM for the Designer

The process of design is greatly affected by BIM (Chelson, 2010). Designing is the primary stage of developing a BIM implemented project and it influences the direction of following stages. Design teams consist of architects and engineers whose primary work is to design, calculate and put out the blue prints of the projects. For designers, it is a challenge to reflect their mind to the 2D CAD drawings. With the BIM implementation during the designing stage, through a good communication and collaboration, designers can transfer the project information to the other construction parties easier than before.

It is obvious that BIM simplifies the work for designers especially in the complex projects. Architects and engineers utilize BIM if there is a complex project and they are curious about how to manage the design with normal 2D drawings (Kaner *et al.*, 2008). Therefore, designers who knows BIM or have an experience with it, are more willing to increase the level of BIM adoption in their future projects. Furthermore, designers perceive BIM as a communication tool which increases the communication among the project parties. That increased communication results in reduced rework for the design team. Last but the least, especially for the projects which aims to obtain LEED certificate, BIM adoption in the design stage is crucial. With the implementation of BIM, the number of LEED certificated buildings are increased.

2.3.4. BIM for the Contractor

In the construction process, contractors are responsible for the construction activities. Thus, involvement of the contractors to the all phases of the project is crucial. BIM enables the involvement of contractor by increasing the collaboration with other construction parties. General contractors (GC) involves into coordination processes via BIM models in coordination with structural, building skin, drywall and etc. and subcontractors involves via implementing all models into a single model which will be utilized for clash detection and detailed planning (Chelson, 2010). With the contractors' involvement, the amount of waste time and material decreases. Clash detection is one of the most important features of BIM and it helps contractors to save money by reducing rework. Clashes can be solved on the drawings before the application. In addition, 4D and 5D BIM applications, planning, scheduling and cost components, makes complex issues clear before the construction starts. Therefore, contractors can monitor the process healthier than before.

On the other hand, most of the contractors who are not completely aware of BIM are scaring about the costs and adoption process of BIM. Many of them are not willing to change their way of doing business. People who are aware of BIM believe that BIM is the future of the project management but majority of them are not planning to implement it within the next 3 years (Ezcan *et al.*, 2013).

2.4. BIM Application Areas

The most common goals of BIM implementation can be stated as; improving collaboration, reducing cost and shorten the duration. The leap from 2D drawings to 3D models has resulted in better coordination of complex building processes, and in turn has sped up project completions, lowered project costs, and improved quality and safety. In order to achieve these goals, BIM has various application areas for different phases of a project.

2.4.1. Virtual Coordination / Clash Detection

Virtual coordination is a process that utilized BIM for identifying and facilitating the resolution of clashes of building systems in an earlier stage. Virtual coordination assures improved understanding of design intent and prevents reworks. It is an iterative process throughout design and construction to check issues arising as design develops. Furthermore, through clash detection; constructability can be improved and opportunities for prefabrication can be maximized.

2.4.2. Scheduling / 4D Sequencing

4D modeling merges 3D building model elements and scheduled activities. In this way, it allows project team to animate the schedule, and enables instant updates on animation to visualize a construction process. 4D Scheduling visually depicts the schedule, work scenario, and helps the project team to understand what is planned and avoid unforeseen conflicts during the actual construction process. It improves efficiency and reduces risks via assisting to make correct decisions.

2.4.3. Cost Estimating

By extracting and validating quantities of the modeled elements, BIM acquires accurate quantities for cost estimates. BIM based quantity take offs can be completed quickly and prevents spending time for counting things. Thus, it allows project team to focus on more complex issues.

2.4.4. Energy Analysis

Linking the model and energy analysis enables project team to complete the energy analysis in an easier and earlier way. Comparing with traditional methods, project team needed to make major changes on the model to save more energy after the analysis. With the model based energy analysis, designers can make right decisions and revise the models to see the results quickly.

2.4.5. Operations and Handover

BIM links the model to the closeout and handover documentation and that provides easy access to product information such as warranties, startup guidelines, wiring diagrams, etc. By linking the model, it helps facilities managers for the operation and maintenance of the building. The majority of a building's cost comes from the maintenance and operation phase. Thus, quality of the turnover documentation is crucial.

2.4.6. Commissioning

Building commissioning is a quality assurance process ensuring the building and its technical systems meet the needs and requirements defined by the client. Building commissioning begins in the predesign phase and goes through the design, construction and occupancy and operation phase used as a risk management strategy that is a part of these project phases. Commissioning is vital to the successful operation of buildings and there are multiple ways BIM can improve commissioning. When using BIM during design there is easier for both the commissioning agent and the operational team to get involved as early as needed. With an updated BIM for commissioning repository you can easily visualise the status of functional tests to see what needs a retest and see if larger systems are ready for test, alternatively what is holding it back.

2.4.7. Site Logistics Planning

A 3D site logistics plan provides project team a virtual environment which can be used to identify, communicate, and plan for the construction process. A logistics plan clearly illustrates the impacts of a project to the site and reveals the site's unique challenges and opportunities. It allows project team to evaluate options to make the most efficient use of the project site by establishing an operations plan for the project.

2.4.8. Site Safety Analysis

BIM enables project team to plan better and to analyze and mitigate potential safety hazards on the project. Safety criteria checking feature shows the non-compliance parts of the project and helps to identify the risks earlier.

2.4.9. Laser Scanning

3D Laser scanning records the geometric information, in detail, about current conditions of the project or site. That can be used to create a 3D model of the existing conditions of a space. Laser scanning allows project team to produce accurate as-builts, to coordinate the existing conditions and new scope. It produces a surveying data more efficiently, easier and cheaper than traditional surveying.

2.4.10. Model Based Layout

Model Based Layout works with the precision of laser-guided materials and the accuracy of BIM to physically locate or verify work in place on the site. Model based layout allows to complete the job faster, safer, and with a higher quality. By easing the surveying process, it enables to work a higher degree of precision than the traditional methods. Before installing a panel or material, project team scans the existing condition and compares the points with the BIM model to avoid reworks.

2.4.11. Model Checking and Analysis

Model based analysis means scanning the geometry and embedded information within a model and checking for compliance according to the prescribed rules. It quickly reveals differences between revisions of a model. Model checking and analysis expedites the production of code compliant drawings. It allows project team to correct errors and to eliminate the costly rework. Model checking can be used to review drawings prior to local Authority submission.

2.4.12. Production Tracking

Production tracking can be used to track the progress of work at the site. BIM captures and reports the status the information about the equipment, materials and labor. It allows project team to visualize the work. Thus, it enables the client and project team to meet at a common understanding of the project status. Project team identifies the issues more proactively before it becomes a problem. Production tracking also ensures availability of the right materials, equipment, people on the site.

2.4.13. 3D Printing

3D Printing can be described as the process of fabricating a physical object from a digital model. 3D printing refers to any manufacturing process which additively builds or forms 3D parts in layers from CAD data. It promotes active engagement in the details of constructability, allows to produce rapid prototypes of models and enables quick experimentation.

2.4.14. Virtual Reality

Virtual reality provides a comprehensive visualization experience and allows the project team to enter a full-scale, 3D environment. In many cases, people can interact with virtual elements as they would in the real world. Enhanced visualization helps project team to predict the potential challenges and safety hazards, to reduce change orders and coordination errors, and to mitigate risks. In addition, VR Mock-ups allow project team to move and manipulate equipment and suggest changes. VR mock-ups are cheaper and less time consuming to construct and modify than physical mock-ups. Furthermore, in the VR model review meetings, project executives can give beneficial feed backs that saves time, money, and labor by preventing rework. Last but not the least, VR safety training prepares workers before a high risk carrying activity.

2.4.15. Augmented Reality

Augmented Reality (AR) can be described as a technology that allows digital objects to be overlaid on the real world. AR can enhance BIM by enabling project team to view BIM model hands-free in 3D. Design teams are able to evaluate the design options for feasibility, function, and aesthetics in a more immersive way. It helps MEP teams regarding the routing services such as HVAC ducts, water pipes, and electrical conduits. Thus, installation errors can be reduced. Last but not the least, visual comparison of as-designed projects versus as-built projects reveals hidden or non-installed materials such as overhead and underground power lines. Thus, inspections can be made by using AR technology.

2.4.16. Equipment Routing

Equipment routing can be described as using the model in order to clearly plan the logistics of the project. The major equipment and materials are modeled according to the actual size and go through the accessible routes with an animation. In this way, confusion between the contractor and subcontractors is eliminated.

2.5. BIM Adoption

Although BIM implementation spreads rapidly, the adoption process works slowly (Azhar, 2011). Thus, the BIM adoption strategies are crucial to accelerate the adoption process. In order to ensure the success of BIM adoption, governments are establishing institutions, organizations and even making regulations and guidelines across the world.

2.5.1. BIM Adoption Throughout the World

Based on the governments initiatives, BIM adoption rate differs from region to region or country to country. The more a government enforces BIM usage in public or PPP (Public Private Partnership) projects, the more the BIM adoption rate increases. Popularity of BIM is increasing and traditional methods are switching to BIM (Ezcan *et al.*, 2013). Companies which has adopted BIM don't switch back to traditional methods (Zeiger, 2008).

According to NBS National BIM Report (2019), within the UK construction industry, 69% of the professionals have been aware and using BIM while 62% are just aware and 2% are unaware of BIM. The constant increase in the BIM adoption rate since 2011 can be seen in the below Figure 2.5 for the UK construction market.

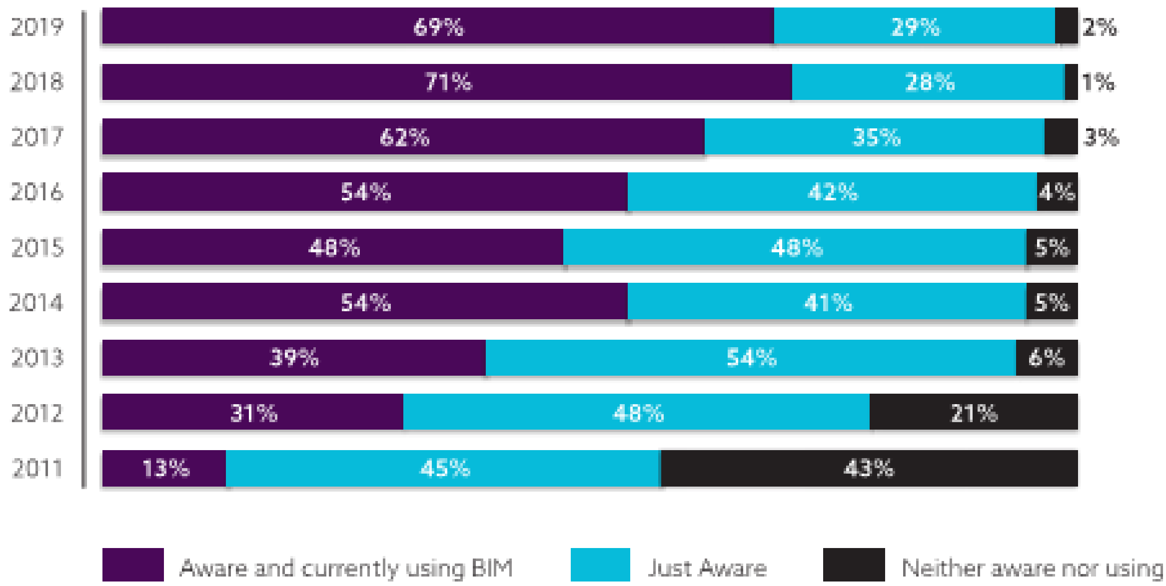

Figure 2.5. The BIM Adoption Level Rate Overtime in UK (NBS, 2019)

Moreover, according to NBS National BIM Report (2019), 96% of the respondents are planning to utilize BIM within five years.

Denmark government established a Digital Construction Initiative to develop common standards and guidelines for digital construction projects in 2007 (Steffensen, 2012). Finnish government published National Common BIM Requirement's (COBIM) as a guideline in 2012 to ensure a successful BIM adoption.

As one of the leading countries in BIM adoption, Singapore government published a BIM guide that outlines the roles and the responsibilities of each party in the construction process. Singapore's BIM guideline helps industry professionals to develop BIM Execution Plans and explains the modelling and collaboration procedures (BCA, 2012). In Australia, a government institution named BuildingSMART published a national guideline (National Guidelines for Digital Modelling, Australia (BuildingSMART, 2009) in order to promote the BIM usage within the country.

South Korea is another leading country for BIM adoption by making BIM mandatory for all public projects costs over 50 million dollars. On the other hand, U.K. government develops BIM standards to strengthen their role in the global construction market.

2.5.2. BIM Adoption in Turkey

Turkey, as a developing country, is at the initial stages of BIM adoption. BIM implementation is not mandated or supported by the government and there is no incentive for BIM adoption yet. In addition, the BIM awareness in Turkey has been found as 53% and the rate of BIM implementation in Turkey has been found as 12% in 2013 (Ezcan *et al.*, 2013).

On the other hand, a more recent research on BIM implementation in Turkish construction industry revealed that the BIM implementation rate in Turkish construction industry is almost 55% and only 1% of the respondents are not likely to utilize BIMin the future (BIMgenious, 2018). In addition, 20% of the respondents state that they are planning to implement BIM within the next 2 years (BIMgenious, 2018).

When compare the two studies, it can be deduced that BIM implementation in Turkish construction industry have increased 12% to 55% in the last 6 years.

Turkey is one of the main contributors to the global construction industry (ENR, 2018). Many of the leading countries in the global construction market have been adopting BIM and their governments are mandating BIM implementation for public projects. Thus, it is very crucial for Turkey to embrace new technologies like BIM in order to keep pace with the global competitors in the international construction market.

2.5.3. Future of BIM

BIM's popularity has been increasing since early 2000s. Concordantly, the rate of BIM adoption is also increasing especially in current years. Governments are giving incentives, setting requirements and making regulations for BIM implementation in order to increase the adoption. In addition, number of clients who requires BIM implementation in their projects are increasing day by day. A broad industry BIM adoption has been expected for the short and medium term. Long term goals about BIM can be stated as; to become an easy and practical tool that utilized in all kind of construction projects, to reduce the project risk and to increase the productivity of construction industry.

In the short run; people will start to get better and faster at BIM usage, demand will continue to increase, consultants and experts will direct the inexperienced firms. Thus, the same trend that held in last few years will continue in the sector for short run.

In the long run; huge amount of money will be saved, a BIM software package become as the industry standard, demand for FM and other BIM related issues will increase, new legal and contractual regulations will be set and developing economy will allow more software developers and this increase the competition for BIM software.

2.6. Concepts Related With BIM

Recent initiatives in the construction industry have common goals such as cost and time reduction, easy management, improved productivity etc. Those initiatives are incorporated with BIM and plays a vital role to speed decisions and streamline processes. BIM alone is not sufficient to overcome the problems within the construction process. It should be implemented together with other concepts such as lean and IPD. BIM related concepts can be described as; lean construction, integrated project delivery (IPD) and green buildings. The relationship among those concepts can be seen in the Figure 2.6.

Figure 2.6. The Relationship Among BIM, LEAN and IPD

2.6.1. Lean Construction

Planning is crucial for an effective construction management of processes. Poor management causes ineffective processes and results in low productivity. Lean Construction (LC), was first utilized by Toyota to maximize the efficiency of their manufacturing system. Lean principles are about eliminating the waste increasing the quality. Lean construction targets to eliminate waste as well as increasing the added value within the production process. Just in time delivery is crucial in order to ensure the goals to be reached.

BIM plays an important role to solve the construction process problems. Without connecting to the BIM model to the schedule, project team cannot fully benefit from look-ahead scheduling process, a lean construction application (Saffarini and Akbaş, 2017). BIM enables construction process to be more efficient by eliminating the waste that occurs during construction process (Eastman *et al.*, 2011). BIM can improve lean construction approach in two ways; (Eastman *et al.*, 2011)

- By eliminating the waste resulted from construction activities, application errors, and re-works. BIM implementation enhance the collaboration among the project parties throughout the construction process. Utilizing BIM at the initial design stage ensures good communications. Thus, problem identification, clash detection and estimation works get better.
- By improving construction look ahead planning, a lean application, it ensures delivery of the materials and resources just in time. BIM shows construction activities in the right sequence and in detail. Thus, with a base model that includes many types of information; transformation, tracking and management becomes easier. Therefore, BIM decreases the waiting time and workflow becomes more effective and reliable.

2.6.2. Integrated Project Delivery

BIM does not require a certain project delivery method to work with. However, in order to fully benefit from BIM and implement it easier to the projects, traditional project delivery methods are not suitable. BIM should be utilized with Integrated Project Delivery (IPD).

Integrated Project Delivery allows new forms of legal collaboration by definition (Salmon, 2009). BIM provides best results when the collaboration is maximized. Thus, better forms of contractual collaboration maximize BIM's efficiency. By working together, reduced energy use, reduced waste, reduced risks and increased productivity can be achieved by the project parties.

IPD helps to reduce waste and increases productivity throughout the process by enabling collaboration of people, systems, business structures and practices into the process. IPD has an important role in BIM implementation process. Collaboration and information sharing among the project parties are vital.

2.6.3. Green Buildings

As BIM use is rapidly expanding within the AEC industries, the green building concept is also getting popular (McGrawHill Construction, 2008). Utilizing BIM together with the sustainable design and green construction techniques via maximizing the conservation of resources is referred as Green BIM (Sharma *et al.*, 2018). Green buildings are less energy consuming than conventional buildings. Therefore, they are more affordable and less costly. As the sustainability gains importance, AEC industries adopt green building concept in order to reduce CO2 emission and energy dependency on fossil fuels.

Expert BIM users are twice as likely to see BIM as helpful on green projects compared to beginners (McGrawHill Construction, 2008). BIM enables project team to manage information throughout the building life cycle. Thus, it allows to benefit from the design data for performance analysis. The embedded information within BIM helps to make better decisions for more efficient use of energy, water, materials, and land. Decisions made in the early design phase have an impact on the life cycle performance of a building. It supports decision-makers to make better decisions regarding the life cycle performance of a building (Schade *et al.*, 2011).

There are tens of green building rating systems / tools utilized within the construction industry. The most common rating systems are CASBEE, BREEAM and LEED.

<u>2.6.3.1. CASBEE System.</u> Comprehensive Assessment System for Building Environmental Efficiency (CASBEE), was developed in Japan, in 2001, with the collaboration of academia, industry, and government. CASBEE structured based on a principal of building environmental efficiency to indicate the overall performance of the building. The principal has two parts and those are;

- The Building Environmental Loadings, that defined as the impact of the building on the world beyond project's boundary.
- Building Environmental Quality and Performance, that defined as improvements for the building users within the project boundary.

2.6.3.2. BREEAM System. Building Research Establishment's Environmental Assessment Method (BREEAM), as one of the oldest rating system, has been developed in the United Kingdom in 1990s. In this system, credits are awarded based on the performance of the structure in different areas and added through a combined weighting process. The building is rated as; Pass, Good, Very Good, or Excellent, and a certificate awarded to the project. BREEAM assesses the performance of buildings in the following areas:

- Management
- Health and Well-Being
- Energy
- Transport
- Water
- Material and Waste
- Land Use and Ecology
- Pollution

2.6.3.3. LEED System. The United States Green Building Council (USGBC) developed the Leadership in Energy and Environmental Design (LEED) rating system in 1998. The aim for developing the LEED system was to establish a standard measurement for green buildings and to compare the performances of those (Krygiel and Nies, 2008). In the LEED system, buildings are assessed based on nine different categories. Each category has different credits to obtain points. There are 110 points in total and buildings are rated as; platinum for 80+, gold for 60+, silver for 50+ and certified for 40+. Major assessment categories are:

- Location and Transportation
- Sustainable Sites
- Water Efficiency
- Energy and Atmosphere
- Material and Resources
- Indoor Environmental Quality
- Regional Priority
- Integrative Process
- Innovation

3. RESEARCH METHODOLOGY

This thesis study aims to identify the critical success factors (CSFs) for BIM implementation process in the construction phase for Turkish AEC companies and to assess those CSFs on real cases by based on interviews with the industry professionals.

