BIM TRANSITION PROCESS IN THE TURKISH ARCHITECTURE, ENGINEERING, AND CONSTRUCTION (AEC) INDUSTRY

by

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B.S., Civil Engineering, Yıldız Technical University, 2016

Submitted to the Institute for Graduate Studies in
Science and Engineering in partial fulfillment of
the requirements for the degree of
Master of Science

Graduate Program in Civil Engineering
Boğaziçi University
2021

ACKNOWLEDGEMENTS

I would like to express my special thanks of gratitude to all people who supports me during my master journey.

First of all, I would like to thank my family for believing and trusting me always.

Secondly, I would like to thank my thesis advisor, Prof. Beliz Özorhon, for her guidance and support.

I would also like to thank all respondents and people who have help me with this thesis for taking their precious time.

Finally, I would like to specially thank Seda Sözer for her patience and understanding during my study, and I would like to express my gratitude to my friend, Ensar Koç, for his endless support.

ABSTRACT

BIM TRANSITION PROCESS IN THE TURKISH ARCHITECTURE, ENGINEERING, AND CONSTRUCTION (AEC) INDUSTRY

Technology is advancing day by day in the world. Each industry wants to reap the benefits of technology by integrating innovations and technological tools into its organizations. However, some sectors, like the Architecture, Engineering, and Construction (AEC) industry, are too conservative to make breakthrough changes. In the AEC industry, altering the way of work processes is tremendously difficult. Nevertheless, in the last two decades, this understanding started to change in the opposite way. The most significant reason for this alteration is Building Information Modeling (BIM). The Turkish AEC industry also began to experience this change, as the other countries did. In this thesis, the BIM transition process has been analyzed in terms of the AEC firms. The main objective of this thesis is to determine the BIM transition process and identified its effective determinants from the perspective of the AEC companies in Turkey. In order to achieve this goal, an extensive literature review has been conducted. Based on the literature review, a proposed BIM transition framework has been generated, and 46 effective factors for the BIM transition process have been determined. Once the framework has been determined, specified effective factors were categorized into 6 components. Then, online interviews were made with industry experts from the AEC companies in Turkey to determine the importance of these factors on a 1-5 Likert scale. Finally, the ratings of the factors were evaluated and discussed by comparing the results according to the AEC companies.

ÖZET

TÜRK MİMARLIK, MÜHENDİSLİK VE İNŞAAT ENDÜSTRİSİNDE BIM'E GEÇİŞ SÜRECİ

Teknoloji dünyada her geçen gün gelişmektedir. Her endüstri, inovasyonları ve teknolojik araçları kendi organizasyonları içine entegre ederek teknolojinin faydalarından yararlanmak istemektedir. Ancak, inşaat endüstrisi gibi bazı sektörler, çığır açan değişiklikler yapmak için fazla gelenekseldir. Dolayısıyla, Mimarlık, Mühendislik ve İnşaat (MMİ) endüstrisinde, iş süreçlerinin şeklini değiştirmek son derece zordur. Ancak, son 20 yıldan beri bu anlayış tam tersine değişmeye başlamıştır. Bu değişimin en önemli sebebi Yapı Bilgi Modellemesidir (YBM). Diğer ülkelerde olduğu gibi, Türk İnşaat endüstrisi de bu değişimi tecrübe etmeye başlamıştır. Fakat, bu değişim göründüğü kadar basit değildir. Bu tez'de, YBM'ye geçiş süreci MMİ firmaları açısından analiz edilmiştir. Bu tezin temel amacı, YBM geçiş sürecini belirlemek ve ardından mimarlık, mühendislik ve inşaat şirketleri perspektifinden etkili faktörleri belirlemektir. Bu amaca ulaşmak için kapsamlı bir literatür taraması yapılmıştır. Literatür incelemesinin sonucunda, önerilen bir YBM geçiş çerçevesi oluşturulmuş ve YBM geçiş süreci için 46 etkili faktör bulunmuştur. Çerçeve belirlendikten sonra, belirtilen etkili faktörler, 6 bileşene ayrılmıştır. Ardından, MMİ firmalarından sektör uzmanları ile çevrimiçi görüşmeler yapılarak bu faktörlerin önemi 1-5 Likert ölçeğinde belirlenmiştir. Son olarak, faktörlerin derecelendirmeleri MMİ firmalarına göre değerlendirilmiş ve bu bulgular karşılaştırma yapılarak tartışılmıştır.

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LIST OF ACRONYMS/ABBREVIATIONS

AEC	Architecture, Engineering, and Construction
AGC	Associate General Contractors
AI	Artificial Intelligence
AIA	The American Institute of Architects
AR	Augmented Reality
BCT	Blockchain Technology
BIM	Building Information Modelling
CAD	Computer Aided Design
CDE	Common Data Environment
COBie	Construction Operations Building Information Exchange
D and B	Design and Built
DLT	Decentralized Ledger Technology
DOI	Diffusion of Innovation
DT	Digital Twin
IDT	Innovation Diffusion Theory
IFC	Industry Foundation Classes
INT	Institutional Theory
IoT	Internet of Things
IPD	Integrated Project Delivery
IS	Information System
LOD	The Level of Development
NBIMS	National Building Information Modeling Standard
NIBS	National Institute of Building Sciences
NIST	The National Institute of Standards and Technology
O and M	Operation and Maintenance
PEU	Perceived Ease of Use
PU	Perceived Usefulness
ROI	Return on Investment
TAM	Technology Acceptance Model

TOE	Technology-Organization-Environment
TPB	Theory of Planned Behavior
TRA	Theory of Reasoned Action
VR	Virtual Reality
WEF	World Economic Forum

1. INTRODUCTION

Building Information Modeling (BIM) has a great impact on the AEC industry since last two decades. Therefore, interest towards BIM is getting increase among researchers. Moreover, it can be said that BIM is one of the most critical innovation for construction industry. BIM can be defined as a technological system that help the companies to improve their work processes. Although most companies want to shift to the BIM system, they do not know how to do this. Therefore, this study tries to explore the BIM transition process and its effective factors.

1.1. Background of the Research

It is widely known that the construction industry is one of the most conventional industries in the world, meaning that it is not open to innovation as much as the others. This situation makes a negatively impact on the productivity of the construction industry. For example, according to NIBS (2007), the difference between non-farm labor productivity and construction labor effectiveness increases dramatically from 1964 to 2004. However, recently, construction industry started to change due to the emergence of BIM. Nevertheless, in order to reap the benefits of BIM, it is required to experience a transition process (McGraw-Hill Construction, 2012). Besides, this process can be challenging and complicated for the AEC firms. Therefore, there is need for the BIM transition framework to understand the transition process, properly. However, the BIM transition framework is not enough alone, its effective factors should also be determined. Based on this background, this thesis investigates the BIM transition framework and its effective factors for the Turkish AEC industry.

1.2. Determination of the Problem

Although there are companies that implement BIM in their projects, in total, most companies do not use BIM yet in the world due to slow adoption rate (World Economic Forum, 2018). There is the same issue in Turkey. While some companies inside the Turkish AEC industry believe that BIM brings an extra burden to them, some of them do not know how to use or to start the BIM system even if they really want to implement it. Therefore, in this study, the BIM transition process has been proposed and critical factors for this process have been determined.

1.3. Statement of the Problem

When the literature is reviewed, there are various studies related to BIM adoption, and BIM implementation papers (Coates *et al.*, 2010; Won *et al.*, 2013; Mom *et al.*, 2014; Smith, 2014; Succar and Kassem, 2015). On the other hand, there are limited studies examined the BIM transition process, comprehensively. For this reason, this thesis analyzes the BIM transition process, extensively and assesses impactful determinants based on AEC industry experts' experiences.

1.4. Related Studies

According to Rogers (2003), innovation decision process consists of 5 stages including, knowledge, persuasion, adoption decision, implementation and confirmation. In the literature, researchers generally investigate adoption and implementation phase of BIM. There are also studies examining BIM more comprehensively. Ahmed and Kassem (2018) analyzed knowledge, persuasion and adoption decision stages. In addition, some studies investigate the factors in terms of technological, organizational, and environmental (Cao *et al.*, 2014; Xu *et al.*, 2014; Chen *et al.*, 2019). Moreover, these effective factors can be grouped as drivers, barriers, benefits, etc. (Eadie *et al.*, 2013; Ullah *et al.*, 2019; Chan *et al.*, 2019; Deng *et al.*, 2020).

1.5. Aim and Objectives

The main aim of this study is to examine the BIM transition process and its effective factors for the Turkish AEC industry. To fulfill this goal, a comprehensive literature review has been conducted. Based on the literature review, firstly, frameworks, models, theories that are related to the BIM transition process have been specified.

Secondly, critical determinants have been identified for the transition process. Thirdly, these factors were evaluated based on AEC industry experts through online interviews. Lastly, the findings of interviews have been analyzed according to the AEC companies to shed a light on the BIM transition process for the companies that are willing to use BIM.

1.6. Research Methodology

After the gap in the literature has been identified, an extensive literature review has been made to determine the BIM transition framework and its critical factors. Based on the literature review, the BIM transition framework was developed, and its effective factors were identified by categorizing them into 6 components. Then, in order to find which factors are the most effective in the BIM transition process, online interviews have been conducted with engineers and architectures in the Turkish AEC industry. During the online interviews, interviewees are asked to designate the importance level of the relevant factors on a 1 to 5 Likert scale (5 corresponds to very important) based on participants' own experiences during the BIM transition process. The findings of the AEC firms are compared to each other. Also, the results are compared according to the experience level of companies that attended the interviews.