For this purpose, an inclusive framework has been developed for the BIM implementation process that consists of 6 components as; drivers, inputs, enablers, barriers, benefits and impacts. Then, a comprehensive literature analysis was conducted and 45 papers, related with BIM implementation process, have been reviewed in detail. All the mentioned CSFs have been noted and an initial list CSFs was established based on this review. The noted CSFs are assigned under the previously developed framework components based on their functions. Among those CSFs, frequency was counted. The frequency is expected to show the significance of each factor in the literature based on how many papers have referred to those factors. Then, this initial list has been modified to obtain a more refined list of factors by grouping/merging similar factors and deleting some irrelevant ones. Three levels of influences namely, industry level, firm level and project level are defined. These influence levels are expected to help to distinguish the perspectives of the industry, companies, and project teams.

Based on the final list of CSFs, a case study form was generated and the CSFs were evaluated for 18 case study projects via face to face interviews with the project executives. To assess the CSFs significance in real construction cases, interviewers are asked to specify the significance level of the relevant CSF on a 1 to 5 Likert scale based on their project's realities (5 corresponds to very important). In order to obtain detailed information about real applications, interviewers are also asked to share their own experiences during the BIM transition process.

3.1. Development of the Framework

In order to cover all aspects of the BIM implementation process, a comprehensive framework was developed. The framework was expected to help to systematically investigate the process. The BIM implementation framework was primarily developed by Ozorhon (2013) in order to investigate the innovation process in the construction industry. The framework defines innovation as a system which has several components related with the participating organizations and to project-specific factors (Ozorhon, 2013). The initial framework can be seen in Figure 3.1.

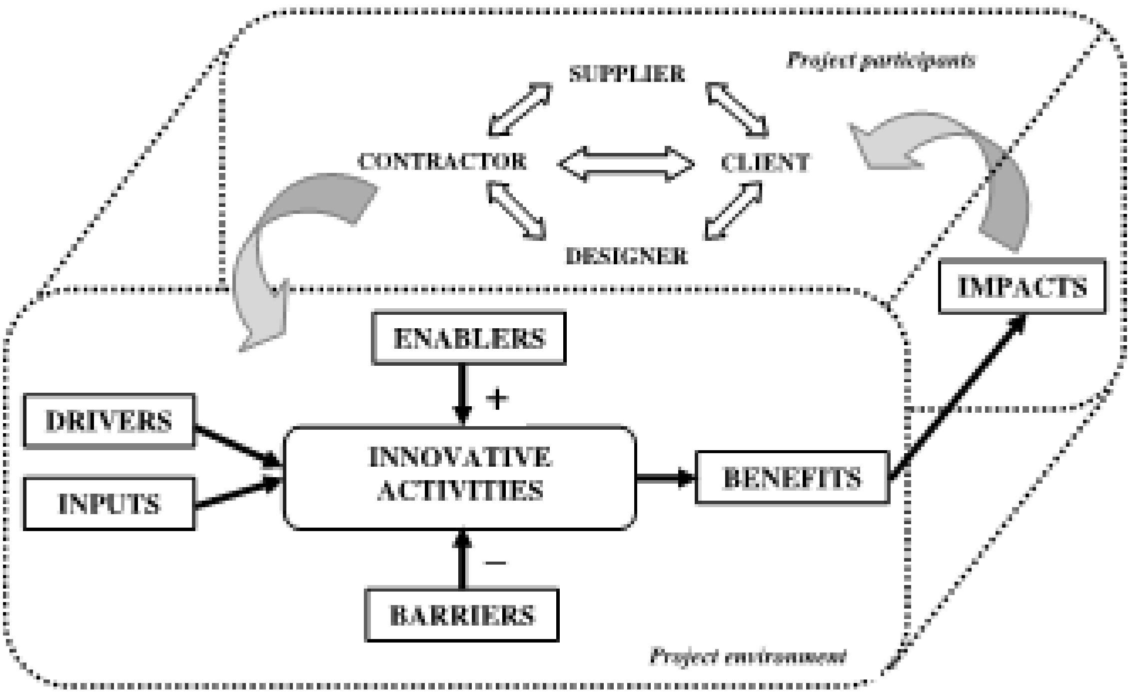

Figure 3.1. The Initial Framework Developed by Ozorhon (2013)

In order to utilize the framework for the purpose of this thesis, some modification was required. The modified framework consists of 6 components namely drivers, inputs, enablers, barriers, benefits and impacts. The framework addresses almost all aspects of the BIM implementation process. Final version of the BIM implementation framework can be seen in Figure 3.2.

3.1.1. Drivers Component

Drivers are the primary and secondary factors that pushes a company to implement BIM. Drivers component is one of the first two components of the framework. They are the motivations of a company that begins the process.

3.1.2. Inputs Component

Inputs are the main resources that enters to the implementation process. Inputs component represents the resources that company utilized and/or invested. It is critical to determine the right resources to be utilized.

3.1.3. Barriers Component

Barriers are the main challenges encountered during the implementation process. Barriers make the BIM implementation process to be complicated. They need to be identified carefully in order to achieve the BIM implementation successfully.

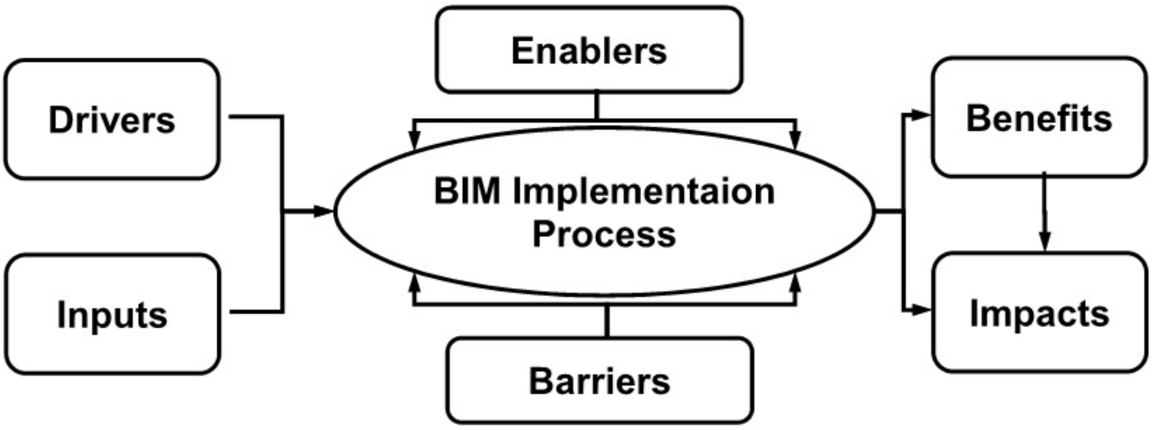

Figure 3.2. The Final Version of the Modified BIM Framework

3.1.4. Enablers Component

Enablers are the factors that simplifies the implementation process. Enablers play an active role throughout the implementation process. They facilitate the effort to overcome the challenges faced.

3.1.5. Benefits Component

Benefits are the short term gains from the BIM implementation. Benefits are mainly the goals of the companies that implementing BIM. They are expected to be project level positive outcomes.

3.1.6. Impacts Component

Impacts are the long term outputs of the BIM implementation. Impacts are more general than the benefits and expected to be company level outcomes.

3.2. Literature Analysis

For academic studies, previous research's findings and structures which are relevant with the content of study, are very important. Researchers' opinions based on the findings of those relevant studies generates a basis for the new studies. In this thesis study, findings of previous research papers are reviewed and helped to develop a list of critical success factors. Review of multiple research papers increases the validity of the obtained information.

An extensive literature review was conducted in order to determine the CSFs that will be evaluated. Research papers are selected by either online reviews or in library reviews. Initially, 54 Papers, related with BIM implementation process, have been selected. After a pre-evaluation period, some of the papers are removed and some new papers added. As a result, 45 research papers, journals, etc. decided to be reviewed in detail. Each paper has different analysis or data collection methods. In addition, each paper focused on different countries, projects or BIM applications. Specific details about the reviewed literature sources can be found in the below Table 3.1, Table 3.2 and Table 3.3.

Each paper has examined attentively and all the CSFs mentioned within the papers were noted. Those noted CSFs were assigned under the relevant component of the previously developed framework. Frequency of the mentioned CSFs were counted. The frequency was expected to reveal the significance of each factor in the literature based on how many paper mentioned them.

Table 3.1. Details of Reviewed Literature Sources.

Source	Country	Project Type	BIM Function	Data collection	Data Analysis
1	USA, UK	-	-	Questionnaire	-
2	-	-	-	Literature Review	-
3	New Zealand	-	5D	Questionnaire, Case Study	-
4	UK	-	4D	Questionnaire	-
5	-	-	-	Literature Review	-
6	UK	Housing	5D	Case Study	-
7	China	-	-	Questionnaire	Factor Analysis
8	-	-	4D, 5D, 7D	Literature Review	-
9	Turkey	-	3D, 4D, 5D, 7D	Questionnaire	ANOVA
10	UK	-	-	Questionnaire	-
11	Australia	-	-	Questionnaire	RII
12	-	-	-	Case Study	-
13	-	-	-	Questionnaire	-
14	-	Federal Building	-	Questionnaire	-
15	-	-	-	Literature Review	-

Table 3.2. Details of Reviewed Literature Sources Continues.

Source	Country	Project Type	BIM Function	Data collection	Data Analysis
16	UK	-	-	Case Study	-
17	China	-	-	Questionnaire	ANOVA
18	Lithuania	Highrise, Industrial	4D	Case Study	-
19	Mixed	-	-	Literature Review	-
20	-	-	-	Literature Review	-
21	-	-	-	Literature Review	-
22	UK	-	3D	Case Study	-
23	Turkey	-	3D, 4D, 5D, 7D	Questionnaire	ANOVA
24	-	-	5D	-	-
25	US	Medical	3D, 4D	Case Study	-
26	-	-	-	-	-
27	Finland	-	-	-	-
28	UK	-	-	Questionnaire	-
29	-	-	-	Literature Review	-
30	-	-	-	-	-

Table 3.3. Details of Reviewed Literature Sources Continues.

Source	Country	Project Type	BIM Function	Data collection	Data Analysis
31	-	-	-	-	-
32	-	-	-	-	-
33	-	-	7D	Literature Review	-
34	-	-	6D	Literature Review	-
35	China	-	-	-	-
36	-	-	-	Literature Review	-
37	-	-	4D	Literature Review	-
38	UK	-	-	Case Study	-
39	-	-	-	Literature Review	-
40	-	-	-	Literature Review	-
41	India	-	-	Questionnaire	Z-test
42	Mixed	-	-	Literature Review	-
43	-	-	3D	-	-
44	-	-	4D	Case Study	-
45	-	-	7D	Literature Review, Case Study	-

3.2.1. Data Collection

Selected research papers are read in detail and factors affecting BIM implementation process are noted. Based on the literature review, an initial table of critical success factors (CSFs), consisting of 170 different factors, has been developed. During this period, the noted factors are checked and rearranged two times with an academician. For example, among the driving factors, “BIM is the future life saver” has been merged to “Not to stay behind the industry” and “Competitiveness”. A factor under impacts component “Future business collaborations” have been merged to “New businesses with past clients”. The final version of the initial table includes 38 drivers, 17 inputs, 35 barriers, 23 enablers, 33 benefits and 13 impacts factors.

3.2.2. Finalizing the Data Table

In order to develop a more compact and refined table, the previously developed initial table has been re-assessed with an academician. Identified CSFs grouped or merged according to their similarities and some of the irrelevant factors deleted. Three level of influences namely, industry level, firm level and project level are defined. These influence levels are expected to help to distinguish the perspectives of the industry, companies and project teams. Each factor’s level of influence has determined and a description has written for each. The finalized table includes 10 drivers, 12 inputs, 11 barriers, 8 enablers, 10 benefits and 6 impacts factors. The finalized table for the data obtained from the literature review can be seen in the Figure 3.3, Figure 3.4 and Figure 3.5.

CSF of BIM in the Turkish Construction Industry			Literature Sources																																													
#	Drivers of BIM	Description	#	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
1	Improving Corporate Performance	Company image, competitiveness, gain experience	12					x		x			x							x					x			x	x				x									x	x	x	x			
2	Improving Project Performance	Efficiency, quality, speed, cost, risk reduction	34		x	x		x	x	x			x	x					x	x	x	x	x		x	x		x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
3	Improving Building's Energy Performance	Sustainability, LEED, lean implementation	26	x	x								x				x		x	x	x	x	x		x	x			x	x	x		x	x	x	x	x		x	x	x		x	x		x		x
4	Improving Collaboration & Coordination	IPD, collaboration, coordination,	33		x	x	x	x	x				x						x	x	x	x	x	x	x	x	x	x	x		x	x		x	x	x	x	x	x		x	x	x	x	x	x	x	x
5	Client Requirement	Contractual obligation	11				x			x		x	x	x						x		x	x			x		x																x				
6	Governmental Push	Law enforcement	12				x	x		x		x	x							x			x							x			x					x						x	x			
7	Design Improvement	Clash detection, visualization, simple revision process	38	x	x	x		x	x	x			x		x				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
8	Improving Construction Productivity	Site logistics, optimized schedules, prefabrication	27				x		x				x		x						x	x	x	x		x		x	x		x		x	x	x	x	x	x	x	x	x	x	x	x		x	x	x
9	Improving HSE Activities	Safety measurements	5										x								x																		x						x	x	
10	Reducing Life Cycle Cost of The Building	Maintenance & usage costs	17		x			x												x		x			x	x					x				x	x		x		x		x	x	x	x	x		x
#	Inputs of BIM	Description	#	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
1	Human Resources	Qualified staff & leader	25				x					x		x		x		x		x	x	x	x	x	x	x			x	x			x				x	x	x	x	x	x		x	x	x	x	
2	Financial Resources	Investment	18	x	x	x	x	x				x		x	x		x	x		x			x			x															x	x	x	x	x			
3	Technological Infrastructure	Technological developments enhancing the scope of BIM	39	x	x		x	x	x		x	x	x	x		x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	
4	Softwares & Hardwares	Modeling & managing programs, computers	40	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x		x	
5	Custom 3D Library	Open family libraries	12			x			x							x				x				x	x			x		x			x			X				x					x			
6	Internal Knowledge	Company know-how	15				x		x			x				x		x		x		x	x		x	x											x	x				x	x		x			
7	External Knowledge & Consultancy	Outsource know-how, consultancy	10									x						x		x	x	x	x			x															x	x		x				
8	Project Information	Drawings, specifications, project data	12			x			x			x			x		x	x			x		x							x												x	x			x		
9	Project BIM Execution Plan	BIM implementaion routeway	15				x		x						x	x			x	x	x		x		x										x		X		x	x	x			x				
10	Company's BIM Policy	BIM implementation approach	15					x	x			x	x					x		x	x					x		x				x			x		X		x		x			x				
11	BIM Guideline	BIM implementation rules	19		x						x	x	x	x		x	x			x			x								x	x	x	x	x			X			x	x		x	x			
12	Training & Education	Internal & external staff trainings	29	x	x	x	x	x	x		x	x		x	x			x	x	x		x	x		x	x		x	x			x	x				x	x	x		x	x	x	x	x			

Figure 3.3. The Finalized Data From Literature Review

CSF of BIM in the Turkish Construction Industry			Literature Sources																																													
#	**Barriers of BIM**	**Description**	**#**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**
1	Availability of Knowledge Based on Experience	Lack of experience, awareness	25		x		x	x		x				x		x				x	x	x	x	x	x	x		x	x	x	x	x				x		x			x	x		x	x			x
2	Unclear Benefits	Lack of tangible benefits	9				x													x			x	x		x		x			x		x					x										
3	Lack of Best Practices	Lack of cases, benchmarks, universal use	21	x			x	x				x		x						x			x	x	x			x	x	x	x				x	x		x	x			x		x	x			x
4	High Costs	Time, HR, software & hardware investment	28	x	x	x	x	x						x		x				x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x		x				x		x	x			x
5	Technology Related Problems	Licensing, data interoperability, reliability	30		x	x	x	x		x	x			x		x				x	x	x	x	x			x	x	x	x	x	x			x	x		x	x		x	x	x	x	x	x		x
6	Change Process Problems	Resistance to change, company culture, fear of failure	31	x	x	x	x			x	x			x		x		x		x	x	x	x	x			x		x	x	x	x	x		x	x		x	x		x	x	x	x	x		x	x
7	Legal & Protocol Problems	Lack of legal protocols, ownership, responsibilities	24		x	x	x	x			x	x		x		x				x	x	x	x	x					x	x			x			x		x			x	x		x	x		x	x
8	Fragmented Nature of the Industry	Number of parties getting involved to the process	11		x	x								x								x	x	x		x										x						x	x	x				
9	Interoperability Problems of Different Parties	Low collaboration, interoperability	17				x		x	x	x			x		x				x	x	x	x			x												x			x		x	x	x	x		
10	Project Specific Problems	Delivery method, contract type, unique requirements	25	x	x	x	x	x	x	x				x		x					x	x	x	x		x	x			x	x					x		x	x		x	x	x		x			x
11	Lack of Government Support	Lack of incentives, initiatives	4																					x		x												x							x			
#	**Enablers for BIM**	**Description**	**#**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**
1	Corporate & Academic Level Collaboration	Academic partnership, research teams	15				x		x			x						x		x	x	x	x			x						x	x				x				x	x		x				
2	Project Level Collaboration	Communication, involvement of parties	30				x		x		x	x		x				x		x	x	x	x	x	x	x		x	x		x	x	x		x	x	x	x	x	x	x	x		x	x		x	x
3	Managerial and Technical Abilities	Experience level, right decisions	16									x		x				x		x	x		x		x	x				x	x	x				x		x				x		x	x			
4	Supportive Organizational Culture	Commitment, internal support	31		x		x	x	x	x	x	x		x		x		x		x	x	x	x	x	x	x				x			x		x	x	x	x	x	x	x	x		x	x		x	x
5	External Grants, Incentives & Promotions	Industry level commitment, governmental support	22		x			x		x		x	x	x	x	x				x		x	x		x					x			x	x	x	x		x			x	x		x	x			
6	Global Standardisation	Common standards, protocols	10																	x				x		x							x	x		x		x				x		x	x			
7	IPD Type Contracts	Integrated delivery system	11				x													x	x	x														x		x				x	x	x	x		x	
8	Planning of BIM Execution Process	Making an implementation plan	11				x											x		x			x	x											x	x					x	x		x	x			

Figure 3.4. The Finalized Data From Literature Review Continues

CSF of BIM in the Turkish Construction Industry			Literature Sources																																													
#	Benefits of BIM	Description	#	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
1	Project Financial Benefits	Cost and time reduction	30	x	x		x	x	x		x				x	x	x		x	x	x	x			x	x		x	x				x	x	x	x	x	x	x			x	x	x	x	x		x
2	Right and Accurate Construction Activities	Less rework, better site planning, reduce risk, high quality	37	x	x	x	x	x	x		x				x	x	x	x	x	x	x	x			x	x		x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
3	Right and Accurate Technical Office Works	Minimize errors, better estimates, clear results	34		x	x		x	x		x				x	x	x		x	x	x	x		x	x	x	x	x	x		x		x	x	x	x	x	x		x	x	x	x	x	x	x	x	x
4	Improve Staff Performance	Staff understandig and awareness of the project	24	x	x			x	x						x					x		x	x	x	x	x	x						x		x	x	x	x				x	x	x	x	x	x	x
5	Knowledge Management Benefits	Better documentation, easy tracking	26	x	x			x	x											x	x	x	x	x	x	x	x	x	x						x	x	x	x		x		x	x	x	x	x	x	x
6	Claim Management Benefits	Reduce RFIs, claims, change orders	23		x	x		x							x	x	x			x		x			x			x	x		x	x		x	x	x		x	x				x	x	x	x		x
7	Reduction of Facility Management Costs	Reduced maintenance & usage costs	20					x			x				x					x	x	x	x	x				x						x	x	x	x	x					x	x	x	x	x	x
8	Client Satisfaction	Happy client	5				x	x	x													x																						x				
9	Improve Communication & Collaboration	Low number of meetings, effective communication	29	x	x		x	x	x						x				x	x	x	x	x		x	x		x	x		x	x		x	x	x	x	x	x			x	x	x	x	x		x
10	Improve Energy Savings	Better energy analysis	14					x														x							x			x	x		x	x	x		x	x			x	x		x		x
#	Impacts of BIM	Description	#	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
1	Company's Productivity Improvement	Improved business value	27		x		x	x	x						x		x			x		x		x	x	x		x	x		x	x	x		x	x	x	x	x	x			x	x		x	x	x
2	Corporate Management Improvement	Better administration, marketing, organizational structure	11						x													x			x	x		x			x					x	x	x							x			x
3	Expanding Company's Scope of Services	New services	6																						x			x						x	x							x		x				
4	Enable New Businesses	Competitiveness, reference projects	12					x		x									x			x			x	x		x		x				x	x		x							x				
5	Improve Corporate Financial Performance	Increased ROI	11					x	x													x			x	x		x					x	x	x									x	X			
6	Generate Corporate Knowledge	Archive of knowledge and information	6	x					x	x															x											x											x	

Figure 3.5. The Finalized Data From Literature Review Continues

3.3. Case Study

Case study is the principal research method in this study. In this section, case study methodology will be described. After a literature review about the case study methodology and its definition, a comparison between qualitative and quantitative research methods were made. Then, strengths and weaknesses of case studies are described. The requirements to apply a case study method are explained. Last but not the least, implementation process of the case study methodology is described.

On the other hand, interviews constitute an important part of the case study methodology. In this thesis, face to face interviews were conducted in order to assess the literature findings based on real cases. Interviews conducted with a good communication, allow to obtain the target information about the BIM implementation process of Turkish construction companies in the construction phase.

3.3.1. Definition of Case Study

Within the literature, there are various definitions made for case study method. Case studies provides detailed information about a studies completeness, richness and depth.

A comprehensive definition of case study methodology made by Schramm (1971, cited in Yin 1989: 22-23) as, "The essence of a case study, the central tendency among all types of case, is that it tries to illuminate a decision or set of decisions: why they were taken, how they were implemented and with what result." This definition describes case studies as indicators of the decision processes.

In contrast, other academicians consider case study as the exploratory phase of a different type of research strategy. In the literature, there are too much common misunderstandings about case study methodology. As an example, Dictionary of Sociology (Abercrombie *et al.*, 1984) describes case study as "The detailed examination of a single example of a class of phenomena, a case study cannot provide reliable information about the broader class, but it may be useful in the preliminary stages of an investigation since it provides hypotheses which may be tested systematically with a larger number of cases."

According to Flyvbjerg (2006), the above mentioned definition is indicative of much conventional wisdom about case study research and so oversimplified as to be grossly misleading. Flyvbjerg (2006) argues that the mentioned definition increases the probability of misunderstanding and shows the case study method as subordinate to investigations of larger samples more than a strategy. The definition also blocks the complementarity that exists between the two types of methodology, case studies and statistical methods.

According to Yin (2009), the initial form of the cases is a study case and the second is the case for research. There are two different opinions that are implemented for the two types;

"A case study is an empirical inquiry that investigates a contemporary phenomenon in depth and within its real life context, especially when the boundaries between phenomenon and context are not clearly evident." and "The case study inquiry copes with the technical distinctive situation in which there will be many more variables of interest than data points as one result relies on multiple sources of evidence with data needing to converge in a triangulating fashion and as another result benefits from the prior development of theoretical propositions to guide data collection and analysis."

The case study is a research strategy covering the logic of design, data collection techniques and specific approaches to data analysis (Yin, 2003). In this context, the case study is neither a data collection method nor a design feature alone (Stoecker, 1991) but a comprehensive research strategy.

3.3.2. Case Study as a Research Method

The case study methodology is a very popular qualitative research strategy that has been utilized in different sciences. It is often used to investigate real life phenomena and to support decision making. Case studies have an exploratory nature rather than developing a hypothesis and testing the theory (Thies and Volland, 2010). According to Yin (2003), there are three types of case studies;

(i) Explanatory case studies are used for causal researches. They investigate an event and its interrelationships in depth.
(ii) Exploratory case studies aim to explore a new research area when the question is not clear. They serve as motivation and define hypotheses.
(iii) Descriptive case studies obtain information on particular properties of an issue. A phenomenon is described in detail and investigated then.

Yin (2003) developed a table that shows relevant situations for different research methods explicitly. According to the table, there are three conditions consisting of type of research question asked, extent of control the researcher has over actual events and degree of focus on contemporary as opposed to past events. These three conditions and their relation with five different research strategies: experiments, surveys, archival analyses, histories and case studies can be seen in the below Table 3.4.

One of the most important conditions for differentiating various research methods is to determine the questions that will be asked. According to the table, if a research asks who and where questions, it usually supports survey methods or analysis of archival records as in economic research. When the research aims to describe the effect of predominance of a phenomenon or when research is to be estimated about certain events, these two methods are advantageous. Surveys conducted in order to find political attitudes can be a good example. On the other hand, how and why questions are more explanatory and usually used in histories, experiments and also case studies. These questions deal with operational links that have to be monitored over time rather than frequencies.

Table 3.4. Relevant situations for different research methods (Yin, 2003).

Strategy	**Research Question**	**Control of Events**	**Focus on Contemporary Events**
Experiment	How, Why	Yes	Yes
Survey	Who, What, Where, How Many, How Much	No	Yes
Archive Analysis	Who, What, Where, How Many, How Much	No No	Yes / No Yes / No
History	How, Why	No	No
Case Study	How, Why	No	Yes

A further differentiation among research strategies is the extent of the investigator's control over and access to behavioral events. As an example, when there is no access or control of behavioral events, histories are used as a research strategy. History deals with the past however case studies are preferred in investigating contemporary events. History and case study have very similar research techniques however there are two additional sources of evidence that are usually not included in historians' methods and those are;

- Interviews with people involved in events,
- Opportunity for direct observation of the events being investigated

Although techniques of case study and history may overlap, the case study's strength comes from its wide variety of evidence including documents, interviews and observations (Yin, 2003).

Last but not the least, another distinction among research strategies is between the case study and the experiment methods. A researcher utilizing experiment method, can manipulate the events directly. This can happen in laboratory environment by controlling all variables or in the field by treating subjects in different ways. However, relevant behaviors cannot be manipulated in case studies. In summary, according to Yin (2003), since case study method has distinct advantages as a research strategy, it is used to identify some situations when “A how or why question is being asked about a contemporary set of events over which the investigator has little or no control.”

Since the answers of questions how and why are sought in this research, case studies are the proper research strategy to be implemented in this thesis. It is aimed to explain decisions by finding reasons of them. There is no control of events in this research and this leads the researcher to case studies. The main focus was on contemporary events during the whole investigation process.

3.3.3. Strengths and Weaknesses of Case Study

There are 3 main applications of case studies that can be described as strengths of this type of research methodology (Siggelkow, 2007). Those are;

(i) An illustrative instrument: concrete examples of theoretical knowledge lead to that the readers easily understand the conceptual arguments. Case data provides a more convincing argument about causal relationships than pure theory or empirical research can.

(ii) Motivating the research question: argumentation in a real life context makes a case a more convincing argument than a pure theoretical motivation.

(iii) Inspiration for new ideas: real life cases provide rich data. They may be used as tools to strength existing theory, especially in cases where limited theoretical knowledge exists.

On the other hand, case studies have also some weaknesses. Those are;

(i) If the number of cases is small then it is generally not a representative for a specific population, hence case studies cannot make use of statistical tests for significance.
(ii) In some situations, results from case studies may seem obvious to readers. This is called the problem of ex-post obviousness.
(iii) Case studies may quickly become too rich in detail and hence may not generate a useful theory. So it is important not to cause an over determination in the case study.

In order to represent the different characteristics of case studies and statistical methods and compare them in order to prove that there is a strict complementarity between these two research strategies, Flyvbjerg (2011) developed a table. Some other strengths and weaknesses of case study method can be seen from that table. The table also presents that if a phenomenon in any degree of thoroughness is sought, case study method should be pursued. From the other aspect, if how widespread the phenomenon is and how it correlates with other phenomena is sought then statistical studies should be applied.

3.3.4. Requirements of Case Studies

A research study must represent a logical set of statements and any given design according to certain logical tests must be proved. Fulfillment of some certain requirements is also important for utilizing the case study methodology. There are four criteria ensure that the case study is credible and persuasive from a methodological point of view and those are; construct validity, internal validity, external validity and reliability (Yin, 2003).

Table 3.5. Complementarity of case studies and statistical methods (Flyvbjerg, 2011).

	Case Studies	**Statistical Methods**
S	Depth	Breadth
S	High conceptual validity	Understanding how widespread a phenomenon is across a population
S	Understanding of context and process	Measures of correlation for populations of cases
S	Understanding of what causes a phenomenon linking causes and outcomes	Establishment of probabilistic level of confidence
S	Fostering new hypotheses and new research questions	
W	Selection bias may overstate or understate relationships	Conceptual stretching by grouping together dissimilar cases to get larger samples
W	Weak understanding of occurrence in population of phenomena under study	Weak understanding of context, process and causal mechanisms
W	Statistical significance often unknown or unclear	Correlation does not imply causation
W		Weak mechanisms for fostering new hypotheses

- Construct Validity: It is related to the quality of operationalization of the concept being investigated. To meet the requirement of construct validity, a researcher must use multiple source of evidence, form a chain of evidence and adopt different point of views in order to look at the phenomenon from different perspectives.
- Internal Validity: It refers to only explanatory case studies in which an investigator determines whether a specific event led to another. If the researcher fails

in concluding that there is a causal relationship between two events knowing also that a third factor caused this, then the research design fails in meeting requirement for internal validity. Establishment of causal relationships can be ensured by clear research frame work, explanation building, pattern matching techniques, rival explanations and use of logical models.

- External Validity: It refers to the problem of knowing if a study's results can be generalized beyond the immediate case study because sufficient statistical generalization is not available for case studies. However, pattern matching techniques that compare models of empirical studies with theories from literature allow analytical generalization. The researcher should provide a clear justification for case study selection. A theory must be tested by replicating the results in a second or third environment where the theory shows that the same results must occur.
- Reliability: In order to meet that requirement, a researcher who followed the same procedures as described by an earlier researcher and conducted the same case study should arrive at the same results and conclusions with the earlier one. Briefly, the study must be without random error which means it can be repeated with the same results. The aim is to minimize errors and biases in a study. Reliability can be provided by transparency through clarification of research procedure and replication through a case study database.

In summary, these mentioned tests are considered relevant in evaluating the quality of a case study research design. In case studies of this thesis study, both archival records and interviews are used during data collection phase in order to satisfy the construct validity. A research framework used to analyze the cases was established based on literature in order to improve the internal validity. In research design, multiple case studies are selected among BIM implemented projects and performed in order to emphasize external validity. To allow replication of the study, a case study database is established so sufficient reliability is aimed to be ensured. The tests and recommended case study tactics can be seen in the Table 3.6.

Table 3.6. Case study tactics for four design tests (Yin, 2003).

Tests	**Case Study Tactic**	**Phase of Research in which Tactic Occurs**
Construct Validity	Use multiple sources of evidence Establish chain of evidence Have key informants review draft case study report	data collection data collection composition
Internal Validity	Do pattern matching Do explanation building Address rival explanations Use logic models	data analysis data analysis data analysis data analysis
External Validity	Use theory in single case studies Use replication logic in multiple case studies	research design research design
Reliability	Use cases study protocol Develop case study database	data collection data collection

3.3.5. Data Sources

In the case study methodology, there are two main information resources namely; primary information and secondary information. Primary information contains any documents about the subject such as reports, forms and letters. Archives like project drawings and name lists are also can be good examples of primary information. Moreover, interviews made with project personnel or clients can be count as secondary information which provides direct observations about the subject. Data sources within case study method are defined by Yin (2009) as;

(i) Interview is the first data source that can be used in case study research method. It is accepted as a qualitative form of data. The researcher has to organize and then analyze the collected data. Open interviews, semi structured interviews and structured interviews are the three types of this source. Case questions are the advantage of interviews and lead to causal actions and references. The disadvantage of interviews is that the data may be biased due to badly formed questions and it may also occur that the interviewer may get the data he/she wants to hear.

(ii) Documentation can be diagrams, reports, documents, contracts and memos etc. Since this source is rarely created for the sake of a case study, the data can give the researcher a better overview of the situation in the case. However, the relevant reports and references can be hard to find among many other documents.

(iii) Archives are precise and quantitative and do not have to be within the organization. They can be provided from other resources. They have similar advantages and disadvantages as the documentation. Besides, they may have limited access due to privacy reasons.

(iv) Direct observation is based on that the researcher is someone out of the case organization and can observe extrinsically what happens within the case using. The researcher's judgment is decisive in choosing what is needed to continue the study. However, this may lead to that the collected data may be biased because of the subjective judgment. Besides, participant observations have similar properties as direct observations. They are insightful into interpersonal behaviors however they may be biased due to the researcher's manipulation of events.

(v) Physical artifacts may be a technological device, a tool and an instrument etc. Such evidences may be collected or observed as part of a visit. They have less potential relevance in case studies but when they are relevant, the artifacts can be important components in the overall case. They have two typical disadvantages namely; availability and selectivity.

3.3.6. Likert Scale

In this research, during the case study interviews, the respondents requested to specify significance of the CSFs on 1 to 5 Likert Scale. Likert scale is one of the most common used rating scales in the literature. Various kinds of rating scales have been developed to measure respondents' attitudes directly.

In 1932, Likert developed the principle of measuring attitudes by asking people to respond to a series of statements about a topic, in terms of the extent to which they agree with them. A Likert scale includes a series of questions that have been asked to the people to answer, and has ideally 5 to 7 balanced responses that the respondents can choose from. It often comes with a neutral midpoint. Likert scale assumes that the strength of the answer is linear. It has a continuous from strongly agree to strongly disagree.

One of the advantages of Likert Scale is that it does not expect a simple yes or no answer from the respondent and allows for degrees of opinion, and even no opinion at all. Thus, as a result of the questionnaire or case study etc. a quantitative data is obtained that easy to be analyzed.

However, the validity of Likert Scale attitude measurement can be compromised due social desirability like in all other survey methods. Respondents may lie to put themselves in a positive light. In this study, offering anonymity reduced pressure, and thus answer are more reliable.

In order assess the significance of the identified CSFs and obtain a more realistic result, it has been determined to evaluate the framework with the industry experts working in BIM implemented projects. In this way, it is aimed to reveal the real process of BIM implementation and to compare the industry facts with the literature. More than 20 BIM implemented case projects are identified. Industry experts within those projects have been reached and a face to face interview request was sent. Among those, 25 industry experts from 18 projects were accepted to make a face to face interview.

A case study form was developed and pursued during the face to face interviews which were completed in 3 months. In the interviews, industry professionals also shared their own experiences about the BIM implementation process and shared the project document which are related to the concept with us.

3.3.7. Case Study Form

A questionnaire was formed in order to apply the literature findings to the case studies. The questionnaire has four sections. First section aims to gather information about the interviewers. In this section, interviewers are asked to answer following information;

- Respondent's Profession
- Respondent's Experience in the Construction Industry (in years)
- Respondent's current position

Second section gathers information about the companies and aims to measure the company's size, activities and BIM experience. Interviewers are asked to answer following questions in this section;

- Company's Field of Operation
- Company's Expertise Area
- Company's Annual Turnover (Not Obligatory)
- Company's Total Number of Employees
- Number of Countries that the Company Operates
- Number of Years that the Company has been Operating
- Number of Projects that the Company Involved
- Number of Years that the Company Utilized BIM

Third section focuses on project information. The goal of this section is to identify the scope, size and components of the projects. In the third section, interviewers are asked to answer following information;

- Project's Type
- Project's Ownership
- Company's Role in the Project
- Project's Total Construction Area in m2
- Project's Contract Type
- Project's Contractual Budget (Not Obligatory)
- Cost Savings (Percentage, if possible)
- Project's Duration
- Time Savings (Percentage, if possible)
- Total Amount of BIM Investment (Percentage)
- Number of Employees Working in BIM Team
- Utilized Softwares

Last but not the least, the fourth section consists of the finalized CSF Table. Interviewers are asked to indicate the significance level for each factor according to their project realities. 1 to 5 Likert Scale was used for specifying the significance level of CSFs. Corresponding significance levels can be found below as;

- 1: Very Low
- 2: Low
- 3: Medium
- 4: High
- 5: Very High

An example of the case study form that has been followed during the face to face interviews can be found in the APPENDIX A.

3.3.8. Interviewers' Profile

In order to obtain information from 18 case study projects, 13 face to face interviews were held with 25 industry professionals in total. Those industry professionals have different backgrounds, working in different positions and have different experiences in the construction industry. Engineers constitute 14 of the 25 interviewers and the other 11 are architects. The variety of the interviewers can be seen in the below charts.

Current positions of the interviewed industry professionals can be seen in the Figure 3.6.

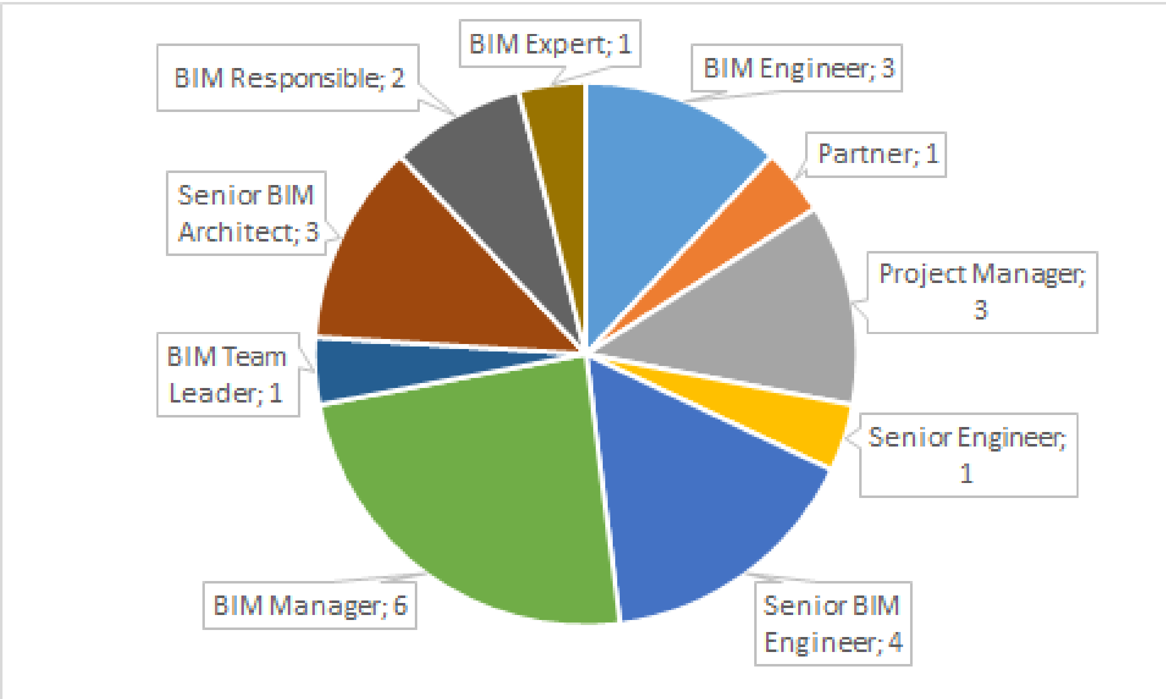

Figure 3.6. Current Positions of the Interviewers

The interviewers are highly consisting of the people who are at a management level position. Most of the interviewers are BIM Managers. Thus, it is expected that they are experienced and has a wider perspective about BIM implementation in construction phase. The experience level of the interviewers can be found in Figure 3.7.