1.7. Importance of The Study

The significance of this thesis is that it provides an understanding of the BIM transition process in Turkey by specifying the related factors. This comprehensive study may guide the companies that have intention to use BIM in their projects. In addition, the researchers in the other developing countries can adapt and examine this study for their AEC industries.

1.8. Scope and Limitations

This research was conducted with the purpose of explaining the BIM transition process in the Turkish AEC industry. However, the interviews were done with 14 industry experts from different companies in Turkey. In order to obtain more accurate results, maybe the number of interviewees can increase.

1.9. Organization of Thesis

The chapters of the thesis are shown and described as follows;

- Chapter 1 gives general information about the thesis and explains the goals of the thesis.
- Chapter 2 describes BIM and its development; then, BIM characteristics have been explained, and lastly, the future of BIM have been investigated.
- Chapter 3 clarifies research methodology.
- Chapter 4 explains the findings of online interviews.
- Chapter 5 discuss the findings by comparing the results of the AEC companies. In addition, in the chapter, the results have been compared to the experience level of firms.
- Chapter 6 represents the conclusion of the thesis.

2. DEFINITION OF BIM AND ITS HISTORY

From past to present, the world changes with the technology. Most industries make an effort to reap the benefits of various technological developments. However, it is widely known that the construction industry was not one of them, at least till recent time. In other words, gone are the days when there is weak collaboration, which leads to cost and time overruns in the projects, between architectural, engineering and construction companies. The reason is that the emergence of an innovative system that can overcome such negativities. The name of this system is Building Information Modelling (BIM). Indeed, BIM reduces construction waste by bringing many technological innovations such as interoperability, visualization of design models and managing cost and time by using simulations.

Nearly, two decades ago, BIM was introduced mainly as a transition from traditionally 2D drawing to 3D modeling. BIM supporters describe it as a lifesaver system, especially, when it is needed to overcome complex and complicated projects since this system makes better time and cost management possible (Kubba, 2017). Nevertheless, the rate of BIM usage in the AEC industry was quite low until the mid-2000s (Azhar *et al.* 2012). After that time, BIM has started to become the most popular innovative system in the construction industry, and over years, the definition of BIM did not remain stable. There are various definitions for Building Information Modelling in the literature. Some of them define BIM as a software application, or a process for modeling and documenting building information. Aside from these descriptions, BIM is defined by some people as a new approach to improve their jobs which requires new policies, contracts, and relationships among project participants (Aranda-Mena *et al.*, 2009). BIM is delineated by Sacks *et al.*, (2018) as a modelling technology and related set of processes to generate, communicate and investigate building models that are characterized by objects that possess computable graphic and data attributes. In addition to these definitions, the National Building Information Modeling Standard (NBIMS) describes that BIM is:

> An improved planning, design, construction, operation, and maintenance process using a standardized machine-readable information model for each facility, new or old, which contains all appropriate information created or gathered about that facility in a format useable by all throughout its lifecycle (NBIMS, 2007).

Another description is made for BIM by The American Institute of Architects 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).

According to the Associated General Contractors (AGC) of America (2014), building information modeling is:

> the process of generating and managing building information model through the use of three-dimensional, intelligent design information.

Penttilä (2007) described BIM as a procedure which comprises policies, processes and technologies to operate building design and project data in digital format throughout all construction phases of building.

2.1. Why is BIM important for the AEC industry in the world?

Technological advancements have started to play a significant role in varied work areas within last 20 years. Especially, for traditional or conservative industries like construction industry. In Construction industry, transition is generally painful and quite slow. The reason probably is that this industry is not sufficiently innovative when compared to other industries (e.g., manufacturing sector) (Bernstein and Pittman, 2004). However, it is obvious that industries have relationship with each other. Therefore, if a conservative company begin to work with a firm that has an innovative vision, and that implement this innovative thinking to their projects, the transition will be inevitable for this conservative company. In other words, due to globalization, this technological transition will be happened sooner or later.

As mentioned before, maybe the construction industry has conventional dynamics, but BIM technology is becoming prevalent among the AEC industry all over the world, and the importance of BIM is increased since construction firms want to gain a competitive advantage, and to maintain a good image. Apart from these, BIM-enabled projects are more profitable compared to others that do not use BIM technology because BIM usage decrease construction waste in the projects (Bernstein and Pittman, 2004; Eadie *et al.*, 2013), and this leads to more accurate cost-estimations and scheduling. Moreover, it is widely known that communication, collaboration, and coordination between project participants in a normal construction project is problematic (Mitropoulos and Tatum, 2000; Chan *et al.*, 2019; Ozener *et al.*, 2020). On the contrary, BIM related tools eliminate or reduce the problems due to ineffective interaction. Common data platforms (i.e IFC) enable project teams to manage productive collaboration and coordination processes (Aranda-Mena and Wakefield, 2006; Oh *et al.*, 2015). Furthermore, BIM has a great impact on the construction firms. In the long-term, BIM usage increase companies' return on investments (ROI) (Arayici *et al.*, 2011; Bryde *et al.*, 2013). It is extremely important for the firms because, in the beginning, they make very costly investments (software, hardware, human resources, etc.) to adopt BIM and to implement it to their projects (Suprun and Stewart, 2015; Jin *et al.*, 2017; Koseoglu *et al.*, 2019). Additionally, the BIM system enhances the business value of the companies when they integrate BIM into their organizations (Ahn *et al.*, 2015; Ghaffarianhouseini *et al.*, 2017; Chiu and Lai 2020).

Taking everything into consideration, BIM plays a critical role in increasing project performance, and this seduces the construction industry that suffers from ineffective project management. Unfortunately, this growing interest in BIM is not the same everywhere. Some countries lead the transition to BIM (e.g., US, England, and Finland). Nevertheless, most of the countries have not yet made progress much (e.g., Turkey, China, and Malaysia). No matter what their BIM level, all countries are aware that BIM is a breakthrough innovation that satisfies all stakeholders due to obtained amazing results. In the future, BIM-related tools and processes will be integrated into organizations, and widely utilized just as CAD programs (e.g., Autocad) are being used in all construction companies (Kubba, 2017).

2.1.1. BIM Characteristics

It is a fact that the productivity of construction projects declines since the 1960s. One of the reasons for this reduction is that the construction industry was behind the time while the world changes (Sacks *et al.*, 2018). Nevertheless, various new software has emerged thanks to technological development in order to make the design process easier. 2D drawings helped the firms to a certain extent because a construction project has a dynamic structure that is needed to effectively manage. However, the construction industry suffers from the absence of collaboration among project participants (Mitropoulos and Tatum, 2000; Kassem *et al.*, 2012; Jin *et al.*, 2017; Sacks *et al.*, 2018; Chiu and Lai, 2020). In 2D design, each project team (e.g., structural engineers, mechanical engineers) has its own model. When the project came to the construction phase after the design phase, these separate drawings cause a lot of difficulties (e.g., confliction between structural and mechanical elements). The underlying reason for the problem is that there is no coordination between project teams. MacLeamy curve is one of the best graphics which depicts how collaboration affects the project effectiveness. According to this curve, if the design decision is made earlier, construction productivity is increasing because this way allows participants to realize the problems, previously (AIA, 2007).

Especially, there have been significant changes in the past 20 years. A system that makes possible better drawings and collaboration became widely known in the construction industry. The name of this system is Building Information Modeling (BIM) which is defined above section. BIM increase project performance if it is implemented properly to the projects, and more importantly complex projects might be achieved by implementing BIM (Coates *et al.*, 2010; Nanajkar, 2014; Singh and Holmstrom, 2015; Sacks *et al.*, 2018). Contrary to popular belief, BIM cannot be evaluated as just an innovative technology. Undoubtedly, the BIM system may be used only for producing drawings through a 3D model, but this 3D model is the center of the information source. So, in order to manage this knowledge, it is required to collaborative behavior between teams (Ashcraft, 2008). At this point, the BIM system provides a collaboration platform to use this information efficiently among different project teams. This data exchange ability is named as interoperability (Sacks *et al.*, 2018).

In the BIM environment, the model of the buildings is generated by using geometric shapes through parametric modeling (Karahan, 2015). Furthermore, an object-oriented model can be created by adding building elements characteristics (e.g., quantity) in the BIM system (Sacks *et al.*, 2018). For example, while it can be drawn a line to specify the wall in 2D drawings, at this 3D model, the wall characteristics are embedded in these intelligent objects.

2.1.1.1. Parametric Modeling. In the BIM system, differently from traditional methods, the digital simulation of the buildings is represented in order to analyze, design, construct and demolish before actualizing the projects. This ability gives an opportunity to make interactive design development to examine the design options (Ashcraft, 2008). It is obvious that this chance provides practitioners to eliminate the potential problems that might occur in the construction phase.