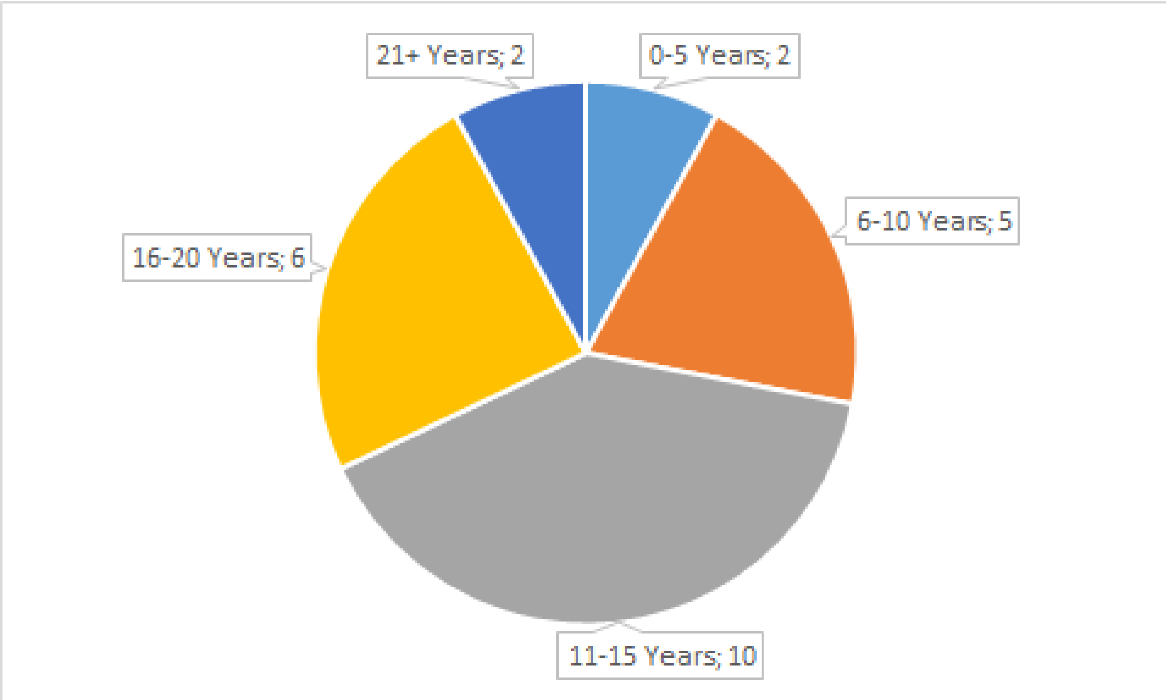

Figure 3.7. Experience Levels of the Interviewers (In Years)

As it can be seen from the Figure 3.7, most of the interviewers has an experience more than 10 years. In addition, there are interviewers almost every experience level from 2 years to 25 years. Thus, the study obtained information from various perspectives.

3.3.9. Companies' Profile

The previously mentioned industry professionals are working for 13 different companies in total. Each company has different number of workers, field of operations and experiences etc. BIM knowledge and BIM experience of each company also differentiates. The variety of companies can be seen in the below charts.

The interviewed companies have various field of operations. Since this study aims to investigate the BIM implementation process for construction phase, most of the companies are contractors. Additionally, all of the companies have played role in the construction phase of the projects. Some as project manager, some as consultant and some as contractor. Field of operations can be seen in the below Figure 3.8.

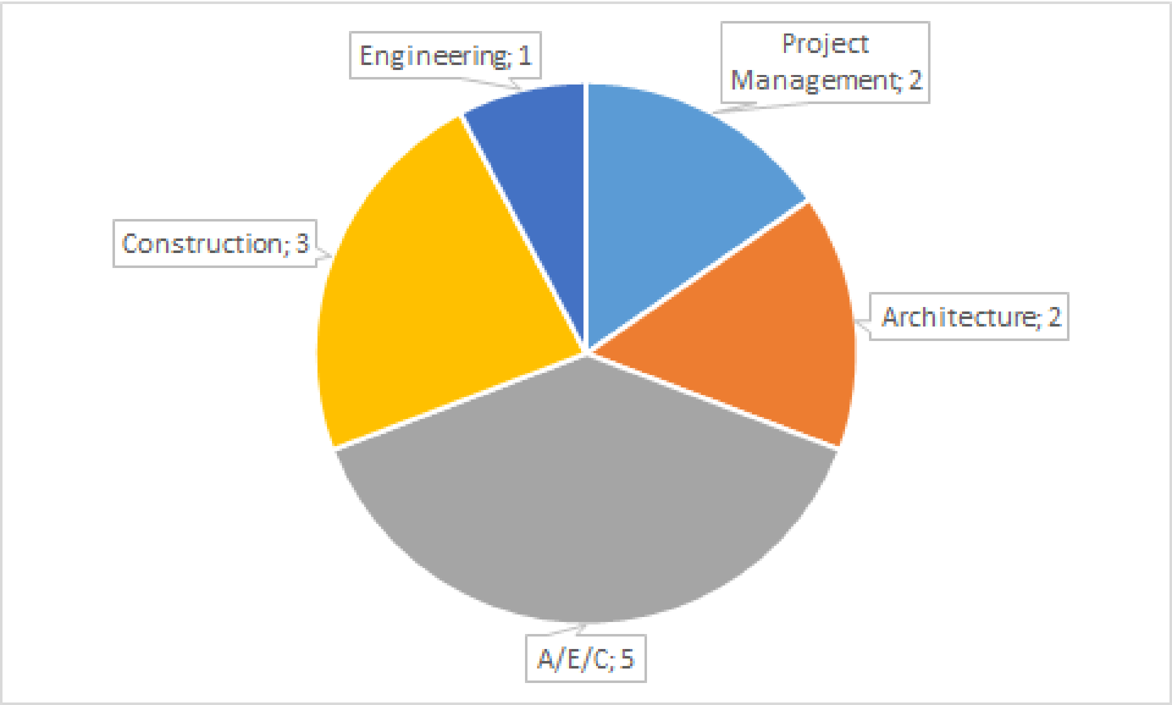

Figure 3.8. Field of Operations of the Companies

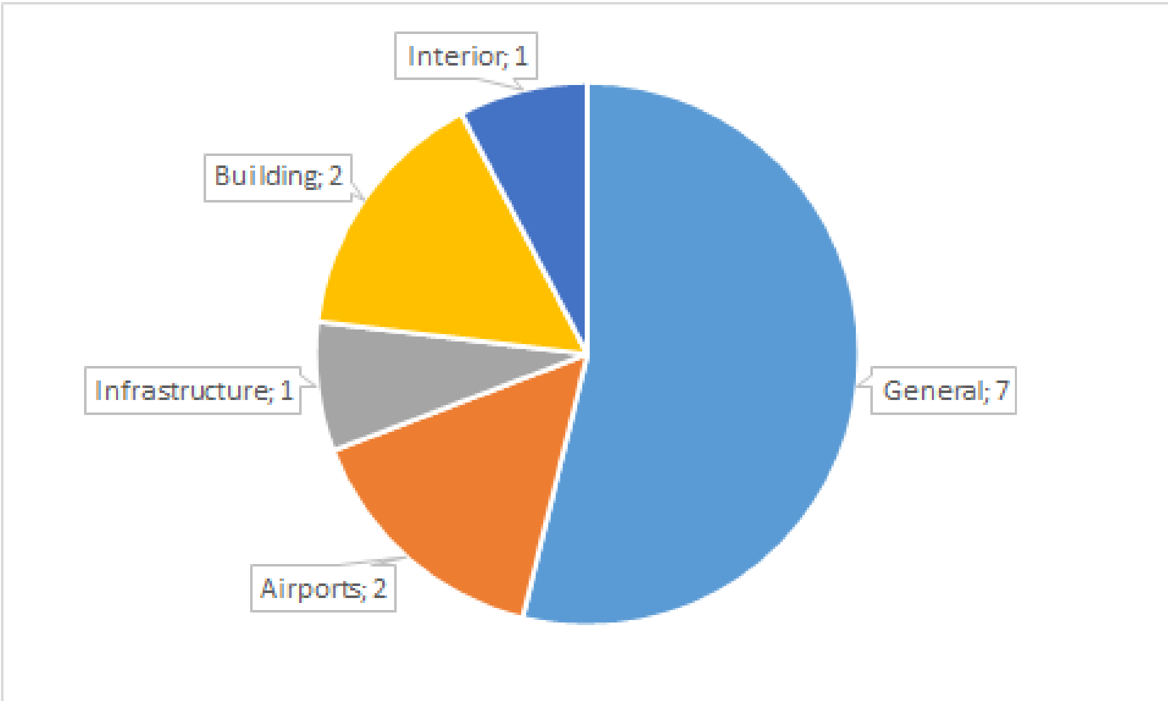

Figure 3.9. Expertise Areas of the Companies

As it can be seen in the above Figure 3.9, expertise areas of the companies differentiate. This variety about the expertise areas of the interviewed companies allows the research to investigate the BIM implementation process for various types of construction companies. However, most of the companies operate various types of construction projects and those are specified as general expertise area.

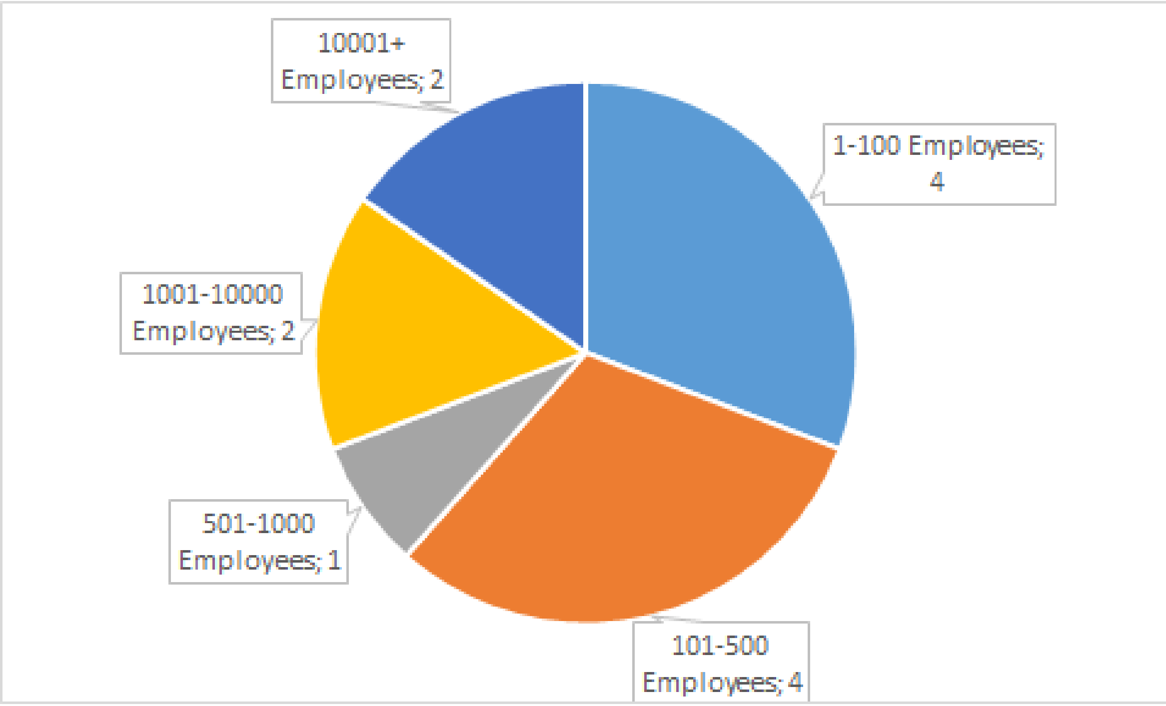

Figure 3.10. Number of Employees of the Companies

Size of a company can be measured with the number of employees. Thus, sizes of the interviewed companies are differing from 20 employees to 45.000 employees. Some of them are small local companies while some of them are very large international companies. Number of employees can be found in the above Figure 3.10.

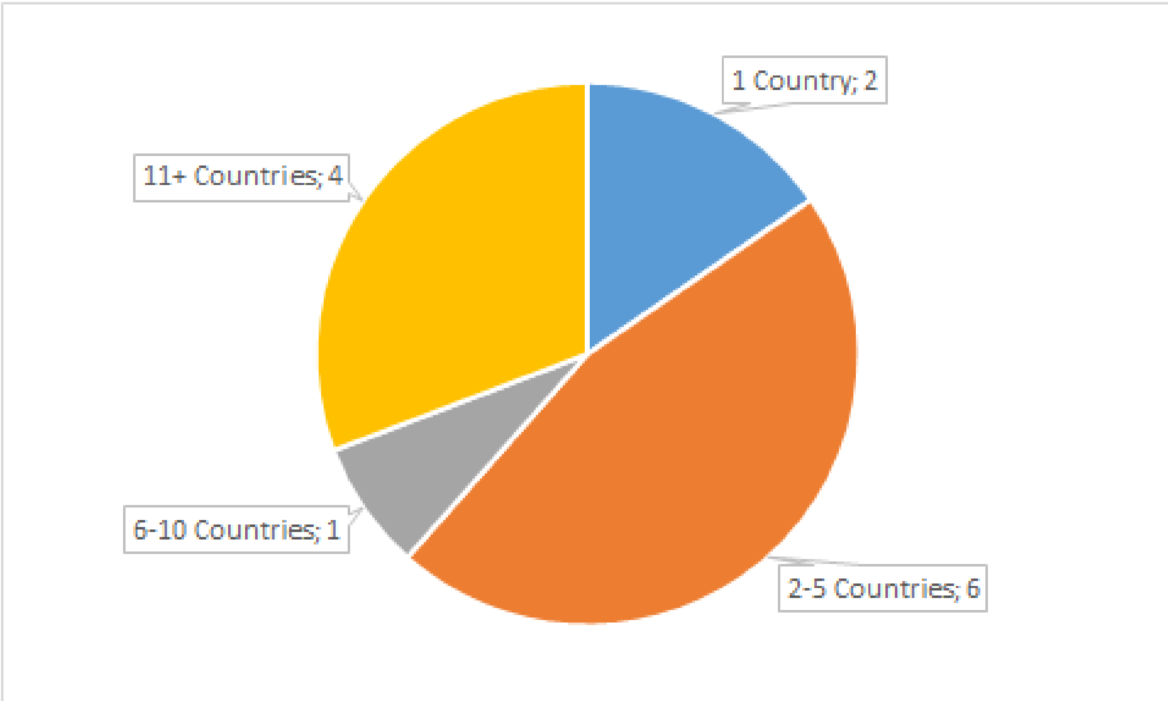

Figure 3.11. Number of Countries Actively Operated

As shown in the above Figure 3.11, number of countries that the companies have been actively operating varies. It means that there are both international and local companies are interviewed. However, most of the companies are international and operating more than 2 countries.

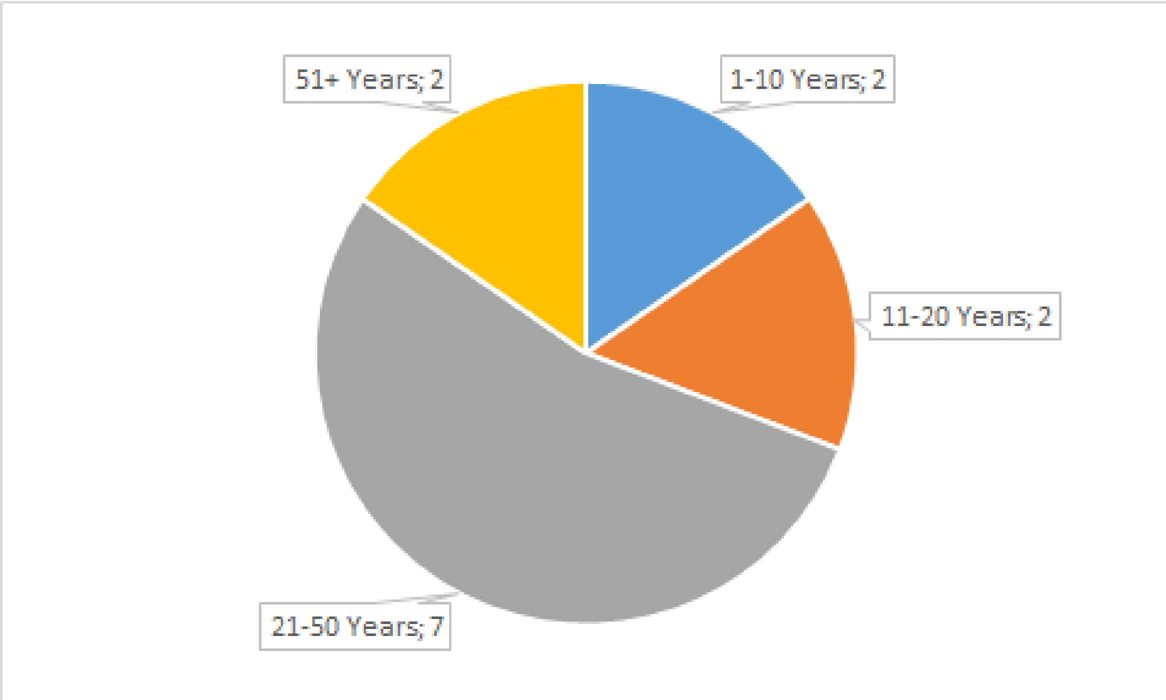

Figure 3.12. Age of the Companies (In Years)

Most of the interviewed companies are long-established companies whose roots are going more than 20 years ago. The variety of the age of the companies enables the study to evaluate the BIM implementation process for companies that has different maturity. Age of the companies are shown in the above Figure 3.12.

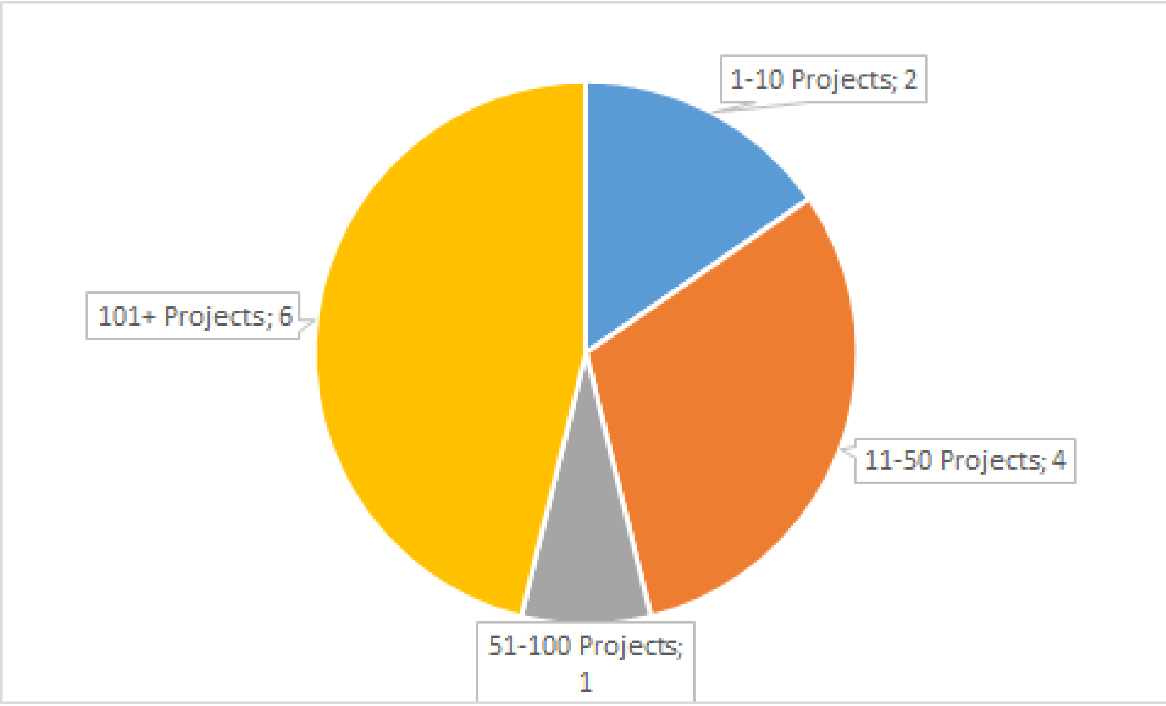

Figure 3.13. Number of Projects Completed by the Companies

Furthermore, the number of completed projects by the interviewed companies can be seen in the above Figure 3.13. It has been observed that various sizes of companies have involved to the research.