Moreover, BIM provides great convenience to its users in the modeling process. To be more precise, in the traditional way, changing the model is exhausted and time-consuming. However, when modifications happen on the shape of elements' geometry, or elements' dimension, the model is updated automatically in BIM-enabled projects (Sacks *et al.*, 2018). The reason for this easiness is parametric modeling. In order to run a parametric model, practitioners benefit from visual scripting to specify the characteristics of model elements such as curvature and dimensions. To write a script to generate a parametric model, special software applications (e.g., Rhino, Dynamo) that were evolved from 2D CAD programs (e.g., AutoCAD) are utilized (Fu et al., 2018). In this way, designers can easily manipulate the peculiarity of the model, and it is extremely important to save the time which is spent on the design stage. It can be said that parametric modeling also helps to achieve the projects that have geometrically complex design elements (Ashcraft, 2008).

In the world, there are various complex structures that were built in the past such as Casa Milà by Antoni Gaudi (1906-1912), and Dancing House by Vlado Milunić and Frank Gehry (1992-1996). Undoubtedly, if in that time, parametric modeling system were applied as it is today, these structures were built in less time and with less effort.

To sum up, parametric modeling gives designers a great advantage about altering the model since there is no need to change entire parameters (length, height, etc.) of the model (Fu *et al.*, 2018). For example, if a designer wants to alter a door structure in his/her model, it is adequate to only adjust one parameter due to other parameters will amend simultaneously, thereby finalizing the model takes much less time, and is painless.

2.1.1.2. Object-Oriented Modeling. According to Ashcraft (2008), object-oriented modeling refers to intelligent objects that have detailed knowledge about building elements such as doors, windows, etc. In traditional 2D drawing methods, designers draw the lines to generate, for example, walls, but they are just lines, and they do not consist of information about the characteristics of the walls. After the BIM system emerged, users started to embed the object-related information in the parametric model.

In addition, this parametric object can be referenced in later drawings to use the same parameters (Sacks *et al.*, 2018). In addition, default object information can be transferred between related objects and if there is an adjustment in these objects, the linked objects are revised accordingly (Ashcraft, 2008).

On the other hand, even though embedding information into the models gives users an advantage to manage their models, this process can also lead to problems due to the model complexity and vagueness (Lee *et al.*, 2006). Therefore, designers can be extremely careful while adding information about the elements and making modifications. In addition, designers can lose their advantage if they put a large number of parameters and geometrical knowledge because the model performance decreases as more and more data are added to the model.

In the end, object-oriented modeling provides visual representation, and beneficial knowledge about the building models. While practitioners can use the objects effectively, at the same time, they can create an object library that has a great number of data information, and then these data might be utilized for their future projects as a guideline.

2.1.1.3. Interoperability. The term of interoperability can be defined by Sacks *et al.* (2018) as the capability of data sharing between applications. Smith and Tardif (2009) explained the interoperability as the essential feature of collaborative tools to achieve complex tasks. It is widely known that collaborative work processes play a significant role in an industry in order to boost the productivity of the projects. Some industries, however, suffer from the lack of collaboration due to their fragmented structure. The construction industry can be given as an example of this.

It was stated in "WEF (World Economic Forum) Shaping the Future of Construction" report in 2018 that construction and engineering firms should develop coordination and collaboration with their trade partners and determine collaboration standards. It is true that there are various stakeholders in a typical construction project such as structural engineers, architectures, electrical engineers, mechanical engineers and so on. Therefore, it is not straightforward to ensure to work all participants together. As a result, inefficiencies in coordination can negatively affect project performance such as cost, and time overruns might occur. However, in the last 2 decades, technological tools, processes, and systems that may be ameliorated the collaboration between stakeholders have emerged.

BIM can make effective communication possible between project participants by providing collaborative workflows and tools. One of the biggest challenges in the construction industry is that there are no appropriate data sharing platforms. This is a huge problem because when distinct departments cannot share their knowledge or models/drawings in the design phase, conflictions between separate models/drawings can occur in the construction phase. This problem extremely reduces work productivity and leads cost and time overruns. Therefore, project stakeholders need interoperable data sharing tool. Due to the technological advancement, most software vendors enhanced their products according to their customers' needs. The models creating by distinct software can be shared now with common data platforms (e.g., IFC).

Maybe, the construction industry lagged behind the times, but it must adapt itself to changing time due to the growth of scale and complexity of construction projects. For this adaptation, interoperability is a key. To meet the need of effective data exchange, openBIM approach can be used. According to BuildingSmart, OpenBIM is a collaborative process which enhances project data management such as accessibility and usability (www.buildingsmart.org). OpenBIM also provides smoothly continuous collaboration between project stakeholders. The following figure represents the example of openBIM workflow.

Well, how will the project participants facilitate the open BIM approach? To operate the collaborative workflow, there must be a standard that is defined for co-operative workflow. IFC (Industry Foundation Classes) is one of the most well-known data exchange standards in the market. IFC can be described as a non-proprietary data platform that is used to share project information among distinct project teams. Sacks *et al.* (2018) delineates the IFC as an extensible data model of building information that enables data sharing between various software applications. As you are a software user, you can turn your data format to IFC and share other project team members. Even if these people use another software, they can easily open shared data through IFC format.

On the other hand, openBIM and common data sharing standards (e.g., IFC) may not be enough to facilitate collaboration among project participants due to the limitations of BIM-related standards (e.g., lack of integrated contract) (Alreshidi *et al.*, 2017). In addition, although BIM provides profound benefits to its users, it also causes collaboration issues that need to handle such as data misuse, intellectual property and legal status (Ashcraft, 2008). Therefore, participants may not want to share their models due to their concerns that are mentioned above. However, all these issues can be solved by a well-defined collaborative contract type (e.g., D&B and IPD).

2.2. Current Status of BIM Across the World

BIM is now getting attention rapidly across the world. It can be said that it is widely utilized various countries, especially in the United States, United Kingdom, Finland, Norway, Denmark, France, Malaysia, Singapore, China, and Germany. However, it should be noted that the BIM system has not reached level 3 maturity in any country. Maybe these countries are leading the transformation in the AEC industry, but a little more time is needed to take full advantage of the BIM system. The question to be asked at this point is, what are these countries doing differently from the others? There is no single answer, but the cornerstone of BIM's spread in the construction industry is mostly government support or pulse. Well, how do they do? There are discrete ways to proliferate BIM usage across the AEC industry. Firstly, many of them develop their own standards for BIM usage. Secondly, they publish National BIM Protocol or BIM roadmap to guide the BIM implementation.

Thirdly, while most countries do not prefer BIM mandate, some countries carry out BIM mandate programs such as Italy and the United Arab Emirates. If it is deeply investigated, or if it is looked from organizations perspectives, architectural organizations are more active than engineering and construction organizations in terms of BIM utilization within the AEC industry all over the world. Nevertheless, most organizations implement BIM to their projects at Level 1 or maybe Level 2.

2.2.1. BIM Maturity Levels

Giel and Issa (2013) pointed out that participants in a project should reach a certain level of BIM maturity so as to gain full benefits of BIM implementation. Maturity levels of BIM are one of the ways of categorizing the BIM system. There are 4 maturity levels, which are level 0, level 1, level 2, level 3, and level 4. Bew and Richards (2008) created a BIM maturity model as it can be seen from figure below.

2.2.1.1. Level 0. At this level, Computer-Aided Design (CAD) programs are used to produce project-related documents (e.g., drawings), and these documents share with other participants via PDF. Shortly, Level 0 is a primitive way to collaborate with project parties. As it will be explained in the following, higher levels deal with more detailed modeling, effective collaboration, and fully integrated interchangeable data.

2.2.1.2. Level 1. According to Sacks *et al.* (2018), at Level 1, companies produce their project models as 3D CAD file, but documentation issues (approval statue, project-related information, etc.) manage with traditional 2D drafting. In addition, researchers indicated that most companies govern their operations at Level 1. Furthermore, as it can be seen from above BIM maturity model, BS 1192:2007 is used to operate CAD standards. Moreover, common data environment (CDE) makes electronic sharing possible, but there is no created model sharing between project team members (Sacks *et al.*, 2018).

2.2.1.3. Level 2. At this level, although each project teams have their own 3D models, there is no federated single model to work each participant together. However, in Level 2, the important point is that there is a collaboration between different teams. Design information can be shared to others through common file format (e.g., IFC and COBie). These file formats facilitate to generate a federated BIM model by combining the data (Sacks *et al.*, 2018). To sum up, it can be easily said that Level 2 is file-based collaboration and information model.

2.2.1.4. Level 3. Level 3 BIM can be referred as integrated BIM which is defined as fully open process and data integration comply with open data standards like Industry Foundation Class (IFC) (BIM Dictionary, 2018). At Level 3, there is generated collaborative federated model, and thanks to this collaborative model, all participants can access and adjust the same model (Sacks *et al.*, 2018). Therefore, openBIM has a great impact on eliminating the risk of conflicting information (Dave *et al.*, 2013). Level 3 BIM also represents new contractual approaches that promotes more collaborative environment, clarity, and openness by creating a culture that is aimed to learning and sharing (NBS, 2014).

2.2.2. Level of Developments (LODs) of BIM

BIM is a model-based technology. In order to create a BIM model, it must be described its characteristics as dimensional, spatial, etc. Maybe it is not necessary to add all information, but it will be adequate to include fundamental information. Nevertheless, it should not be forgotten that these information's level might change in accordance with phase of the project. Therefore, it is crucial to determine the level of development of generated model conveniently as much as possible. For this, it can be used appropriate level of development (LOD) framework which helps project parties to understand description and definition of model elements to communicate to one another (AIA, 2013). Level of details or level of development is categorized in five standard levels. In detail, these levels consist of two components: Model element content requirement and authorized uses. Content requirement of model element represents minimum content requirement to qualify the model. As for authorized uses, it can be described as the extent to which reliance can be placed on a model element, and these uses can be adjusted according to particular needs by document users (AIA, 2013).

2.2.2.1. LOD 100. The model at LOD 100 is mostly primitive compared to other development levels, and LOD 100 is defined as conceptual level. There is no representative of actual geometry at this level. Symbols with information are utilized to depict the model. At the early design stage, LOD 100 elements are very beneficial since they give users the chance to insert varied information into the model such as costs and system boundaries. Moreover, it is quite advantageous to make cost-estimating through the model which is generated with LOD 100 elements. When compared to other traditional approaches, in that way, estimating process will be effective and the results will be more accurate and satisfying. Furthermore, it can be projected overall project duration by using these elements. In addition, it is possible to make analysis of space volume, areas and orientations at this level of detail.

2.2.2.2. LOD 200. LOD 200 is defined as schematic level. Elements are modelled with approximate quantities, size, shape, location, and orientation (AIA, 2013). Likewise, at LOD 100, model elements at LOD 200 have non-graphic information. Cost information can be given as an example of this. While working on the cost, model element might be utilized to determine approximate cost. Similarly, it may be used for scheduling. Moreover, different from LOD 100, the model element at this level enables coordination with other model elements from many aspects such as size, shape, and locations.

2.2.2.3. LOD 300. This level class is defined as detailed design which means that LOD 300 model element is graphically depicted within the model as specific assemblies such as wall types, structural members, and system components (AIA, 2013). Therefore, it can be appropriate to make accurate bidding and quantity take-offs. Furthermore, shop drawings can be drawn since actual drawings have clear measures and exact locations. Besides, clash detection which is one of the most useful BIM features can help effective coordination at this level.

2.2.2.4. LOD 350. LOD 350 model elements are related to construction documentation. As it is mentioned above, construction documents are generated for building authorization process by using LOD 300 model elements. Since these model elements are placed correctly with suitable dimensions (e.g., structural beams, plumbing lines), contractors count on these authorization drawings for exchange data coordination. However, there is no usable level of a detailed model to proceed with document coordination. Moreover, necessary information for LOD 400 might not be available until the later shop drawing stage. This situation creates a gap between LOD 300 and LOD 400. At that point, in order to close this gap, LOD 350 model elements can provide needed more definite model, and this precise model can be used for the exchange of construction documentation.

2.2.2.5. LOD 400. LOD 400 model elements are categorized as fabrication and assembly. At this level, elements are depicted as objects or assemblies with definite quantity, size, shape, location, and orientation. In other words, LOD 400 model elements form a basis for detailing, fabrication, and installation operation issues. It is noted that the term 'fabrication' assign to project-specific fabrication does not refer to the manufacturing of the components. (AIA, 2013).

2.3. LOD 500

At this level, elements are modeled for operation and maintenance. LOD 500 model elements are named as as-built because their geometry and data can be produced as as-built. In addition, LOD 500 helps the field verification of elements by providing a specific indication, thereby owners can know whether the elements are verified or not (AIA, 2013).

2.4. What Would Be the Future of BIM?

BIM is getting attention among construction companies, and BIM environment is developing day by day to meet the users' needs. In the last years, collaboration between project teams have been ameliorated in a certain extent (e.g., through cloud-based information sharing), visualization and simulation of construction projects through VR (virtual reality) and AR (augmented reality) technologies make the projects more understandable and predictable, especially in terms of scheduling and cost estimation. Moreover, artificial intelligence, blockchain technology, internet of things, and digital twin concept will play an important role in the future of BIM.

In the world, BIM adoption rate generally remains low such as Malaysia and India (Rogers *et al.*, 2015; Ahuja *et al.*, 2016). Nevertheless, this adoption rate can increase with the support of governments, professional institutes, etc. To exemplify, some countries (e.g., UK) published BIM mandatory program in order to make the use of BIM more widespread among construction companies. In the UK, according to NBS BIM report (2020) it is stated that just %6 of professionals say that BIM will be utilized for their all projects within 5 years. In the same report, %12 of participants say that BIM will be never used in their projects within 5 years. Sacks *et al.* (2018) indicated that BIM mandatory program which is assisted with BIM contracts, and specified guides, roadmaps and standards can be created an extensive transformative impact on the construction industry.

In addition, due to rising in the awareness of owners towards BIM system, the demand of BIM use is growing all over the world. The reason for this is probably that BIM benefits (e.g. reduction on project life cycle cost) seduce the owners of projects. It is obvious that construction project is always very costly. Therefore, any system that can decrease the project cost can be demanded by owners.

2.4.1. Cloud Computing And BIM

It is widely known that work processes in the construction sector are mostly fragmented. Besides, communication between teams in terms of data sharing rely on 2D drawings. The usage of 2D document between project participants usually leads to errors and omissions. These inefficiencies at the end of the construction process can cause cost overruns and schedule delays (Sacks *et al.*, 2018). According to McGraw Hill Construction (2014), deficiency of collaboration and coordination in the construction sector can be minimize by utilizing BIM in the construction projects. But the question is how does BIM increase communication.

With the development of technology, BIM continues to expand its boundaries. This development can help solve various problems faced by companies on projects. For example, one of the most critical developments is the emergence of cloud-based BIM technology. This technology can augment coordination amongst both project stakeholders and project teams by using the cloud system (Wong *et al.*, 2014). So, what is exactly cloud technology and cloud-based BIM collaboration.

Cloud computing concept firstly was announced in nearly 20 years ago (Vouk, 2008). The National Institute of Standards and Technology (NIST) defined as cloud computing is a model for "enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storages, applications and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction". PEGA's The Future of The Work Report (2020) pointed out that %51 of respondents indicated that they would invest in cloud-based solutions. The report also stated that when extraordinary situations (e.g., Covid-19 pandemic) occurred, most sectors have been negatively affected and expressed that if companies invest in cloud-based solutions that facilitate better collaboration, their business rapidly adapts to the changing business environment due to catastrophic circumstances.

Wong *et al.* (2014) explains cloud-BIM technology as second generation of BIM that has high potential to bring about considerable changes across the industry. Cloud-BIM can be used as data storage and exchange by users in the projects. Therefore, the higher level of information sharing, and effective inter-disciplinary communication can be achieved thanks to cloud-BIM (Wong *et al.*, 2014; Juan and Zheng, 2014).

The importance of cloud technology is to give users the opportunity of data interoperability among cloud services (Wong *et al.*, 2014). Also, Juan and Zheng (2014) indicated that cloud-BIM usage is one of the critical success factors for BIM implementation. The reason for this is that cloud technology enables real-time collaboration among project participants and makes decision-making process easier and effective by sharing significant data with decision-makers (Redmond *et al.*, 2012).

On the other hand, although cloud system plays an important role in effective collaboration, it needs to figure out some barriers such as data security, ownership, and stability (Mahamadu et al., 2013). Likewise, McGraw Hill Construction (2014) pointed out that various countries all over the world have concern over security of cloud technology (e.g., US, UK, Japan). In addition, Redmond *et al.* (2012) stated that contractual issues (e.g., ownership of shared data, flaw of contractual relations) are deemed to be significant obstacle for cloud-BIM usage. Furthermore, Dippl *et al.* (2013) indicated that data interoperability among cloud applications is a critical challenge to be solved. Because cloud-BIM applications have been produced by distinct vendors (Yang *et al.*, 2011).

2.4.2. Blockchain Technology and BIM

Blockchain, also referred as Decentralized Ledger Technology (DLT), is an important invention that can be defined as decentralized public ledger of data, assets and transactions. Immutability, transparency and trust relationship are the key advantages of the DLT technology (Underwood, 2016). The idea behind blockchain technology is to prevent complete authority between participants by splitting data to several nodes (decentralization). Thereby, transparency of activities has been ensured and data security, one of the most critical issue, has been improved (Nawari and Ravindran, 2019). Another significant feature of blockchain is to enhance "trust" between participants without the need for reliable 3rd party organizations (Mathews *et al.*, 2017).

Egan (1998) indicated that the construction industry is quite fragmented and suffers from the lack of collaboration. Collaboration deficiency is regarded as one of the most powerful obstacles for successful construction projects (Kassem *et al.*, 2012; Alreshidi *et al.*, 2017; Chan *et al.*, 2019). To fulfill true collaboration, it is needed to build trust. At this point, BCT (blockchain technology) can help to eliminate trust problem between stakeholders (Mathews *et al.*, 2017). The question is that how does DLT do that? Blockchain entirely rearranges current workflows inside the organization, and by doing this, it adds value to organizations such as network security, enhanced collaboration, immediate data exchange, and shared knowledge/information (Nawari and Ravindran, 2019).