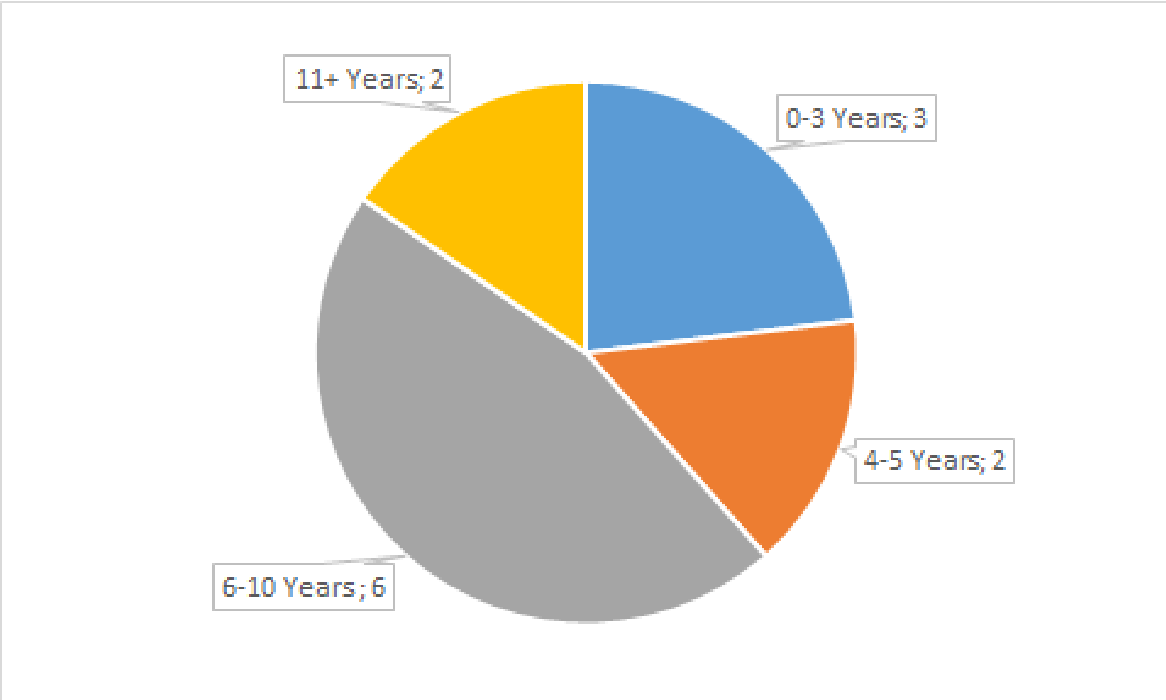

Figure 3.14. BIM Experience of the Companies (In Years)

Last but not the least, most of the interviewed companies has a BIM experience of 5 to 10 years. Thus, the BIM knowledge of those companies is expected to be in a good level. Overall, each company has different level of BIM experience that can be seen in the above Figure 3.14.

3.3.10. Case Projects

18 Different construction projects have been utilized as a case study within the context of this research. Each project has different characteristics that enables the study to analyze the BIM implementation from various aspects. Detailed information about the case projects can be seen in the below Table 3.7 and Table 3.8.

Table 3.7. Interviewed Case Projects.

Company Code	Project Code	Project Type	Interviewed Party	TCA (M2)	Contract Type	Budget	Duration (Months)	Size Of BIM Team	BIM Application
C1	P1	Retail Building	PM	150 K	Unit Price	-	24	7	5D
C2	P2	Airport	Consultant	12 M	Lump Sum	-	24	35	7D
C3	P3	Interior	PM	6 K	Unit Price	-	6	7	4D
C4	P4	Airport	GC	76 M	Unit Price	35 B TL	42	15	7D
C5	P5	Industrial	Designer	60 K	Lump Sum	-	6	5	5D
C6	P6	Airport	GC	700 K	Lump Sum	2 B USD	60	40	-
C6	P7	Airport	GC	60 K	Lump Sum	200 M EUR	24	15	-
C6	P8	High Rise	GC	350 K	Lump Sum	500 M USD	36	-	4D
C7	P9	Building	GC	113 K	Unit Price	600 M TL	25	7	5D

Table 3.8. Interviewed Case Projects Continues.

Company Code	Project Code	Project Type	Interviewed Party	TCA (M2)	Contract Type	Budget	Duration (Months)	Size Of BIM Team	BIM Application
C8	P10	Medical	PM	12 K	Lump Sum	-	4	8	4D
C9	P11	High Rise	Designer	430 K	Lump Sum	2 B TL	36	5	4D
C9	P12	High Rise	Designer	-	Lump Sum	-	-	5	-
C10	P13	Medical	GC	1 M	BOT	1.5 B USD	36	9	5D
C11	P14	Industrial	Designer	650	Lump Sum	-	8	8	-
C11	P15	Industrial	Designer	-	Lump Sum	-	24	3	-
C12	P16	Building	GC	-	Lump Sum	-	-	3	4D
C12	P17	Retail Building	GC	200 K	Lump Sum	-	36	10	4D
C13	P18	Infrastructure	Consultant	-	-	2.3 B TL	36	10	-

As it can be seen from the table above, there are various type of projects taken into consideration. This variety helps the study to analyze the CSFs of BIM implementation process based different project types and to compare them. The number of different project types that have been discussed can be seen in the below Figure 3.15.

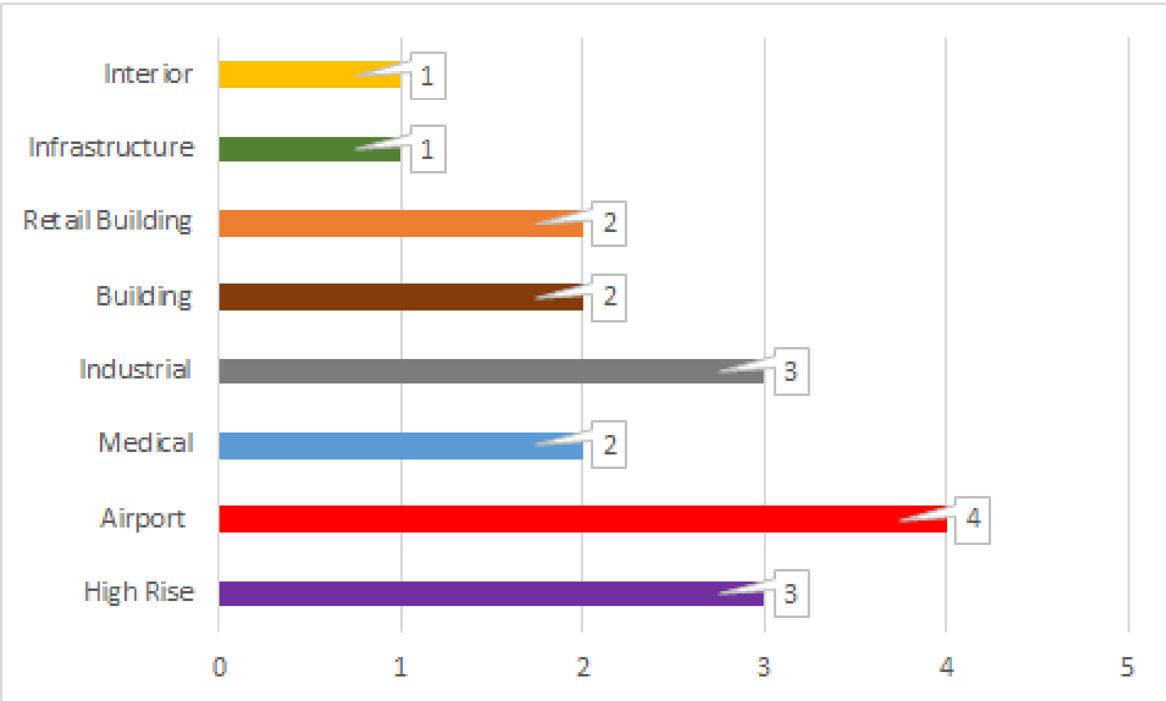

Figure 3.15. Types of Case Study Projects

Moreover, the interviewed case study projects were applied BIM for different purposes. This creates a variety in level of BIM application. The number of case study projects based on BIM application can be seen in the Figure 3.16.

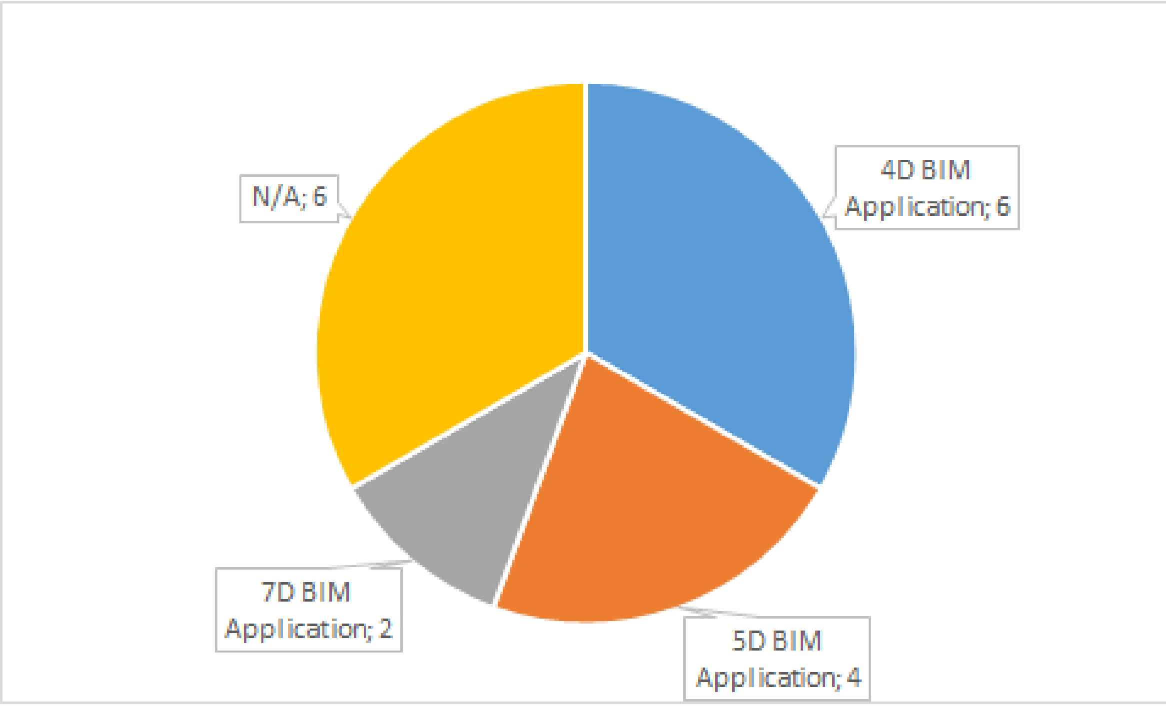

Figure 3.16. Number of Case Study Projects Based on BIM Application

4. FINDINGS

In this chapter, findings of the case studies will be provided as well as some of the important quotes from the interviews. Average of the evaluations will be calculated and provided together with the max and min values for the relevant CSF. This is expected to identify the significance of CSFs according to real experiences. Furthermore, quotes from the interviewers are expected to help to transfer the experience of the interviewer for a certain CSF. The findings will be outlined respectively, according to the framework components.

4.1. Drivers of the BIM Implementation Process

Drivers can be described as the forces that pushes a company to implement BIM. The case study ratings for the previously identified CSFs under drivers component can be seen in the below Table 4.1.

When the evaluations of the industry experts are analyzed, among the driving CSFs, "improving the project performance" emerges as the most important one. With a slightly lower rating, "improving the collaboration and coordination" found as the second most important driver. Other important drivers can be count as "design improvement" and "improving corporate performance" respectively. Only the project P1 evaluated the "design improvement" with a low significance.

According to industry experts, "governmental push" is the least significant factor as a driver. It has a high significance only for project P8 since it is an oversees project of a Turkish company. Furthermore, "improving HSE activities" is evaluated as the second least significant factor. However, projects P4 and P5 rated it as significant factor.

Table 4.1. Case Study Ratings for Drivers Component of the Framework.

#	CSFs	Influence Level	Min Case Study Rating	Max Case Study Rating	Avg. Case Study Rating
1	Improving Corporate Performance	Firm Level	3	5	4.45
2	Improving Project Performance	Project Level	3	5	4.78
3	Improving Building's Energy Performance	Project Level	1	5	2.83
4	Improving Collaboration & Coordination	Project Level	4	5	4.72
5	Client Requirement	Project Level	1	5	3.61
6	Governmental Push	Industry Level	1	4	1.44
7	Design Improvement	Project Level	2	5	4.56
8	Improving Construction Productivity	Project Level	3	5	4.50
9	Improving HSE Activities	Project Level	1	4	1.61
10	Reducing Life Cycle Cost of The Building	Project Level	1	5	2.78

Industry experts are not agreed on the significance of "reducing life cycle cost of the building" and "improving building energy performance". Those two factors are evaluated as the least significant and as the most significant at the same time for different projects. Within the construction industry, 6D and 7D BIM implementation have not became widespread yet. Thus, some of the projects are not targeting the facility management and energy analysis outputs of the BIM.

During the interview with company C1 for project P1, interviewees state that "Since our main mission in that project was to optimizing the resources and construction schedule, improving construction productivity was the main driver for BIM implementation."

Interviewees working for Project P2 of Company C2 implied that "...we get a job just to reduce the life cycle cost of the building and I believe that it is an important driver for BIM implementation."

For project P4 of company C4 the main driver was told as "Increasing the collaboration was crucial for our project."

BIM Manager of company C9 working in project P11 stated "Design improvement pushed our team to utilize BIM because we thought that BIM facilitates the decision making process by providing visual and accurate results for different design alternatives."

Another BIM Manager working for company C10 implied that "Our company implemented BIM to gain competitive advantage in the industry."

BIM responsible of project P17 stated "... at the beginning of the BIM implementation, we planned to conduct energy analysis on the given model."

4.2. Inputs of the BIM Implementation Process

Inputs can be described as the utilized resources for the BIM implementation. Evaluations of the CSFs under inputs component of the framework based on the case studies can be seen below Table 4.2.

Among the 12 inputs of BIM implementation, "internal knowledge" is evaluated as the most important resource. Internal knowledge can be also described as the company know-how that have been produced from the past projects. In addition, "human resources" and "project BIM execution plan" are the second most significant resources based on the average of the ratings by the industry professionals. For all of the case projects, those resources are evaluated to have at least medium level of significance.

Except the "external knowledge and consultancy", all of the input factors are evaluated as a significant factor for the case projects. Thus, identifying the resources and investing on the right ones are crucial for a successful BIM implementation.

BIM Engineer of company C1 told that "A leader is essential to coordinate the BIM implementation process." and added "... in general, Turkish companies see BIM as a tedious drudgery, however more BIM investments should increase together with the awareness.". The interviewee also added "In project P1, we have suffered from lack of a well-developed BIM execution plan."

During the interview, company C4 employees stated "Our company trained more than a hundred employees about the BIM usage and even organized some workshops."

For project P9 of company C7, interviewees stated "It is hard to initiate the process if you have not got enough capital. So the investment is an important input." and added "Since we are a contractor, each project requires special family libraries, it was not an important input for us."

Table 4.2. Case Study Ratings for Inputs Component of the Framework.

#	CSFs	Influence Level	Min Case Study Rating	Max Case Study Rating	Avg. Case Study Rating
1	Human Resources	Project Level	3	5	4.67
2	Financial Resources	Project Level	2	5	4.17
3	Technological Infrastructure	Industry Level	2	5	4.28
4	Softwares & Hardwares	Firm Level	3	5	4.50
5	Custom 3D Library	Industry Level	1	5	3.56
6	Internal Knowledge	Firm Level	4	5	4.72
7	External Knowledge & Consultancy	Project Level	1	5	2.89
8	Project Information	Project Level	3	5	4.50
9	Project BIM Execution Plan	Project Level	4	5	4.61
10	Company's BIM Policy	Firm Level	1	5	4.06
11	BIM Guideline	Industry Level	1	5	4.22
12	Training & Education	Firm Level	2	5	4.50

BIM Team Leader of the company C8 implied “Improved softwares are enhancing the BIM implementation. The more the technology develops, the more easy to implement BIM and convince people.”

BIM manager of company C9 implied “... for project P12, consultation was important to determine the BIM implementation process...”

BIM manager of company C10 stated “Our company has a strong BIM policy that supports the implementation process.” and added “International guidelines are essential for developing a common data environment.”

Training was crucial for project P13 as the interviewees told “We even educated out subcontractors in to utilize BIM effectively.”

BIM expert working for project P18 stated that “I believe consultation is crucial for a smooth BIM implementation”

4.3. Barriers for the BIM Implementation Process

Barriers are the representation of the challenges encountered during the BIM implementation process. Significance of the identified barriers according to industry professionals can be seen in the below Table 4.3.

There are a total of 11 barriers that have been identified from the literature review. Among those barriers, “availability of knowledge based on experience” and “change process problems” are the most significant barrier factors with an equal rating according to the industry professionals. Case project P2 have been evaluated both of the top significant barriers as the least significant. Since the company working for the project P2 is a very young company that have been established its business based on BIM, they have not encountered such problems.

Table 4.3. Case Study Ratings for Barriers Component of the Framework.

#	CSFs	Influence Level	Min Case Study Rating	Max Case Study Rating	Avg. Case Study Rating
1	Availability of Knowledge Based on Experience	Firm Level	1	5	3.83
2	Unclear Benefits	Project Level	1	5	2.56
3	Lack of Best Practices	Industry Level	1	5	2.67
4	High Costs	Project Level	1	5	2.39
5	Technology Related Problems	Industry Level	1	4	2.22
6	Change Process Problems	Industry Level	1	5	3.83
7	Legal & Protocol Problems	Industry Level	1	4	1.67
8	Fragmented Nature of the Industry	Industry Level	1	5	2.61
9	Interoperability Problems of Different Parties	Project Level	1	5	3.00
10	Project Specific Problems	Project Level	1	5	2.78
11	Lack of Government Support	Industry Level	1	5	2.22

Interestingly, although some of the case projects have been evaluated some barrier factors as very significant, overall, none of the barrier factors have an average rate of 4 or more. The barriers component has a medium level significance according to industry professionals.

The least significant barrier is revealed as "legal and protocol problems". In addition, none of the interviewers rated this factor as highly significant. Furthermore, it is obvious that there is not a consensus among the industry professionals about the significance of the barriers. Almost all of the barriers rated as 1 to 5 according to case projects.

Interviewees working for project P1 stated "Tangible and measurable benefits are very important for decision making especially in the Turkish construction industry."

Partner of company C2 stated "Since project P2 is an airport project, interoperability of different parties was a huge barrier. There were lots of groups involved into the construction process."

BIM manager of company C7 implied "Since our protocols are clear, we have not encountered with legal (ownership etc.) issue." and added "We got tax incentive from the government, thus lack of government support is an enabler more than being a barrier for us."

An interviewee working for project P10 told that "... in contrast, I believe that BIM benefits are tangible." and added "Resistance to change was the biggest barrier for BIM implementation."

During the interview with project P11 employees stated "When different parties use different softwares, it became a problem to merge the models."

A BIM Manager working for project P12 told "Lack of best practices is a barrier for benchmarking."

Another BIM manager working for project P13 implied that "There is no technology related barrier for BIM, indeed, BIM solves those problems." and added "People did not want to change their way of doing business."

For project P13 it has been said that "Hospital projects have too much revisions which makes the process getting more complicated."

4.4. Enablers for the BIM Implementation Process

Enablers can be described as the factors that facilitates the BIM implementation process. The evaluations according to case study projects are at the below Table 4.4.

When we examine the ratings, "planning of the BIM execution process", "project level collaboration" and "supportive organizational culture" are evaluated as the most significant enabling factors respectively. Among all of the case projects, none of them have considered the most significant factors are to have a very low significance. There is a consensus about the significant enablers.

On the other hand, although case projects P1, P3 and P10 have evaluated the "external grants, incentives and promotions" as very significant, it has the lowest average rating and evaluated as the least significant enabler overall.

In addition, none of the enabling factors has been evaluated to have a very low significance. Industry professionals thinks that enablers are significant for a successful BIM implementation.

For project P1 ist has been said that "Collaboration was definitely the most important enabler for BIM implementation."

Table 4.4. Case Study Ratings for Enablers Component of the Framework.

#	CSFs	Influence Level	Min Case Study Rating	Max Case Study Rating	Avg. Case Study Rating
1	Corporate & Academic Level Collaboration	Industry Level	1	5	3.22
2	Project Level Collaboration	Project Level	3	5	4.61
3	Managerial and Technical Abilities	Firm Level	3	5	4.50
4	Supportive Organizational Culture	Firm Level	2	5	4.39
5	External Grants, Incentives & Promotions	Industry Level	1	5	2.45
6	Global Standardisation	Industry Level	1	5	3.95
7	IPD Type Contracts	Project Level	1	5	2.67
8	Planning of BIM Execution Process	Project Level	3	5	4.78

Partner of company C2 stated that "Global codes (global standardization) helps to overcome local problems."

Interviewees from project P4 implied "A BIM champion is an important factor to facilitate the BIM implementation process."

BIM Manager working for project P11 stated that "Commitment is important to ensure a successfull BIM implementation."

During the interview with company C10, is has been argued that "Supportive organizational culture is a very important enabler."

Interviewees working for project P18 implied that "BIM ensures right decisions to be made by providing reliable information." and added, "We got consultation from an oversees country and enabled us to implement BIM truly."

4.5. Benefits of the BIM Implementation Process

Benefits are the short term gains from the BIM implementation. Significance of the CSFs under benefits component of the framework based on case projects can be seen in the below Table 4.5.

Among the 10 previously identified benefit factors, "knowledge management benefits" have been evaluated as the most significant short term outcome of the BIM implementation. Since this study aims to investigate the BIM implementation for construction phase, the second most important benefit has been evaluated as "right and accurate construction activities". None of the case study projects have been considered those two benefits to have a significance of medium level or low.

Table 4.5. Case Study Ratings for Benefits Component of the Framework.

#	CSFs	Influence Level	Min Case Study Rating	Max Case Study Rating	Avg. Case Study Rating
1	Project Financial Benefits	Project Level	1	5	4.17
2	Right and Accurate Construction Activities	Project Level	4	5	4.72
3	Right and Accurate Technical Office Works	Project Level	3	5	4.56
4	Improve Staff Performance	Project Level	3	5	4.67
5	Knowledge Management Benefits	Project Level	4	5	4.83
6	Claim Management Benefits	Project Level	3	5	4.28
7	Reduction of Facility Management Costs	Project Level	1	5	2.45
8	Client Satisfaction	Project Level	3	5	4.28
9	Improve Communication & Collaboration	Project Level	2	5	4.17
10	Improve Energy Savings	Project Level	1	5	2.78

Those two factors have been followed by “improve staff performance” and “right and accurate technical office works” respectively. The top 4 most important benefits are very crucial for contractors to increase the efficiency of their workflow.

The two least significant benefits of the BIM implementation are revealed as “reduction of facility management costs” and “improve energy savings”. However, both of the mentioned benefits are evaluated as highly significant for case projects P2 and P4. This condition matches with the findings of the driving component that resulted from frequency of the 6D and 7D BIM implementation within the construction industry.

Last bu not the least, according to industry professionals, none of the benefits of BIM implementation has a low significance. All of the BIM benefits has at least medium level significance for the case projects.

Interviewees working for project P1 stated that “We have benefitted in terms of cost more than time. We exported the project data in IFC format and can access all information from a single model”

Partner of company C2 implied that “number of RFIs was really decreased thanks to BIM.”

BIM Manager of project P3 stated that “Since we are doing interior works, energy saving was not an important BIM benefit for us.”

For project P4, interviewees stated that “BIM coordination model went 5 or 6 months ahead of the construction schedule and allow everybody to access right information and documents.”

BIM manager of project P11 also argued that “BIM reduced the number of RFIs as well as the number of meetings.”

In project P12, a BIM benefit was described as “Due to a design change in a mechanical equipment, there was a clash appeared regarding the ceiling elevation and we updated the BIM model to check clashes. Then revised it and prevented a rework on the site.”

BIM Manager of company C10 argued that “... client satisfaction is highly correlated with the effective BIM usage.”

In project P17, a BIM benefit was described as “We have improved the facade design based on the energy analysis that we have conducted.”

4.6. Impacts of the BIM Implementation Process

Impacts can be described as the long term outcomes of the BIM implementation. Below, the Table 4.6 shows the evaluations for impacts component of the framework based on case study projects.

Industry professionals have been evaluated the “enable new businesses” and “generate corporate knowledge” as the most significant impacts of BIM implementation with an equal rating. Those two factors are followed by factor “company’s productivity improvement”.

All of the identified factors under impacts component has an average significance rate more than 4. It means that industry professionals find the long term outcomes of the BIM implementation highly significant.

An impact of BIM implementation was described by interviewees working for project P2 as “We have started doing new type of businesses that we have never done before thanks to BIM.”

Table 4.6. Case Study Ratings for Impacts Component of the Framework.

#	CSFs	Influence Level	Min Case Study Rating	Max Case Study Rating	Avg. Case Study Rating
1	Company's Productivity Improvement	Firm Level	3	5	4.61
2	Corporate Management Improvement	Firm Level	2	5	4.28
3	Expanding Company's Scope of Services	Firm Level	2	5	4.11
4	Enable New Businesses	Firm Level	3	5	4.67
5	Improve Corporate Financial Performance	Firm Level	3	5	4.17
6	Generate Corporate Knowledge	Firm Level	4	5	4.67

BIM Manager working for project P9 stated "... of course, utilizing BIM helps us to get new businesses..."

Interviewees working for company C9 stated that "BIM definitely helps to generate corporate knowledge." and gave a final comment "Local authorities need to adapt themselves to the system. This way, implementing BIM become more beneficial and also easier."

For company C10, BIM manager implied that "Since BIM decreases costs, it improves corporate financial performance. However, a company should carefully plan that is BIM going to be used for all of the projects. Maybe some small scale projects do not need BIM implementation."

5. DISCUSSION

In the previous chapter, findings of the case studies are published. This section aims to analyze and discuss various findings. Firstly, the case study findings are compared with the literature study results for each component of the framework. Secondly, the findings are analyzed and compared according to different project types. Thirdly, the findings are analyzed based on BIM applications of case studies. Lastly, significance of the previously assigned influence levels are compared based on the CSFs ratings.

5.1. Literature Results Versus Case Study Results

In this section, case study results are compared with the literature and some key points are revealed for each component of the framework.

5.1.1. Discussion on Drivers

According to literature analysis, 10 CSFs have been identified as the drivers of BIM implementation process. Below Figure 5.1 shows the comparison of literature and case studies for the drivers component of the framework.

Based on the literature analysis, “design improvement”, “improving project performance” and “improving collaboration and coordination” have been identified as the top three factors mentioned in the literature as drivers. Also industry experts have evaluated those three factors as the most important. Based on a survey study participated by 30 organizations, Eadie *et al.* (2013) has identified “improving design quality” as one of the most important drivers. Moreover, Dawood *et al.* (2012) identified “an internal push force by clients” and “an external push force by governments” as driving forces. The study conducted for 4D BIM implementation within the UK AEC industry. Thus, the local legislation in the UK may strengthen the importance of those.

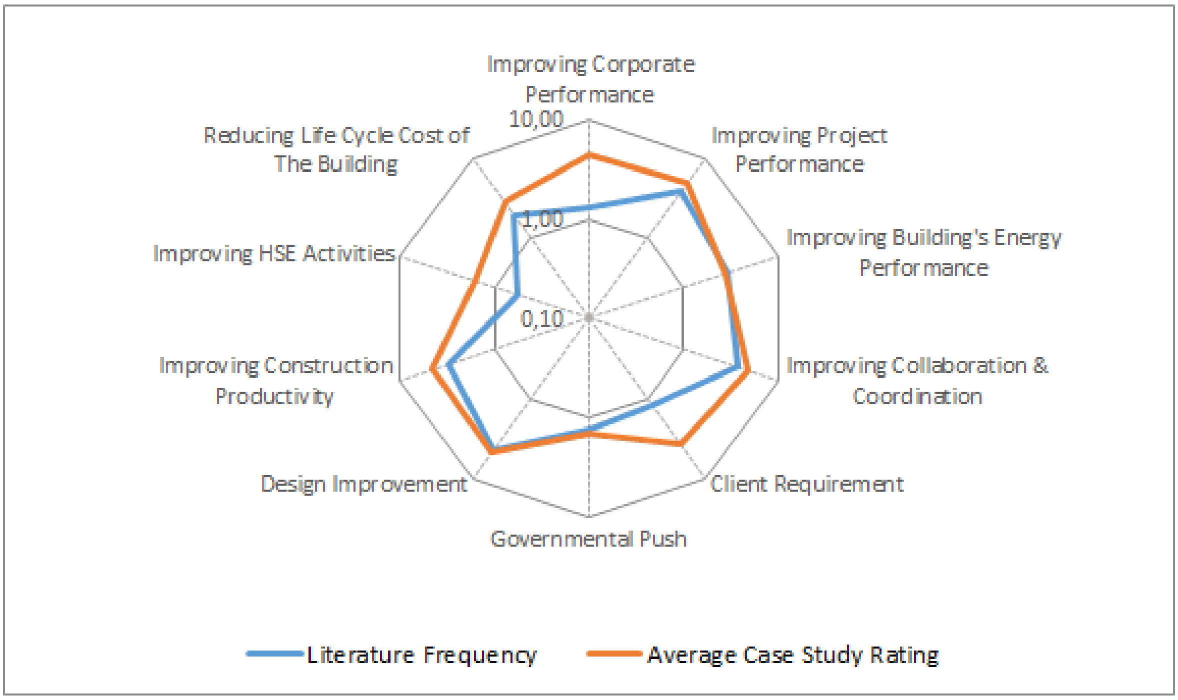

Figure 5.1. Comparison of Literature and Case Studies for Drivers Component

On the other hand, "improving HSE activities" has been identified as the least important factor as a driver by both of the literature and the industry experts. The research conducted by Eadie *et al.* (2013) also revealed that "design health and safety into the construction process" is one of the least important drivers. However, Eadie *et al.* (2013) argued that "automation of schedule" is also one of the least important drivers. In contrast, this thesis study identified "improving construction productivity" as an important driver. This difference results from different type of project characteristics.

Case study interviews also showed that although the importance of "improving HSE activities" is low, there is a high potential for combining BIM with safety tools. Industry professionals indicated that "Coordinating HSE discipline with BIM would be great to identify potential risks". At this point, Virtual Safety Analysis For Engineering Applications (V-SAFE) can be a good research area to investigate. A previous research conducted by Kiral *et al.* (2015) argues that V-SAFE can improve the risk recognition capability and the spatial awareness of the users.

Since BIM implementation simplifies the processes, it is a very important lean improvement for a project. Thus, BIM implementation is vital for a project that aims to be lean. In addition, BIM implementation also improves sustainability by enabling project parties to analyze building's energy performance in a better way.

When the min and max ratings of the driving factors are considered, it can be deduced that significance of the "improving collaboration and coordination" is very high regardless of anything such as the country, project type, size and BIM application.

It is also obvious that min and max ratings of the factor "building's energy performance" has varies between 1 to 5. Significance of that factor depends on 6D BIM application. Moreover, same situation is valid for the factor "reducing the life cycle cost of the building". Significance depends on 7D BIM implementation for that factor.

5.1.2. Discussion on Inputs

Based on 45 research papers, 12 CSFs have been identified as the inputs of BIM implementation process. Below Figure 5.2 shows the comparison of literature and case studies for the inputs component of the framework.

As the top mentioned inputs, "softwares and hardwares" and "technological infrastructure" have been identified in the literature. The case study results show that technology is essential for BIM implementation in both firm level and industry level. In a previous research, a remote construction project has analyzed as a case study by Arayici *et al.* (2012) and decision on utilized software was told as very important. Furthermore, "training and education" and "human resources" are also need to be addressed as significant inputs according to literature. However, other input factors have not got high frequencies among the literature.

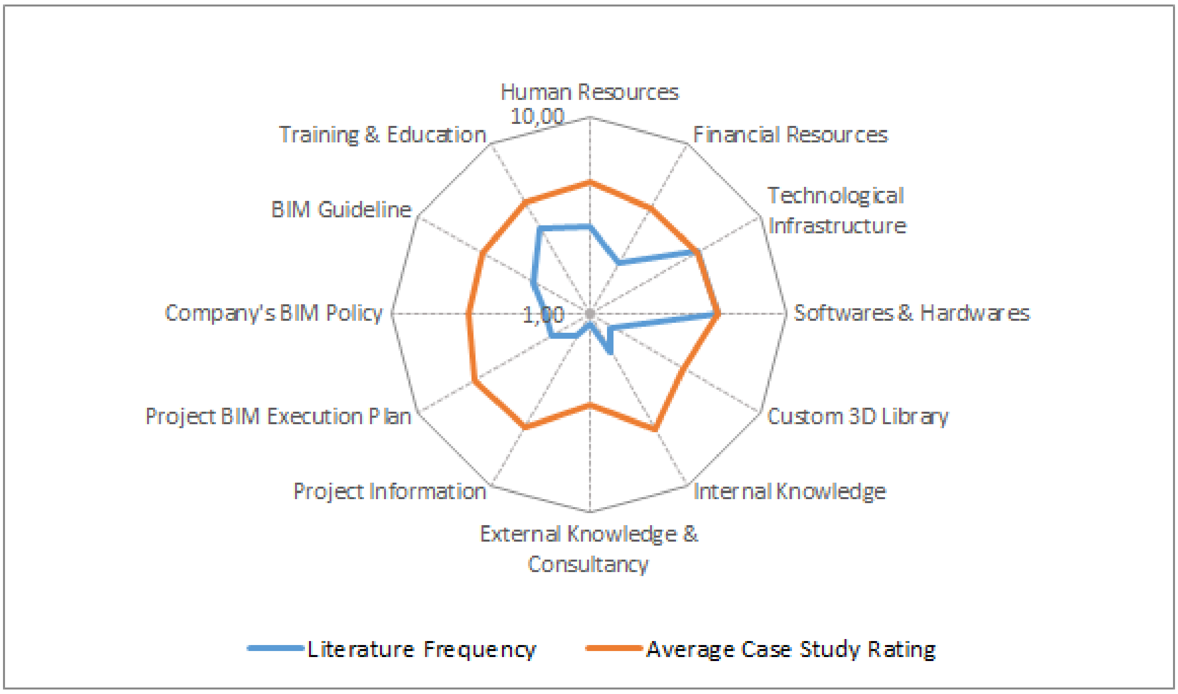

Figure 5.2. Comparison of Literature and Case Studies for Inputs Component

According to industry experts, all the input factors were essential for a successful BIM implementation on their project. However, "external knowledge and consultancy" got one of the least average ratings but still considered as an important input. Similarly, based on the counted literature frequencies, consultancy has identified as the least mentioned factor in the literature.

Since the factors "internal knowledge" and "project BIM execution plan" have a minimum rating of four, it is obvious that their significance as an input is very high regardless of any specific situation.

Findings of this study showed that combination of BIM implementation with the most recent technology is highly significant. Laser scanning of existing structures are getting popular and especially using unmanned aerial vehicles (UAVs - Drones) for the laser scanning may be a good development for BIM implementation.

5.1.3. Discussion on Barriers

Based on the literature, 11 CSFs have been identified as the barriers for BIM implementation process. Below Figure 5.3 shows the comparison of literature and case studies for the barriers component of the framework on a spider web.

"Change process problems" and "technology related problems" have the highest frequencies among the literature. Change process problems are commonly described as "resistance to change" in the literature. Based on a research that analyzed 4 case studies, Migilinskas *et al.* (2013) argues that data transfer among the particular tools (software and hardware) was limited due to incompatibility and transmission of the consistent information to other participants. In addition, Migilinskas *et al.* (2013) also argued that there are many barriers keeping project participants from using the latest technology including fears of too low success low or big failure, high initial investment costs, the time to learn how to use the software and lack of support.

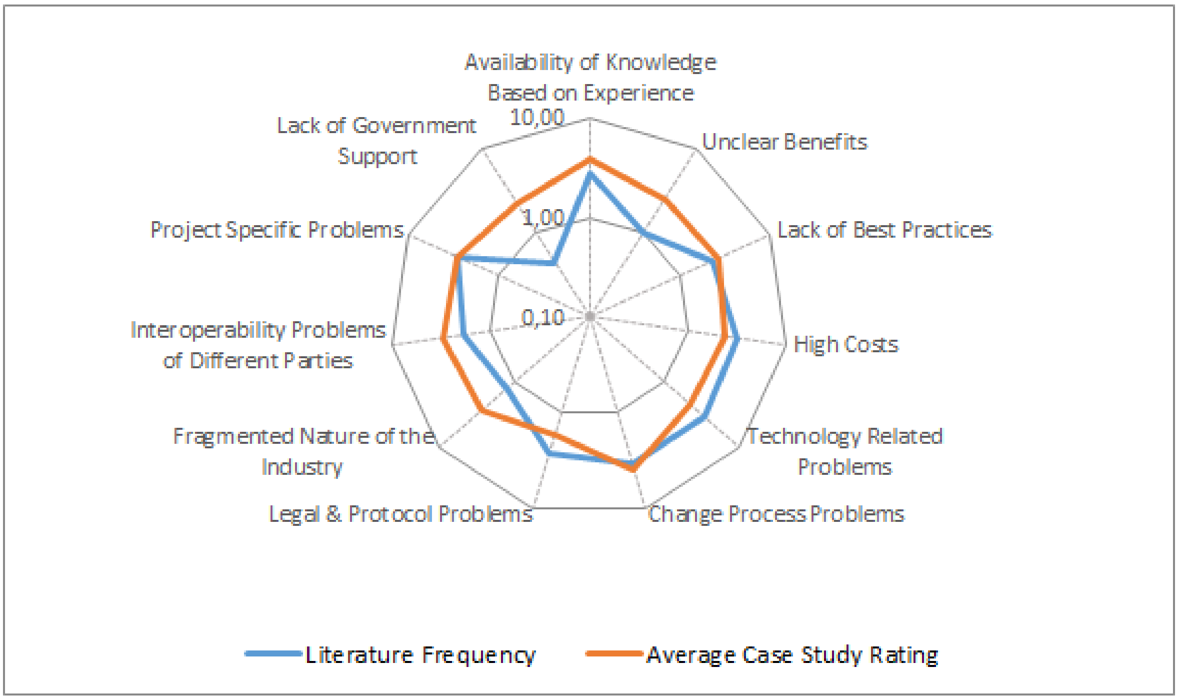

Figure 5.3. Comparison of Literature and Case Studies for Barriers Component

On the other hand, industry experts have identified "availability of knowledge based on experience" and "change process problems" as the most significant barriers. Newton and Chileshe (2012) has conducted a study on barriers of BIM implementation in South Australia and revealed that lack of understanding and awareness acting as a barrier to BIM. Gerrard *et al.* (2010) also supports this finding as they reveal lack of BIM knowledge and expertise is the greatest barrier. Yan and Damian (2008) argues that "Decisions made in organizations are mainly derived from a business perspective (make profit). The AEC industry is not glad to invest in BIM, because of the lack of case study evidence of the financial benefit of BIM.".