In the last years, BIM technology plays a significant role in overcoming collaboration difficulties in the construction industry (Arayici *et al.*, 2011; Bryde *et al.*, 2013; Koseoglu *et al.*, 2019). BCT-adopted BIM software however can assist to solve popular issues that cause to ineffective collaboration such as data ownership, confidentiality, and traceability (Eastman *et al.*, 2010; Ahn *et al.*, 2015; Turk and Klinic, 2017). But there is one crucial thing that takes into consideration while integrating blockchain technology into BIM applications. The critical point is the selection of BCT that is compatible with application conditions. Otherwise, sufficient efficiency will not be obtained from BCT (Xu *et al.*, 2018).

Another well-known issue in the construction industry is data ownership. Block-chain environment has coins that are created for design and engineering agreement such as AECoin (Mathews *et al.*, 2016). This kind of advancements can play an important role in eliminating the problems of assigning responsibilities and liabilities. Therefore, Block-chain has a potential to eliminate BIM workflow dilemmas such as overlapping roles and responsibilities, risk allocation, privacy, and intellectual property protection (Eastman *et al.*, 2010; Ahn *et al.*, 2015; Turk and Klinic, 2017).

Maybe integration of DLT and BIM can be evaluated as Level 2 BIM since DLT help to provide adequate level collaboration. However, there is the need for more networked and integrated forms that are catered by Level 3 BIM (Heiskanen, 2017; Kinnaird and Geipel, 2018; Mason, 2017). NBS (2014) stated that DLT help to generate more integrated contractual framework at Level 3. Therefore, it can be said that blockchain technology promotes smart contracts for construction industry (Szabo, 1994).

Basically, smart contract can change completely how organizations do business and negotiate without any human interaction (Li *et al.*, 2019). Smart contracts, in its essence, are digital protocol that prevent contractual disputes and accelerate payments (Cardeira, 2015). The Winfield Rock Report (2018) indicated that blockchain-enabled smart contracts play a significant role in eliminating the challenges of BIM adoption process by increasing reliability, integrity, and transparency of the data. McDermott (BIMplus.com, 2017) defined the main aim of smart contract is to fulfill contractual terms and decrease the need for intermediary parties (e.g., Lawyer and consultant). Ramage (Constructable.com, 2018) explained how smart contract concept can works. According to the author, every project has milestones that are needed to complete by project stakeholders (general contractor, owner and subcontractor). When a milestone is accomplished, a smart contract is achieved. While the process of completing milestones carries on, each fulfilled smart contract is illustrated as a proceed on the BIM model thereby, all participants can follow easily progress. When the task is approved as a precondition, funds are released from the owner's wallet to general contractor's, and from general contractor's wallet to the subcontractor's according to this progress.

Although smart contracts have great potential for organizations, when they start to use substituted for traditional construction contracts, they can be more expensive and more ineffective than traditional contracts (Sklaroff, 2017). Likewise, according to Mason (2017), smart contracts should be used short-term and immediate since full implementation is not possible at this time. The author explained that it is hard to maintain documentation, storage for smart contracts. Moreover, interoperability and reliability issues of smart contract are also the key obstacles.

2.4.3. Artificial Intelligence (AI) and BIM

Artificial Intelligence (AI) term has been emerged in 1968 during the Dartmouth conference (McCarthy and Hayes, 1968), which was organized by researchers who have deep interest in artificial intelligence. Russel and Norvig (2010) explained the term of AI as a machine that imitate human?s behavior (e.g., thoughts, decision-making) to deal with a problem. McCarthy (1956) defined AI as an intelligent machine that displays learning, reasoning, perception, knowledge, and has the ability to control objects. To exemplify, an AI machine can learn from big data by utilizing advanced algorithms. Then, it can use its knowledge obtained from data to help industry practitioners (Jiang *et al.*, 2017). Furthermore, AI gives tremendous opportunities its users to improve productivity by analyzing large amount of data immediately and accurately (Patricio and Rieder, 2018).

Construction processes intrinsically produce enormous information (Chassiakos and Sakellaropoulos, 2008). It is important to reach the information to make construction more sustainable (Sodagar and Fieldson, 2008). Moreover, the usage of information efficiently between project parties can play a critical role in eliminating barriers of data management (Erbas *et al.*, 2011). Artificial intelligence can contribute productive information management by hampering duplication and malfunction of data (Haymaker, 2011). In terms of AI, Building Information Modeling is an appropriate platform since BIM has parametric characteristics. AI-adopted BIM has the ability to analyze distinct design alternatives (Banihashemi *et al.*, 2015).

Sacks *et al.* (2018) point out that the model checking can be performed by using machine learning technique. Researchers mentioned that machine learning implementation also enhances as-built information. They indicated that laser scanning usage for obtaining geometry in the field is a new trend in the construction industry, but also this implementation does not reach its value since it needs high investment to interpret point clouds and create essential building objects that can be utilized in a BIM model. However, Sacks *et al.* (2018) then added that researchers, who are the member of the EU Infravation SeeBridge project, achieve to determine objects in point clouds by training software.

Furthermore, in the literature, there are various studies that examine AI technology to see its impact on construction practices. Moon *et al.* (2014), for example, used AI to amend construction planning and scheduling that modelled by utilizing BIM. In addition, Yuan *et al.* (2013) tried to improve BIM model by integrating AI. Moreover, Banihashemi *et al.* (2015) investigated BIM-based energy efficient buildings by developing an AI-adopted framework. Konstantinidis (2018) used Artificial Intelligence in the design of Earthquake resistant buildings. Another example of AI application for construction practices is intelligent agent. Intelligent agent was utilized to propose the owner distinct design options and solutions. The point is to increase the client's satisfaction by adjusting or changing their design solutions according to client's requests (Karan *et al.*, 2021). Moreover, intelligent agent can be used for better scheduling because an intelligent agent can evaluate all possible scenarios related to project delivery, resources, time constraints and repeatedly renew durations (Liu *et al.*, 2018). AI-enabled 3D printing also plays an important role in construction processes. To exemplify, when AI is used in 3D concrete printing, 3D machine can enhance and alter the concrete mix to obtain better results according to weather conditions, concrete thickness, etc. (Paul *et al.*, 2018).

2.4.4. Virtual Reality and BIM

The term of Virtual Reality can be defined as an application that enables interact with spatial data in real-time (Whyte, 2002). Delgado *et al.* (2020) describes Virtual Reality (VR) is a technological tool that generates virtual environments. Warwick *et al.* (1993) delineated VR as an immersive interactive media technology that builds augmented virtual surroundings. There are three characteristics of Virtual Reality: 1) its users can connect with model, 2) VR models are depicted three spatial dimensions, and 3) real time feedbacks can be obtained from VR models (Whyte, 2002).

Virtual Reality (VR) plays a significant role in the AEC industry since built environment is highly related to 3D dimensional space (Whyte and Nikolic, 2018). Because it makes possible to experience the project designs before they are constructed. More clearly, VR is the digital reflection of final product (Zaker and Coloma, 2018). Specifically, in the last two decades, sympathy towards VR technology in the construction industry has regularly increased in order to enhance current work processes (Wang and Schnabel, 2008). Donalek *et al.* (2014) highlighted that when VR is used inside BIM environment, it assists user to comprehend design surroundings in an entirely immersive form by creating semantically rich visualization. In addition, since the information can be used directly from the VR model, multi-disciplinary collaboration on models is achieved (Singh *et al.*, 2011).

VR technology can be utilized for various goals in AEC industry. To exemplify, VR can be used for seducing the potential clients because in that way, clients make more accurate examination and thus, they can easily understand built assets (Grudzewski *et al.*, 2018). Also, design review might be made by using VR to see the problems (e.g., errors and conflicts) and evaluate design alternatives in early design stage (Kumar *et al.*, 2011; Du *et al.*, 2018; Lin *et al.*, 2018). Another example is to increase design collaboration. In the early design phase, it is highly crucial to work different project teams collaboratively (Koutsabasis *et al.*, 2012). Virtual Reality improves collaboration between project participants especially in terms of mutual learning and dependencies by giving the opportunity to participants to adjust and assess the model in a real time manner (Zhang *et al.*, 2020).

Furthermore, the construction management process is also affected positively by VR applications. Especially, the feature of model visualization of it helps detect errors and clashes in the beginning during the construction process (Whyte, 2003). In addition to these examples, VR technology plays an important role in increasing construction safety. In a construction project, dangerous accidents can be taken place frequently due to its nature (O'Reilly *et al.*, 1994). These fatal casualties can be minimized or eliminated by education, training and increasing awareness. By utilizing VR technology, experience-based scenarios can be generated, and users can recognize possible risks (Li *et al.*, 2018).

VR has a great impact on construction processes, but it has also difficulties. The most critical issue is to convert design data to VR environment. First of all, this converting process is time-consuming and complicated (Bille *et al.*, 2014). Secondly, there is no real-time data synchronization between design data and VR. For example, when the design was changed, this alteration cannot be demonstrated in VR (Du *et al.*, 2017). Third one is that if alterations occur frequently, data integrity might not be protected (Du *et al.*, 2012).

2.4.5. Internet of Things (IoT) and BIM

Unlike the previous years, the construction industry is making progress to become more innovative and digitalized with BIM (Gerbert *et al.*, 2016; Kassem and Succar, 2017; Chakravarty, 2018). Internet of thing (IoT) is another technological development that is shown growing interest by academia and industries (Gubbi *et al.*, 2013; Jin *et al.*, 2014). Tang *et al.* (2019) pointed out that the integration of BIM and IoT devices gives a great opportunity to enhance construction processes and increase productivity.

IoT technology is evaluated as one of the most important cornerstones of fourth industrial revolution because it has considerable potential in innovations and is beneficial for population (Nizetic *et al.*, 2020). According to Forbes (2018), it is stated that investment in IoT technologies will reach 120 billion USD by 2021 and annual growth rate will be approximately %7.3. IoT can be described as technological devices that enable people and things can be connected anytime, anyplace with anything and anyone by utilizing appropriate any network and any service (Sundmaeker *et al.*, 2010; Ovidiu and Peter, 2013). "The things" in the IoT concept refers to being intelligent enough to act according to messages that are sent from people. To exemplify, a person can set up turning on heater before coming home by using technological devices ((e.g., cell phone, tablets, etc.) (Isıkdag, 2015). IoT plays a crucial role in making processes easier for distinct fields (e.g., construction). Moreover, it aims to assure a better productivity of systems. In addition to these, IoT also has a positive impact on improving life quality (Nizetic *et al.*, 2020).

The AEC industry suffers from inefficiency of work processes for decades. Fragmented structure of these organizations hampers the industry to embrace digital transformation compared to other industries (e.g., manufacture, and financial industries) (Woodhead *et al.*, 2018). However, the emergence of BIM changed this situation to the opposite way. BIM technology enables the users to collect data and information about buildings (Siountri *et al.*, 2020). From this point, IoT technology can be adopted to the BIM environment. This integration provides several benefits to the AEC industry such as real-time access to on-demand data, information collection about the current state of buildings, increasing collaboration and easier decision process, and warning, discovering, and anticipating urgently important issues (Siountri *et al.*, 2020).

In the literature, there are various studies which are related to integration of BIM and IoT in distinct fields. To begin with, sensors that are associated with the BIM model can help to monitor the on-site environment by capturing real-time environmental conditions to analyze and compute compactor?s path, automatic crane operations, etc. (Kuenzel *et al.*, 2016; Arslan *et al.*, 2017). These sensors (e.g., Bluetooth low energy and motion sensors) have also influence on tracking labors, materials, and equipments in complex construction sites (Ding *et al.*, 2013; Park *et al.*, 2017). Moreover, Ding *et al.* (2018) supported that IoT devices increase collaboration and communication among different participants by collecting real time construction data. Furthermore, IoT devices can play an important role in construction performance and progress monitoring since they have the ability to capture real-time project information.When these tools combine with the BIM model, construction process can be monitored effectively, and construction schedule can be updated accordingly (Matthews *et al.* 2015).

Recently, smart city concept started to gain importance in the world. The reason for this is that population and urbanization is increasing rapidly in the cities. Consequently, this growth necessitates effective utilization of resources for these cities in the future (Ugurlu and Sertyesilisik, 2019). From this point, IoT technologies can assist to meet the needs of this rapid growth. IoT fosters technological devices that have a potential to boost the life quality in cities. In addition, these tools can increase to productivity of transportation, smart energy system and smart water management, etc. The most crucial impact of IoT in cities is the ability of discovering infrastructure inefficiencies such as traffic jam, energy supply, water shortage, etc. (Nizetic *et al.*, 2020). One of the examples of smart city-IoT concept is the SmartSantander project (SmartSantander, 2010). In this project, more than 12,000 distinct devices (citizens, smartphones, mobile sensors, etc.) were used throughout the city. Thanks to these devices, city was examined from various aspects. For instance, devices that were placed in the city center monitored environmental parameters like temperature, CO, car presence, light, noise, etc. Also, in this project parking sensors were utilized in order to assist drivers to find free parking lots. Moreover, approximately 60 devices analyzed traffic intensity by installing in the critical points of the city of Santander (Lanza *et al.*, 2016). However, according to Sanchez *et al.* (2020), it does not make sense to implement all devices at the same time. The paper indicated that infrastructure deployment should be made gradually and cyclically with respect to the city priorities.

On the other hand, there is need to solve some issues for the rapid technological advancement of IoT technologies (Techradar, 2019). To exemplify, it is a problem to develop various technologies to monitor network operations (Kakkavas *et al.*, 2020). Another example is the management of security tools (Conti *et al.*, 2020). In addition, Nizetic *et al.* (2020) pointed out that the speed and coverage of wireless networks are the critical challenges in order to perform IoT effectively. Furthermore, Dave *et al.* (2018) indicated that if closed, proprietary standards and systems are deployed in the environment, wider expansion of IoT will be prevented.

2.4.6. Digital Twin and BIM

Even though the construction industry made progress about digital transformation in the last decades, it is still assessed as one of the least digitalized industries (Bughin *et al.*, 2016). According to Bughin *et al.* (2016) there is a gap between construction industry and the others (e.g., Finance). In order to bridge the gap, Brilakis *et al.* (2019) indicated that digital transformation plays a crucial role. One of the significant developments inside the construction industry in terms of digitalization is Building Information Modeling (BIM) (Nassereddine *et al.*, 2019). The built environment has been transformed by BIM in a lot of ways such as increasing collaboration between distinct project parties, improving quality of the final product, and reducing fragmentation of the construction industry (Succar, 2009). However, although the construction industry suffers from being low digitalized, and BIM is not effective yet in operation and maintenance phase, it is obvious that the construction industry will adopt the new technologies with the Industry 4.0 revolution. One of the essential features of the Industry 4.0 is Digital Twin (DT) (Khajavi *et al.*, 2019).

Even though there are various definitions about Digital Twin in the literature, there is no yet common description (Kritzinger *et al.*, 2018). According to Arup (2019), a digital twin is a bridge to connect digital models and simulations with real world data, and also it enables to optimize, monitor and control the physical asset. Although, in its proposed descriptions, digital twin (DT) is evaluated as a computational model, there is a potential for DT to develop into an autonomous system by means of AI-enabled design and control. El Saddik (2018) defined digital twin as a bridge between physical world and virtual world, and this virtual world is the imitation of physical entity.

In addition, Grieves and Vickers (2016) explained that digital twin has two systems that are linked to each other. The first one is physical system which always live, and the second one is virtual system that has all the information associated with physical system, and the information flows between these two systems because they are linked. Gallan *et al.* (2019) clarified that digital twin is a virtual portrayal of a physical object that facilitates understanding, learning, and reasoning of physical system. Similarly, Brilakis *et al.* (2019)) indicated that DT is a virtual replica of real object. This real object or physical twin can demonstrate buildings, railways, hospitals, bridges, etc. in the built environment. In addition, the paper pointed out that it is needed to select a particular update frequency for DT and to bring to date it with respect to the current condition of a physical object.

Although, there is no clear answer about the differences between BIM and DT, it can be said that DT has more comprehensive concepts than BIM environment. The reason for this is that DT gives attention to enormous facilities and adopts various knowledge from distinct sectors. Thus, information exchange between different sectors can be fulfilled (Brilakis *et al.* 2019). Lu *et al.* (2020) claims that especially in the operation and maintenance (O&M) phase, BIM remains incapable in terms of asset management. However, DT is more beneficial at that stage because it is not just the bridge between virtual and physical assets, it has also the ability of transmitting information between these two (see Figure **??**).

Digital twin can be used in several areas inside the construction industry. The first area is asset condition monitoring. By monitoring the conditions of an asset, risks can be detected explicitly, and decision-making process becomes much less painful (Al-Sehrawy and Kumar, 2021). To exemplify, the current circumstances of a bridge can be monitored by employing digital twins, thereby it can be compared to current and previous situations of the bridge, and this comparison gives an advantage to evaluate the options for the maintenance of the bridge (Blakis *et al.*, 2019). Secondly, facility management is another example of the usage areas of digital twin. By using digital twin, environment conditions can be analyzed and predicted and then optimize according to people' physical and mental health in a facility (Blakis *et al.*, 2019; Al-Sehrawy and

Kumar, 2021). Thirdly, digital twins can be utilized for simulations of an assets in order to evaluate diverse design scenarios in terms of lighting, heating etc. Furthermore, designers, with the help of VR equipment, can generate own digital twins of their models and present the changes and modifications to the clients (Blakis *et al.*, 2019; Al-Sehrawy and Kumar, 2021).

On the other hand, Al-Sehrawy and Kumar (2021) stated that there are the issues need to be solved for better digital twin implementations. For instance, it is not clear how data can be exchange. Besides, how this data will be integrated from distinct sources. In addition, the authors also implied that data security and privacy are other issues need to be eliminated.

2.5. Theoretical Frameworks for BIM Transition

2.5.1. Theoretical Models/Frameworks/Theories

Innovation Diffusion Theory (IDT), Technology Acceptance Model (TAM), Institutional Theory (INT), and Technology-Organization-Environment framework (TOE) are widely known and utilized in the literature. In this thesis, proposed framework is developed by exploiting these models.

2.5.1.1. Innovation Diffusion Theory. Innovation Diffusion Theory is well-known technology adoption model in the Information System (IS) literature (Oliviera *et al.*, 2014). According to Rogers (2003), there are 5 stages of the innovation decision process which are needed for an innovation to diffuse. They are: 1) The knowledge phase; 2) The persuasion phase; 3) Adoption decision phase; 4) Implementation phase; and 5) Confirmation phase. Although innovation diffusion theory was emerged to deem individuals' adoption behavior, there are studies that evaluate organizations' adoption behavior (Lai and Guynes, 1997). However, the deficiency of organizational and environmental factors is assessed as the limitation of innovation diffusion theory (Lee and Cheung, 2004).