Although "lack of government support" has the lowest frequency among the literature, it has been identified as one of the most important barriers by the industry experts. Since this study was limited with the Turkish construction industry, lack of government support is not an important barrier for other countries. This proves that Turkish Government need to support BIM implementation within the industry.

When the min and max ratings are considered for the barriers component, it can be argued that significance of almost each barrier depends on specific situations such as project type, BIM application, etc. for that particular project.

5.1.4. Discussion on Enablers

According to literature review, 8 CSFs have been identified as the enablers for BIM implementation process. Below Figure 5.4 shows the comparison of literature and case studies for the enablers component of the framework.

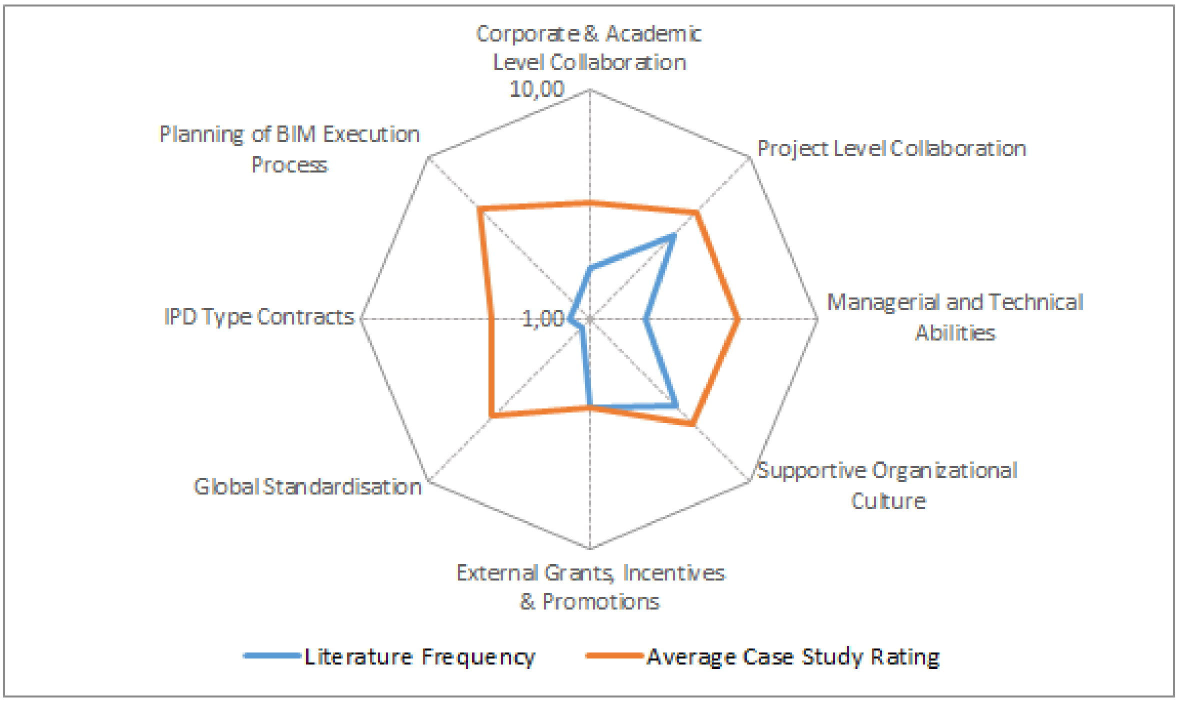

Figure 5.4. Comparison of Literature and Case Studies for Enablers Component

The most frequently mentioned enablers in the literature are identified as "supportive organizational culture" and "project level collaboration". Abbasnejad *et al.* (2016) argued that knowledge sharing and communication play a vital role for BIM implementation. In parallel, average case study ratings indicate that "supportive organizational culture" and "project level collaboration" are highly significant enablers. Most of the enabling factors have relatively low rate of frequency among the literature. This shows that more research is need to be conducted to address the enablers for BIM implementation.

On the other hand, "global standardization", "IPD type contracts" and "planning of BIM execution process" are the least frequently mentioned factors in the literature. Similarly, "IPD type contracts" evaluated to have low significance by industry experts. However, "global standardization" and "planning of BIM execution process" have been identified as one the most important factors by the industry experts.

Since IPD type contracts improves the project level collaboration, BIM implementation in IPD projects is expected to give better results.

5.1.5. Discussion on Benefits

Based on the research papers in the literature, 10 CSFs have been identified as the benefits of BIM implementation process. Below Figure 5.5 shows the comparison of literature and case studies for the enablers component of the framework.

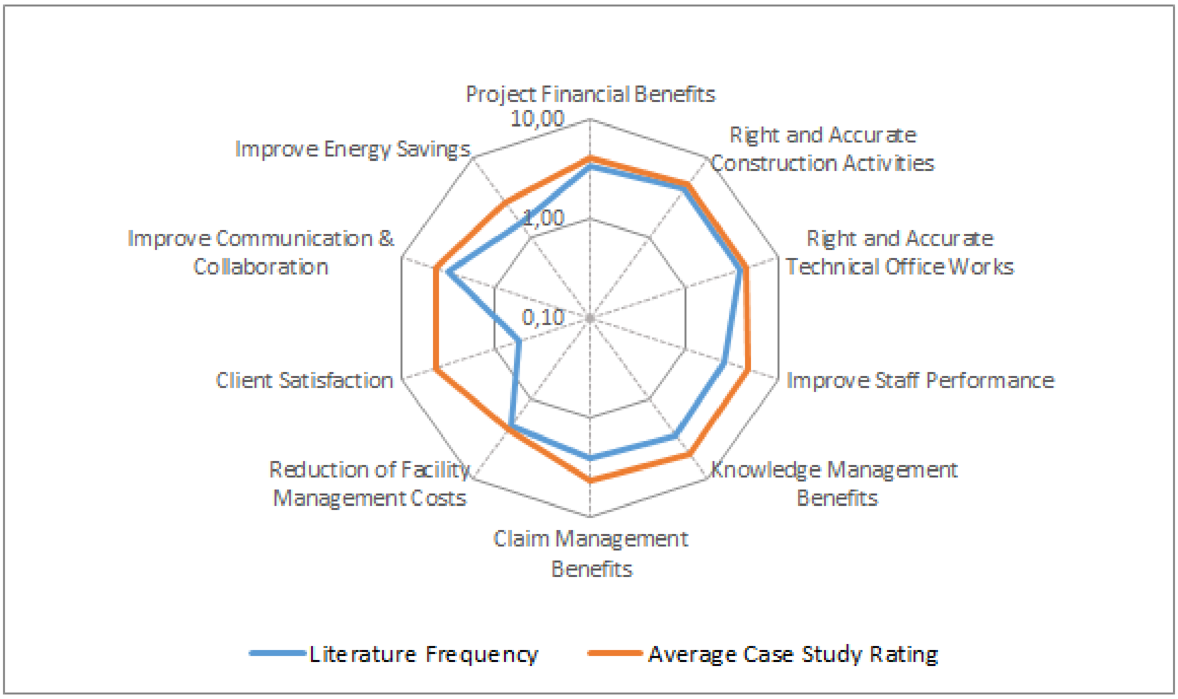

Figure 5.5. Comparison of Literature and Case Studies for Benefits Component

According to literature review, "right and accurate construction activities" and "right and accurate technical office works" have been identified as the top mentioned factors in the literature. Those factors are most commonly described as "less rework" and "reducing risks" within the literature. Based on the research conducted by Yan and Damian (2008), reducing time and cost and improving quality were identified as the most important benefits of BIM in UK and US construction industries. Moreover, Stanley and Thurnell (2014) investigated the 5D BIM implementations in New Zealand and revealed that earlier risk identification is improved at an earlier stage compared with traditional approaches.

In terms of benefits, literature frequencies and industry evaluations are almost parallel except “client satisfaction”. According to industry experts, each benefit factor has an importance level of at least 4 out of 5. The least mentioned benefit of the BIM implementation is “client satisfaction” in the literature even though it has been identified as one of the most important benefits. Bryde *et al.* (2012) claims that “owner received a big injection of confidence in the GC when the PM showed how design decisions impacted cost and schedule.”

Among the factors under the benefits component of the framework, “right and accurate construction activities” and “knowledge management benefits” have been evaluates at least four out of five. This indicates that, those benefits are highly significant no matter that project type, size, country etc.

On the other hand, “improve energy savings” and “reduction of facility management costs” are depends on the BIM application objective of a particular project. If a company targets 6D BIM implementation, then energy savings become an important benefit. If a company targets 7D BIM implementation, then facility management costs become an important benefit.

When it comes to operations and facility management, one of the most important steps at the end of the construction phase is commissioning. If there is a well developed BIM model, whenever a test was done, a checklist was filled or an issue was coordinated, it is easier access to the component and system specs and by working in the shared repository you automatically update the component and system history.

Moreover, is can be also argued that some of the case projects have not obtained financial benefits from the BIM implementation. This may result from the costs of first time BIM application for a company.

5.1.6. Discussion on Impacts

According to literature analysis, 6 CSFs have been identified as the impacts of BIM implementation process. Below Figure 5.6 shows the comparison of literature and case studies for the barriers component of the framework on a spider web.

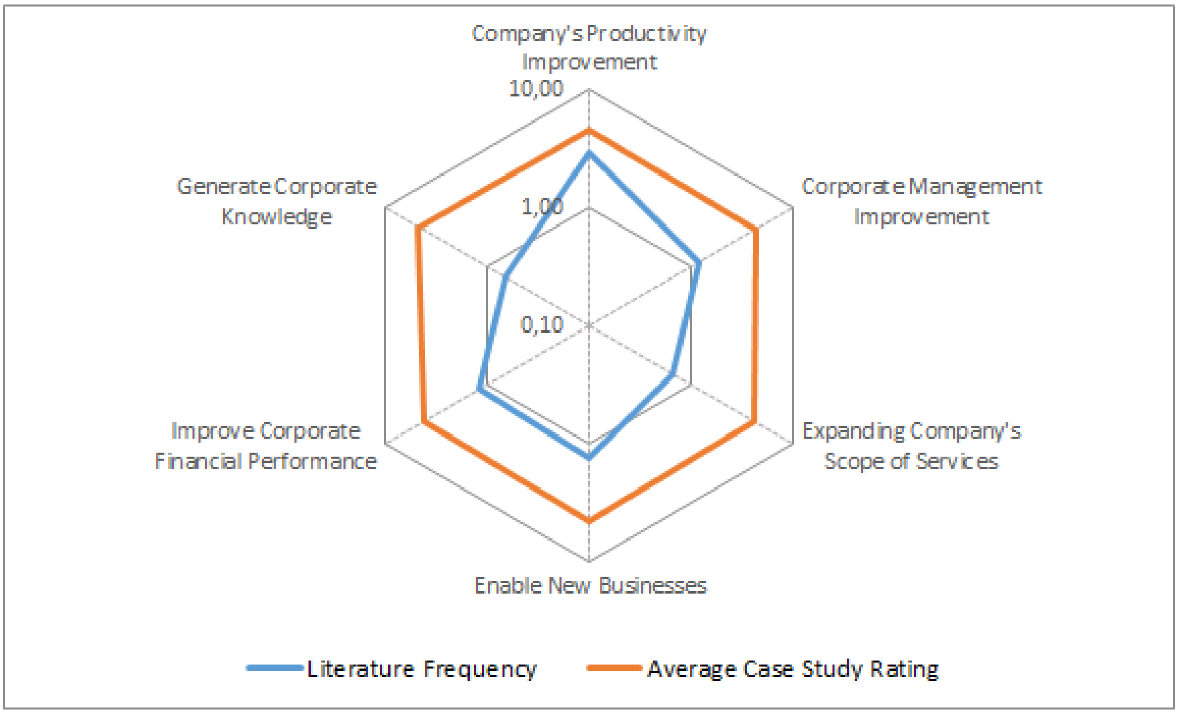

Figure 5.6. Comparison of Literature and Case Studies for Impacts Component

According to literature review, “company’s productivity improvement” is the most frequently mentioned impact of BIM implementation. Based on a case study research, Arayici *et al.* (2011) argues that BIM adoption in the case company had internally big impact to gain efficiencies and effectiveness as the adoption established the required capacity internally. Moreover, Ghaffarianhoseini *et al.* (2017) argues that long term benefits of BIM are fewer contractual claims and reduced construction costs.

Nevertheless, “enable new businesses” is also need to be addressed as an important impact factor. Ghaffarianhoseini *et al.* (2017) states that maintaining relationships with past clients for new businesses is a major impact of BIM. From the industry experts’ perspective, all the CSFs of the impact component is highly significant.

When the min and max ratings are considered for the impacts component of the framework, it can be deduced that regardless of anything, companies mostly utilize BIM for the impact of “generate corporate knowledge” in the long term.

5.2. Comparison of CSFs for Different Project Types

In this section, case study ratings are analyzed for different project types in order to reveal the significance that differs project to project. 4 main project types namely, high rise projects, airport projects, medical projects and industrial projects are taken into consideration.

5.2.1. High Rise Building Projects

High rise buildings are the complex structures that have some specific features defined as;

- The number of storeys means occupants need to use a lift to reach their destination
- The height is beyond the reach of available fire-fighting equipment.
- The height can have a serious impact on evacuation.

In this study in three high rise buildings are considered as a case study. Findings show that high rise buildings identified some of the CSFs as more significant than the others. In addition to the overall average ratings, “client requirement” and “improving construction performance” are also identified as the most significant drivers. For the inputs and barriers components, the results are parallel with the overall average ratings.

Moreover, for the high rise buildings “corporate and academic level collaboration” identified as the least significant enabler different from the overall ratings. In addition to the overall average ratings, “project financial benefits” and “improve communication and collaboration” are also identified as the most significant benefits. Lastly, “company’s productivity improvement” has been identified as the most significant impact for the high rise projects.

5.2.2. Airport Building Projects

Airport projects are generally public or public private partnership (PPP) projects that funded by the governments. When constructing an airport, lots of parties involve into the process due to the complexity and scale of the projects. In this study, four airport projects are taken into account.

Findings reveal that significant of the driving factors are parallel with the overall average ratings. When it comes to inputs component, “training and education” has been evaluated as the most important input for the airport projects. In terms of barriers, airport projects differentiate from the overall ratings. The most significant barriers are identified as “project specific problems” and “fragmented nature of the industry” for the airport projects. Since governments are somehow involving to the airport projects the least important barrier has been evaluated as “lack of government support”.

Furthermore, significance of the enablers, benefits and impacts components are parallel with the overall average ratings for the airport projects.

5.2.3. Medical Building Projects

Medical projects can be defined as hospital or clinic buildings that contains health care equipment and some other specific components. This research examined two medical building projects one as a hospital and one as a clinic building.

In medical building projects, “improving corporate performance” is identified as one of the the most important driver and “client requirement” as the least important driver different than the overall average ratings. When it comes to inputs, all of the factors are identified as highly significant for the medical projects. Different than the overall average ratings, “availability of knowledge based on experience” and “lack of best practices” are identified as the most important barriers and “interoperability of different parties” as the least important barrier.

Furthermore, almost all of the enabler, benefits and impacts factors are evaluated as significant for the medical projects. However, “reduction of facility management costs” and “improve energy savings” are evaluated as least important benefits for the medical projects even the fact that they expected to be highly important benefits for the medical projects.

5.2.4. Industrial Building Projects

Industrial buildings are mainly consisting of complex structures that works together with the mechanical equipment on the production line and need to have resistance against industrial materials, chemicals etc. In this thesis study, three industrial buildings are analyzed as a case study.

According to case study analysis, almost all CSFs under drivers and inputs components of the framework are evaluated as significant. On the other hand, almost all of the barrier factors are evaluated to have low significance. In contrast with the overall average ratings, “fragmented nature of the industry” has been evaluated as the least significant barrier for industrial building projects.

When it comes to the enablers component of the framework, “supportive organizational culture” has been evaluated as the most important enabler for industrial building projects. Lastly, almost all factors under benefits and impact component are evaluated as highly significant for industrial building projects.

5.3. Discussion Based on BIM Application Level

In this section, the average ratings of the case studies based on BIM applications will be compared in order to reveal the key points among the BIM application levels. As previously mentioned, there are several types of BIM application that are considered as a case study. Within the context of this thesis, 4D, 5D and 7D BIM utilized projects are interviewed.

When the driving factors are considered, it can be interfered that in contrary to 4D and 5D BIM implemented projects, "improving building's energy performance" has an average rating of 5 out of 5 for the 7D BIM implemented projects. On the other hand, "client requirement" is evaluated as more significant for 5D BIM implemented projects.

In terms of inputs, although "BIM guideline" have been evaluated as highly significant for 4D and 5D BIM implemented projects, it is evaluated to has a significance level of 1 out of 5 for 7D BIM implemented projects. Since the 7D BIM application has a relatively low adoption rate within the industry, most of the guidelines may not cover 7D implementations.

When it comes to barriers, "availability of knowledge based on experience" and "lack of best practices" have been differentiated for 7D BIM implementation with a low level of significance. 4D and 5D BIM implemented case studies almost rated equally for the barriers.

As an enabler "corporate and academic level collaboration" has been evaluated as highly significant for 5D and 7D BIM implemented projects whereas it has been evaluated to have a low level of significance for 4D BIM implemented projects. On the other hand, since the 7D BIM implementation is not common in the industry, "external grants, incentives and promotions" has been evaluated as the least significant factor for 7D BIM implemented projects.

Except the factor “reduction of facility management costs”, all of the benefit factors are almost evaluated equally and as highly significant. Since 7D BIM implementation is more about facility management, “reduction of facility management costs” has an average rating of 5 out 5 for 7D BIM implemented projects and 2 out of 5 for 4D and 5D BIM implemented projects.

Lastly, all of the factors within the impacts component have been almost evaluated equally and as highly significant. In summary, it can be argued that 7D BIM implemented projects differentiate from the 4D and 5D BIM implemented projects in terms of significance of the CSFs.

Regardless of the BIM function utilized within a project, is has been observed that collaboration is crucial for a successful BIM implementation and IPD approach enhances the BIM implementation. It can be argued that implementing BIM together with the other related concepts such as IPD, LEAN, Sustainability or Agile fosters the BIM implementation.

5.4. Discussion on Influence Levels and Comparison of Components

Within the context of this thesis study a framework consisting of 5 components have been developed, and CSFs from the literature have identified. Each one of the CSFs is assigned a level of influence namely industry level, firm level and project level. In this section, the findings of the study will be discussed based on the influence levels and the components of the framework will be compared. Below table 5.1 shows the average case study ratings for components and influence levels.

Table 5.1. Average Case Study Ratings for Components and Influence Levels.

Framework Component	Influence Level	Avg. Case Study Rating	Overall Avg. Case Study Rating
Drivers	Industry	1.44	3.53
	Firm	4.44	
	Project	3.67	
Inputs	Industry	4.02	4.22
	Firm	4.44	
	Project	4.17	
Barriers	Industry	2.54	2.71
	Firm	3.83	
	Project	2.68	
Enablers	Industry	3.2	3.82
	Firm	4.44	
	Project	4.02	
Benefits	Industry	N/A	4.09
	Firm	N/A	
	Project	4.09	
Impacts	Industry	N/A	4.42
	Firm	4.42	
	Project	N/A	

5.4.1. Comparison of Components

First of all, when the components are compared with each other, it can be deduced that benefits and inputs are differentiated as highly significant and impacts component as the most significant component of the framework. Since the impacts can be defined as the long term firm level effects of BIM implementation, this result indicates that utilizing BIM is highly significant for the companies.

On the other hand, the table shows that barriers is the least important component of the framework. This results from the fact that all of the interviewed projects have been implemented BIM therefore, they have already achieved most of the identified barriers. Only some of the specific barriers are encountered in the specific projects.

Lastly, drivers and enablers components have an average overall rating between 3 and 4 out of 5. Thus, they have a medium level of significance according to case projects examined.

5.4.2. Discussion on Influence Levels

First of all, there are a total of 57 CSFs identified from the literature analysis. The number of factors based on influence levels can be seen in the below Figure 5.7.