2.5.2. Innovation Diffusion Stages

2.5.2.1. The Knowledge Stage. Rogers (2003) explains that the first stage in the innovation decision process is the knowledge stage, which aims to gain insight into the innovation what it is, and how it works. When an individual or other decision-making unit starts to seek information about an innovation system (e.g., BIM), the process begins. However, some researchers argued that it is significant to know whether an individual exposes the information inadvertently, or not because if it is, innovation will create just a little impact on the individual. In addition to this, individuals‘ beliefs, needs, attitudes play a crucial role in their willingness towards innovation. At that point, there is a phenomenon which is defined as selective exposure. Basically, it can be said that individuals have a tendency to avoid the information that is related to the innovation, when they see a confliction between their beliefs and information. Moreover, if they realize that the innovation meets their needs, they will enthusiastically seek information about it, and this process is called as selective perception.

Rogers (2003) points out that there are three types of knowledge about an innovation, including awareness-knowledge, how-to knowledge, and principles knowledge. Awareness-knowledge is related to the question of what is the innovation? Thus, this steers individuals to seek answers for other questions such as “how does it work”? and “why does it work”?. The person or organization who adapts the innovation needs to understand how to use it. This is extremely important because if individuals or organizations have no sufficient level of how-to knowledge before implementing it, it is high likely that the result will be rejection and discontinuance. Rogers (2003) pointed out that it is also needed to know the principles of an innovation which indicate how it works. The author underlined that it is possible to adopt an innovation without its standards, but this, eventually, increases the risk of misusage, and it is high likely that the innovation does not continue. Therefore, it is also crucial to understand the principle of a new idea to eliminate the discontinuance possibility.

2.5.2.2. The Persuasion Stage. After adequately informed about the innovation, the second stage, the persuasion phase, begins. In this stage, organizations or other decision-making units try to develop a favorable or unfavorable attitude towards the innovation. Rogers (2003) says that at the persuasion stage, psychology plays an important role while an individual determines his or her behavior, so individuals generate perceptions about the innovation. Therefore, innovation characteristics, such as relative advantage, compatibility, and complexity, have a great influence on this stage. Furthermore, organizations try to interpret the future consequences when they adopted the innovation. Besides, an individual or an organization may normally have doubts about the new idea, but typically, he or she seeks reinforcement from his or her peers to approve his or her initial opinions about the innovation because they believe that their peers' views are more reachable and convincing compared to the mass media. In that point, in the literature, various researchers named this situation as internalization which has indirectly influence on intention of use (Deutsch and Gerard 1955; Kelman 1958; Warshaw 1980; Venkatesh and Davis 2000). In addition, an individual has an intention towards the new idea since he or she wants to gain a status in his or her workplace. This kind of creating social image is called as identification, which also indirectly impacts the intention of users, in the literature by some researchers (Kelman 1958; French and Raven 1959). It can be said that innovations have certainly both benefits and drawbacks, and individuals/organizations undoubtedly want to minimize these possible negative consequences. Moreover, it is expected that an individual's intention leads to a decision (accept or reject) according to their behavior towards the innovation, but in fact, this might not always happen. Nevertheless, sometimes a stimulus can be enough in order to change behavior. This stimulus can be external, or internal for an organization (Rogers, 2003).

2.5.2.3. The Adoption Decision Stage. Rogers (2003) contends that when an individual or other decision unit have a favorable attitude towards the innovation, the third phase, the decision stage begins. There are two options in that stage. First one is adoption which can be defined as a decision to use completely an innovation, and second one is rejection which can be defined as a decision to do not integrate an innovation into organization. In addition, according to Rankin and Luther (2006), before making a decision, there are three cores of stages, namely evaluation, trial, and adoption. It is widely known that a new idea has inherently uncertainties. Therefore, most individuals want to make trial before making any decision in order to specify the innovation's usefulness for their jobs. It is extremely important that if an individual or other decision-making unit think that the innovation has relative advantage at a certain degree, individual will try the innovation and then make the decision. In addition, supplying free samples of the innovation's tools to clients usually increase the rate of adoption because clients have a chance to try the system, thereby they can make more accurate decisions about the innovation. Furthermore, in order to speed up the adoption, individuals/organizations can make vicariously trial. However, it must be known that rejection can occur at each stage of decision-making process. For example, if a rejection decision has been made after adoption of the innovation, this process results as a discontinuance (Rogers, 2003).

2.5.2.4. The Implementation Stage. According to Rogers (2003), an individual or other decision-making unit, after acceptance the innovation, starts to use the innovation. At the first three stages, individuals represent mental efforts, but associated with the implementation phase, they begin to utilize the innovation in their jobs. Normally, uncertainties about the innovation carry on in this stage. Individuals or organizations usually think that how to use the innovation in their jobs, or what kind of problems which they possibly need to solve. Then, they seek answers actively for these thoughts. However, there is a fact that when the innovation brings about considerable changes to work processes, employees want to resist towards the innovation (Venkatesh and Bala, 2008; Hamada et al., 2016; Li et al., 2017; Ozener et al., 2020). They normally think that their job routines and habits will be altered by the new idea. Maybe they feel that these alterations will negatively affect their relationships with co-workers, or they are even afraid of weakening their prestige or status in the organization (Markus, 1983; Beaudry and Pinnsonnealt, 2005; Lapointe and Rivard, 2005). All of them are expected attitudes, especially in the case of incorrect evaluations and understanding of the innovation. Nevertheless, in order to play down the possibility of resistance, organizations should develop effective implementation strategies. Moreover, when we look from the perspective of organizations, it is realized that there is distinction between organizations and individuals because an organization has various individuals that are involved in decision process, and it is likely that in the implementation stage these individuals might be different from the first three stages. In addition to this an organization has often complex structures. Therefore, resistance against a new idea can be more powerful compared to individuals. In the end, this stage will reach at a point that the system is regulated, and the innovation turns into institutionalized inside the organization (Rogers, 2003).

2.5.2.5. The Confirmation Stage. When individuals or other decision-making units implemented the innovation, they start to evaluate the results. In the confirmation stage, just as in the intention phase, individuals seek reinforcement to support their decision that they made before as adoption. Therefore, Liu *et al.* (2018) defined user acceptance as a dynamic process. Rogers (2003)explains that confirmation stage is directly related to the psychology because users look support for their decision that is already made. If they encounter negative consequences, they might tend to behave reversely compared to before decision. Therefore, in this phase, individuals can decide to discontinue the innovation since they have doubts about it. However, generally, individuals try to dodge a decision of discontinuance, or at least they try to reduce the thought of discontinuance about the innovation. Moreover, it is possibly that individual behavior changes by dissonance, but individuals seek to decline this disequilibrium, and there are three types of dissonance reduction (Rogers, 2003). First, individuals have the awareness of their needs, and they look for information about an innovation to meet these needs. Second, although some individuals have a favorable attitude towards the innovation, they can be skeptical, and they can decide to not adopt the innovation. After that, this decision can be altered by dissonance that is between individuals‘ beliefs and their actions. It is high likely that this change occurs in the decision and the implementation stages. Third, if individuals think that they should not have adopted the innovation, and later, they expose the massages that support the innovation, this can lead to dissonance, and in order to decrease it, individuals can adopt the innovation. Furthermore, it can be said that altering prior decision is difficult for individuals. Therefore, individuals avoid negative messages which can generate confliction. Apart from these, in the confirmation stage, discontinuance can occur. There are two types of discontinuance, namely replacement discontinuance and disenchantment discontinuance. Replacement discontinuance occurs when individuals reject the innovation that adopted before in order to replace better one. As for disenchantment, it occurs when individuals reject the innovation because of its poor performance. Moreover, using the innovation alone will not be adequate to affirm, but it will be enough to observe that the organizational goals targeted during the implementation process are accomplished (Rankin and Luther, 2006).

2.5.2.6. Attributes of Innovations. Rogers (2003) also introduced five attributes of innovations that have a direct impact on adoption rate of the innovation. According to Rogers (2003), an innovation will be adopted quickly and easily if the innovation has these attributes. These characteristics are relative advantage; compatibility; complexity; trialability; and observability.

2.5.2.7. Relative Advantage. Relative advantage was defined by Rogers (2003, p. 229) as “the degree to which an innovation is perceived as being better than the idea it supersedes”. Another definition about relative advantage was made by Moore and Benbasat (1991, p. 195) as “the degree to which an innovation is perceived as being better than its precursor”. Wang *et al.* (2011) pointed out that it is hard to distinguish definitions of relative advantage and perceived usefulness because they are quite similar. Therefore, researchers described relative advantage as “the degree to which using a particular ICT is perceived as being better in terms of enhancing job performance than using its preceding/competing technologies”. We can describe the degree of relative advantage in terms of cost and time effectiveness, quality, task performances, social prestige, security improvements and the like. On the other hand, Tornatzky and Klein (1982) approached relative advantage skeptically. They advocate that relative advantage is too broad, and it can be used more specific terms instead of it, such as profitability and time saved. However, in the literature, many studies evaluated relative advantage as an innovation characteristic. (Rogers, 2003; Ahmed and Kassem, 2018; Hameed *et al.*, 2012) It is clearly known that organizations or individuals look for information to diminish uncertainties in process. There is no doubt that a new innovation or technology which is more worthwhile, is more probably adopted (Venkatesh *et al.*, 2003). Moreover, people who have intention to adopt a new idea naturally want to know whether this new idea is more beneficial than those that have already, or not. Therefore, the relative advantage has a great significance on both adoption and diffusion processes. Furthermore, incentives or subsidies have a positive impact on relative advantage and rate of adoption (Rogers, 2003). Especially, from BIM perspective, the rate of adoption is tried to increase by vendors by giving encouragement to clients in order to boost adoption. The main purpose in this is to rise the degree of relative advantage of the innovation (Saka *et al.*, 2020).