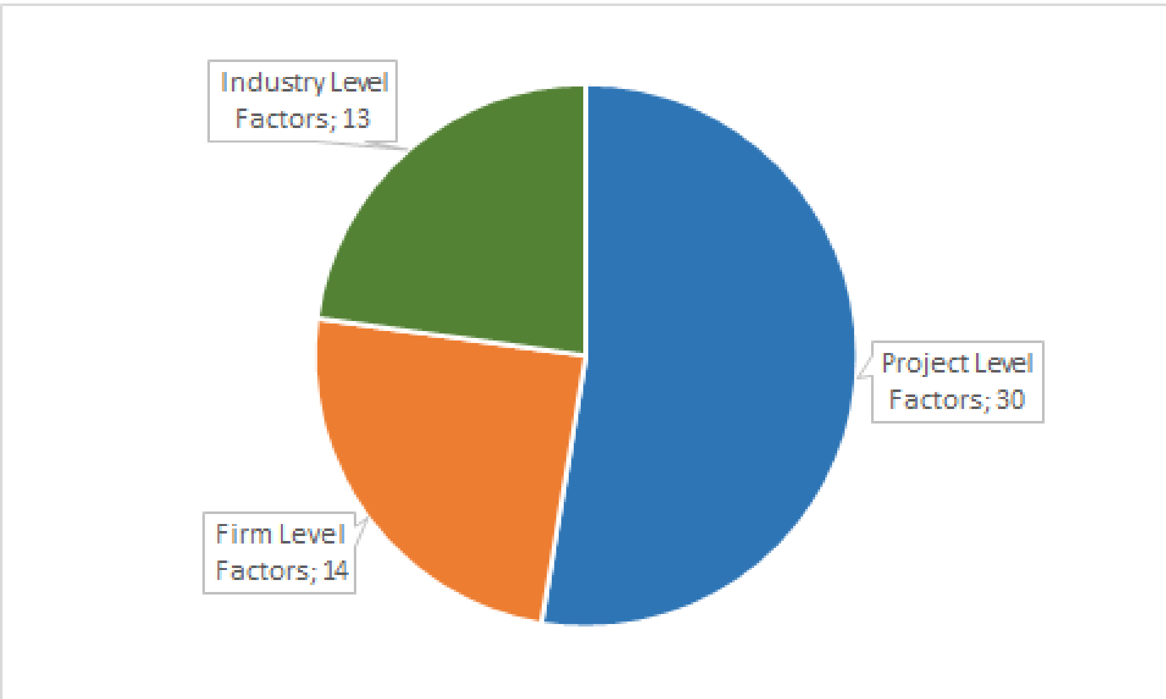

Figure 5.7. Number CSFs Based on Influence Levels

According to the above chart, it can be seen that the identified CSFs are mainly consist of project level factors. In addition, industry and firm level factors are almost equally shared.

For the drivers component, project and firm level factors are considered as significant whereas industry level factors evaluated to have a lower significance. It can be deduced that firm level factors are the most important drivers for the BIM implementation.

When it comes to inputs component, is observed that project, firm and industry level factors has almost equal average ratings. All of the influence levels are evaluated as highly significant as an input.

For the barriers component, similar to the drivers, firm level factors have evaluated as more significant than project and industry level factors.

When the enablers component is considered, again it can be deduced that firm level factors are more significant than project and industry level factors as enablers. However, it is also obvious that industry level factors are not very significant as an enabler. It is most probably result from lack of industry level BIM initiatives in Turkey.

By the definition, benefits component contains only project level factors and impacts component contains only firm level factors.

Moreover, when the literature findings are considered, it is observed that project level factors are mainly grouped under drivers and benefits component of the framework. Furthermore, most of the firm level factors are a member of inputs or impacts component. When it comes to the industry level factors, they are mostly enablers and barriers.

It can be argued that industry level initiatives have the power to enhance the BIM implementation as well as set a barrier against it. In addition, inputs of the BIM implementation should be provided by companies in order to gain positive impacts.

It has been revealed that project level factors drive the BIM implementation and again the project obtain benefits from the implementation. Moreover, it is observed that factors under enablers component are equally shared by the influence levels.

Last but not the least, the overall average ratings for each influence level are calculated. It is observed that the most important influence level is the firm level. Firm level factors are evaluated as highly significant. Project level factors are evaluated as significant and industry level factors are evaluated to have a medium level significance. The results can be seen in the below Figure 5.8.

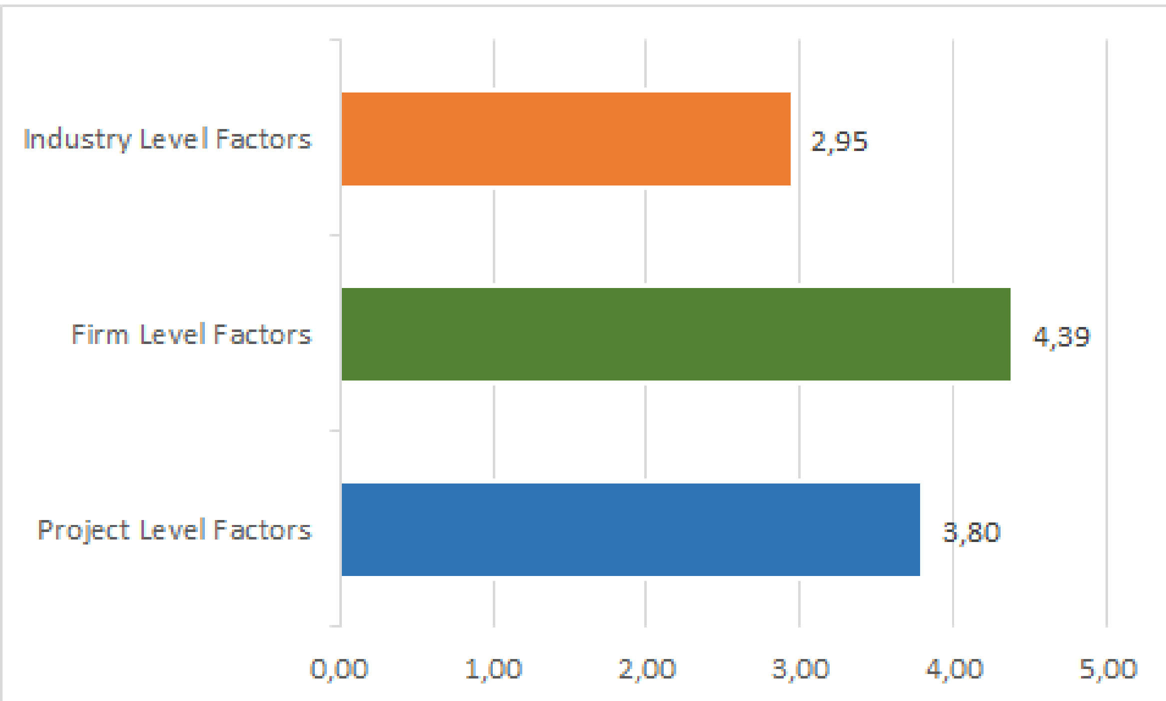

Figure 5.8. Average Ratings of the Influence Levels

6. CONCLUSION

As the main goal of this thesis study, the BIM implementation process in the construction phase for Turkish construction companies has been investigated.

As the first objective of the study, all of the CSFs for a successful BIM implementation in the construction phase have been identified via an extensive literature review. As the second objective of the research, a comprehensive framework was developed the represents the BIM implementation process with all aspects.

Another important objective of the study fulfilled by assessing the identified CSFs on case studies and determining the significance based on real construction projects. Lastly, as the last objective of the study, the findings are discussed to shed a light on the BIM implementation process and to give industry professionals a lead.

6.1. Conclusion Based on Research Findings

Although BIM adoption rate have been increasing by time, the adoption process is quite slow. Due to lack of a certain guide for BIM implementation process, companies mostly have no idea about what will they face during the implementation process. Identifying the components of BIM implementation process with the underlying CSFs would be an essential guide for the companies at the beginning of BIM implementation process.

Unlike the other studies in the literature, this research has identified the CSFs based on a comprehensive framework. On the other hand, identified factors have been distinguished to influence levels and compared with each other.

Moreover, different than the other studies, this research has investigated a large number and various types of case studies. This enabled the study to compare the results for different type, sizes and functions of the projects.

This study fills an important gap in the literature by identifying the CSFs of BIM implementation process and by assessing them on various real case projects.

Research findings revealed several key points as well as the highly significant factors that need to be considered for a successful BIM implementation. The case study analysis made it possible to evaluate the process from the industry experts' perspective. Essentially, the literature and the industry applications differentiates at some point which need to be taken into consideration carefully before implementing BIM. This study expected to bear a torch to the construction professionals.

In addition to the previous study findings, this study revealed that significance of the CSFs depend on the BIM implementation objectives of the industry professionals. If a company or project is not targeting to utilize BIM for facility management, then the factors regarding the facility management become inefficient.

It has been observed that regardless of the country, project type or BIM implementation type, "improving collaboration and coordination" is very significant as a driver. Nevertheless, by comparing the case studies, it has been revealed that significance of "design improvement" as a driver depends on the BIM application type.

Another important point is that since the factors regarding collaboration have found highly significant, it can be argued that settling the IPD approach in the industry, fosters the BIM implementation.

On the other hand, a lesson learned is that inputs are essential for a successful BIM implementation and more literature work is still needed to investigate the inputs. At the project level, "project BIM execution plan" is the key inputs whereas "internal knowledge" at the company level and technology at the industry level.

When it comes to barriers, it can be concluded that regardless of any specific situation (country, company size, type etc.) "change process problems" or "resistance to change" in other words is the biggest barrier against BIM implementation. Similarly, it has been observed that "supportive organizational culture" and "project level collaboration" are the most significant enablers regardless of any specific situation. Benefits and impacts of the BIM implementation only differs according to BIM application.

Comparing the BIM application within the case studies revealed that significance of the factors for 7D BIM applied projects differs from 4D and 5D BIM applied projects. In addition, is has been observed that significance of the factors differentiates according to project types.

All in all, it can be concluded that implementing BIM together with the other related concepts such as IPD, LEAN, Sustainability or Agile etc. enhance the gains obtained from the BIM approach.

6.2. Recommendations

Turkey, as a developing country, is at the initial stage of BIM adoption. In recent years, BIM implementation become widespread within the Turkish construction industry. Since this research has been conducted for Turkish construction companies, the results may be applicable for companies at other developing countries.

At the industry level, findings of this research can be analyzed in order to enhance BIM implementation. Industry level organizations, institutions and governments may analyze the findings of this research and understand the deficiencies and requirements to enhance the BIM implementation. According to findings, it is observed that the governmental organizations are required to support BIM implementation to achieve an increased adoption rate.

From the companies' perspective, findings of this research can be a perfect guide for BIM implementation. The necessary applications that the firms need to utilize and key points that need to be considered can be interfered from the findings and discussions. A construction company that eager to implement BIM may found the required inputs and the barriers that will be possibly encountered within this research. In addition, identified impacts of BIM implementation may facilitate the decision process.

At the project level, industry professionals may fully benefit from the findings of this research. Before implementing BIM in a project, experts need to consider various factors. All of the CSFs identified within the context of this research comprise the process from the beginning to the end. Nevertheless, significance of those factors may guide industry professionals and show where to focus and what to care. It is very important to fully understand a process before it begins.

6.3. Future Research

Further studies might analyze the BIM implementation process based on this research's findings and develop a BIM implementation roadmap for the industry. Moreover, further studies may investigate different kind of innovations within the construction industry based on the followed methodology.

Another key point that may require extra research is the correlation of the CSFs with the project budget. Since most of the case projects in this research are large scale, the significance of the CSFs may differ when small scale construction projects are considered. Another extra research can be conducted to investigate the internal correlation among the framework components in order to reveal the inter-depended CSFs.

As the combination of BIM implementation with the recent developments in the technology fosters its benefits, future studies may investigate obtaining a model based on the laser scanning of existing structures. Especially, scanning of on-going constructions via using unmanned aerial vehicles (UAVs - Drones) may provide a better construction monitoring process.

Most importantly, this research was limited to new construction projects that are actually on-going constructions. However, since Turkey has an enormous number of existing building and infrastructure stock, investigation of BIM implementation for existing structures with the help of laser scanning and big data technology would be a great field of research.

Although the number of examined case studies are very high compared to similar research, this research was limited to Turkish construction industry and construction phase of the projects. For further studies, this framework may be used in different countries and with different case studies for comparisons.

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APPENDIX A: CASE STUDY FORM

BOĞAZİÇİ UNIVERSITY
INSTITUTE OF GRADUATE STUDIES IN SCIENCE AND ENGINEERING
CIVIL ENGINEERING DEPARTMENT
CONSTRUCTION MANAGEMENT MASTER THESIS QUESTIONNAIRE

Thesis	: Investigation of the BIM Implementation Process in the Construction Phase: Case of the Turkish Companies
Student	: Ahmet KARACIĞAN
Professor	: Assoc. Prof. Beliz ÖZORHON ORAKÇAL

GENERAL INFORMATION (Respondent)

1)	Your profession	:
2)	Your experience in construction industry (years)	:
3)	Your position in your company	:
4)	Your Age (Optional)	:

GENERAL INFORMATION (Company)

5)	Company name (not obligatory)	:
6)	Field of operation	: ☐ ENGINEERING ☐ ARCHITECTURE ☐ CONSTRUCTION ☐ PROJECT MANAGEMENT ☐ CONSULTANT
7)	Your company's expertise areas	: ☐ BUILDING ☐ INFRASTRUCTURE ☐ TRANSPORTATION ☐ OTHER:
8)	Annual turnover of your company (Optional)	:
9)	Total number of employees of your company	:
10)	Number of countries that your company has been operating	:
11)	Number of years that your company has been operating (general / in Turkey)	:
12)	Total number of projects that your company involved in Turkey	:
13)	Year that your company adopted BIM	:
14)	Projects utilized BIM in Turkey (specify function (Design, Construciton, Facility Management))	:

GENERAL INFORMATION (Project)

15)	Project name	:
16)	Project type	: ☐ BUGILDING ☐ INFRASTRUCTURE ☐ TRANSPORTATION ☐ OTHER:
17)	Project ownership	: ☐ SOLE ☐ JOINT VENTURE ☐ CONSORTIUM ☐ OTHER:
18)	Your company's role in the project	:
19)	Total construction area of the project (m2)	:
20)	Contract type of the project	: ☐ UNIT PRICE ☐ LUMP SUM ☐ TURNKEY ☐ COST PLUS FEE ☐ OTHER:
21)	Contractural budget of the project	:
22)	Total amount of cost savings (if possible, %)	:
23)	Duration of the project	:
24)	Total amount of time savings (if possible, %)	:
25)	Total amount of BIM investment for the project (%) (Specify type if possible)	: AMOUNT (%): ☐ HR ☐ SOFTWARE ☐ CONSULTANCY ☐ TRAINING ☐ OTHER:
26)	Number of employees in your BIM team	:
27)	Softwares / Tools to utilize BIM	: OTHER:

☐ Revit ☐ 3D Studio Max ☐ Dynamo ☐ ArchiCAD ☐ V-Ray ☐ CorelCAD ☐ Bentley ☐ Naviswork

☐ SAP2000 ☐ ETAPS ☐ AutoCAD ☐ GIS ☐ Plaxis ☐ Geodin ☐ Micro Station ☐ Tekla BIMsight

☐ BIM360 Glue ☐ Naviswork ☐ Synchro ☐ Maximo ☐ ARCHIBUS ☐ Primavera ☐ Eco domus

☐ BIM360 Docs ☐ BIM Track ☐ Prolog ☐ Aconex

Figure A.1. Case Study Form

28) DRIVERS (Pushed you to utilize BIM) - Please indicate the importance level of the relevant critical success factor in your project (1 Lowest - 5 Highest)

	Description	1	2	3	4	5
Improving Corporate Performance	Company image, competitiveness, gain experience					
Improving Project Performance	Efficiency, quality, speed, cost, risk reduction					
Improving Building's Energy Performance	Sustainability, LEED, lean implementation					
Improving Collaboration & Coordination	IPD, collaboration, coordination,					
Client Requirement	Contractual obligation					
Governmental Push	Law enforcement					
Design Improvement	Clash detection, visualization, simple revision process					
Improving Construction Productivity	Site logistics, optimized schedules, prefabrication					
Improving HSE Activities	Safety measurements					
Reducing Life Cycle Cost of The Building	Maintenance & usage costs					

29) INPUTS (Resources used to utilize BIM) - Please indicate the importance level of the relevant critical success factor in your project (1 Lowest - 5 Highest)

	Description	1	2	3	4	5
Human Resources	Qualified staff & leader					
Financial Resources	Investment					
Technological Infrastructure	Technological developments enhancing the scope of BIM					
Softwares & Hardwares	Modeling & managing programs, computers					
Custom 3D Library	Open family libraries					
Internal Knowledge	Company know-how					
External Knowledge & Consultancy	Outsource know-how, consultancy					
Project Information	Drawings, specifications, project data					
Project BIM Execution Plan	BIM implementaion routeway					
Company's BIM Policy	BIM implementation approach					
BIM Guideline	BIM implementation rules					
Training & Education	Internal & external staff trainings					

30) BARRIERS (Problems encountered during the process)- Please indicate the importance level of the relevant critical success factor in your project (1 Lowest - 5 Highest)

	Description	1	2	3	4	5
Availability of Knowledge Based on Experience	Lack of experience, awareness					
Unclear Benefits	Lack of tangible benefits					
Lack of Best Practices	Lack of cases, benchmarks, universal use					
High Costs	Time, HR, software & hardware investment					
Technology Related Problems	Licensing, data interoperability, reliability					
Change Process Problems	Resistance to change, company culture, fear of failure					
Legal & Protocol Problems	Lack of legal protocols, ownership, responsibilities					
Fragmented Nature of the Industry	Number of parties getting involved to the process					
Interoperability Problems of Different Parties	Low collaboration, interoperability					
Project Specific Problems	Delivery method, contract type, unique requirements					
Lack of Government Support	Lack of incentives, initiatives					

31) ENABLERS (Things that facilitates BIM adoption)- Please indicate the importance level of the relevant critical success factor in your project (1 Lowest - 5 Highest)

	Description	1	2	3	4	5
Corporate & Academic Level Collaboration	Academic partnership, research teams					
Project Level Collaboration	Communication, involvement of parties					
Managerial and Technical Abilities	Experience level, right decisions					
Supportive Organizational Culture	Commitment, internal support					
External Grants, Incentives & Promotions	Industry level commitment, governmental support					
Global Standardisation	Common standards, protocols					
IPD Type Contracts	Integrated delivery system					
Planning of BIM Execution Process	Making an implementation plan					

32) BENEFITS (Project level gains from BIM) - Please indicate the importance level of the relevant critical success factor in your project (1 Lowest - 5 Highest)

	Description	1	2	3	4	5
Project Financial Benefits	Cost and time reduction					
Right and Accurate Construction Activities	Less rework, better site planning, reduce risk, high quality					
Right and Accurate Technical Office Works	Minimize errors, better estimates, clear results					
Improve Staff Performance	Staff understandig and awareness of the project					
Knowledge Management Benefits	Better documentation, easy tracking					
Claim Management Benefits	Reduce RFIs, claims, change orders					
Reduction of Facility Management Costs	Reduced maintenance & usage costs					
Client Satisfaction	Happy client					
Improve Communication & Collaboration	Low number of meetings, effective communication					
Improve Energy Savings	Better energy analysis					

33) IMPACTS (Company level gains from BIM) - Please indicate the importance level of the relevant critical success factor in your project (1 Lowest - 5 Highest)

	Description	1	2	3	4	5
Company's Productivity Improvement	Improved business value					
Corporate Management Improvement	Better administration, marketing, organizational structure					
Expanding Company's Scope of Services	New services					
Enable New Businesses	Competitiveness, reference projects					
Improve Corporate Financial Performance	Increased ROI					
Generate Corporate Knowledge	Archive of knowledge and information					

Figure A.2. Case Study Form Continues