2.5.2.8. Compatibility. Compatibility was described by Rogers (2003, p. 240) as "the degree to which an innovation is perceived as consistent with the existing values, past experiences, and needs of potential adopters". There is a positive relationship between compatibility and the rate of adoption, which means that more compatible innovations with your system or workflow make the adoption process easier and increase the adoption rate (Tornatzky and Klein, 1982; Rogers, 2003). It is not surprise because when a new idea came out, people tend to compare their existing practice with the innovation in order to assess its compatibleness (Gledson and Greenwood, 2017). Tornatzky and Klein (1982) claimed that there are two types of compatibility. The first type is cognitive compatibility that is persistent to thoughts and feelings of people towards an innovation. The second type is operational compatibility that is related to people?s action (Brandner, 1959). Compatibility can be affected certainly by sociocultural values and beliefs, some degree of familiarity about new idea from past innovations, and the needs of clients. In the traditional industries, new ideas cannot be accepted as much easy as the industries which are compliance with new technologies because of their strict rules and beliefs. In addition, new innovation can show resemblances with other innovation systems which are recognizable for individuals or organizations from the past. This might make it easier to understand a new idea. Moreover, it is extremely important to meet the needs of customers so that the innovation is used by a wide range of individuals or organizations. If the innovation fulfills clients‘ needs, this steer the people to use the innovation (Rogers, 2003).

2.5.2.9. Complexity. Complexity is the degree to which an innovation is perceived as relatively difficult to understand and use (Rogers 1995). Innovations might be evaluated as complex or simple systems by potential adopters (Tornatzky and Klein, 1982). Therefore, complexity makes great contribution to assess the advantages and disputes of an innovation (Tsai *et al.*, 2010). According to Rogers (2003), there is a negative association between the complexity of innovation and the rate of adoption. The other meaning is that complexity is classified as a very significant drawback to adoption. It is obvious that individuals or organizations do not want to utilize the complex systems for their business since they make their works complicated. However, not all evaluate the complexity as much crucial as relative advantage or compatibility. It is possible that people ignore the complexity when they adopt a new idea.

2.5.2.10. Trialability. Trialability is “the degree to which an innovation may be experimented with on a limited basis” (Rogers 2003, p.). A trial process can help to understand a new idea whether it is beneficial for individuals or organizations, or not. It is highly possible that uncertainties may be dispelled by trial. Rogers (2003) suggests that trialability plays a positive role in increasing innovation‘s rate of adoption. It can be said that a more easily designed trial process of the innovation equals a faster rate of adoption. Trialability feature also influences early and late adopters differently because later adopter may not need trial process since they have many precedents who tried and adopted the innovation, but earlier adopters have no chance to learn others (Rogers, 2003). Therefore, they need to try the innovation at first.

2.5.2.11. Observability. Observability is “the degree to which the results of an innovation are visible to others” (Rogers 1995). It is hard to observe and describe some innovations compared the others. Rogers (2003) claims that there are positive relationships between observability and its rate of adoption. If an innovation has more observable features, this will boost the degree of adoption. To exemplify, technology mostly consists of software and hardware, but hardware is tangible, which compose of tools and physical objects, and as for software, it is intangible, which makes observability harder. Therefore, the speed of software adoption generally is much slower than hardware has. Furthermore, it is clear that to create a favorable impression about a new idea for potential adopters, they should understand how this idea makes difference for their business. If they see the distinctness, of course on the positive side, they will want to adopt the system more eagerly. According to Tornatzky and Klein (1982) indicated that it is more likely that an innovation will be adopted and implemented, when the results of that innovation are more visible.

2.5.3. The Institutional Theory (INT)

The institutional theory (INT) contend that environmental factors can influence in the development of an organization (Tsai *et al.*, 2013). In addition, the institutional theory stated that institutional environment has a positive impact on reaching convenient organizational structures, operations, behaviors, and practices by meeting social expectations and norms (Meyer and Rowan, 1977; Zucker, 1987). It is significant to satisfy these expectations for a company to carry on its legitimacy in the field (DiMaggio and Powell, 1983; Heugens and Lander, 2009). From this point of view, while an organization decides to integrate an innovation, it gains knowledge about institutional expectations and norms, then employs this information to evaluate the possible advantageous of integrating the innovation, and also takes precautions against ambiguities (Choi and Eboch, 1998; Scott, 1995).The institutional theory consists of three external isomorphic pressures which encourage organizations to carry out behavioral and structural changes, at the same time, they look for obtain social legitimacy. There are three external pressures that shape organizational behaviors namely, coercive, mimetic, and normative pressures. The responses of organizations that develop towards these pressures specify the institutional legitimacy. It can be described institutional isomorphism as an advantageous tool that provides better understandings about modern organizational life (DiMaggio and Powell, 1983).

2.5.3.1. Coercive Pressures. Coercive pressures can be described as the pressures come from political effects applied by dominant institutions and organizations (e.g., suppliers, customers) (DiMaggio and Powell, 1983; Teo *et al.*, 2003). Political impact and the problem of legitimacy have a significant influence on coercive isomorphism. According to DiMaggio and Powell (1983), these pressures can be derived from both formal and informal ways. To be more precise, coercive pressures may be stemmed from an institution or an organization or government (Cao *et al.*, 2014). These associations might generate pressures by forcing or persuading an organization to act in compliance with their wishes. In some situation, even cultural beliefs might play important role in creating coercive pressures (DiMaggio and Powell, 1983). For example, sometimes governments all over the world publish mandate programs for companies to adopt a system. It is obvious that these environmental pressures can lead to behavioral and structural change in organizations (Cao *et al.*, 2014).

2.5.3.2. Mimetic Pressures. Mimetic pressures can be explained as the imitating of another similar organization's act (Sherer *et al.*, 2016). An organization can be transformed over time to another organization by the effect of mimetic pressures (DiMaggio and Powell, 1983). For instance, a firm that shares the same goals, and experience similar obstacles with successful firms inside the same industry probably imitates the actions of lucrative organizations in order not to lag behind in successful firms (Burt, 1987). Uncertainty is the most important factor that creates mimetic pressures. Organizations always do not produce appropriate innovative solutions for their problems, or their goals can be defined as vague, or maybe the environment in which they make business can generate ambiguity (Cao *et al.*, 2014). In that situation, in order to overcome uncertainties, organizations examine their peer organizations and mimic their behavior or structure to become legitimate, and also make progress. In return, these organizations maintain their competitiveness through mimicry (DiMaggio and Powell, 1983). To exemplify, in a competitive market, organizations do not want to lag behind their rivals. Therefore, they can make benchmarking, or directly imitate their peers' lucrative practices. Moreover, organizations that mimic others need less human capital, and this leads to lower expenses for these kinds of organizations (Teo *et al.*, 2003).

2.5.3.3. Normative Pressures. DiMaggio and Powell (1983) defines normative pressures as an organizational change that are derived from professionalization. Burt (1987) contended that normative pressures are deemed as influential by the community. Moreover, organizations obtain knowledge about the innovation from adopters that have relations with them. According to Heugens and Lander (2009) indicates that normative pressures derived from collective expectations. In addition, researchers emphasize that there are two aspects of professionalization. The first one is university specialists who give formal education and create cognitive base for industry professionals. The second one is widening professional networks that helps to promulgate quickly changing such as association participation, conference communication and professional consultation (DiMaggio and Powell 1983). Normative pressures are highly crucial in terms of creating awareness in the market because in this way organizations can make necessary changings in their organizations since they realize benefits. Furthermore, normative pressures have a great impact on both individuals and organizations. Individuals can improve themselves through trainings, conferences, etc. In return, they can contribute problem solving processes in their organizations. This gives organization an advantage to handle their issues easily and effectively (Cao *et al.*, 2014).

2.5.3.4. Technology - Organization - Environment (TOE) Framework. The Technology, Organization, and Environment (TOE) framework was developed by Tornatzky and Fleischer (1990) to integrate technology into organizations. Both internal and external factors play an important role in the efficacy of an organization. From this point, factors that include technological, organizational, and environmental determinants should be considered to make a decision (Accept/Reject) by decision-makers. According to Oliviera and Martins (2011), the TOE framework provides powerful theoretical basis and empirical support to examine the adoption of technological innovations. TOE framework was used in the literature to analyze technology or innovation adoption (Kuan and Chau 2001; Zhu *et al.* 2003; Teo *et al.* 2006; Liu, 2008). In addition, TOE framework was used with other frameworks like Diffusion of Innovation Theory (DOI) was developed by Rogers (2003) in the literature (Chen at al 2019; Wang *et al.* 2010; Chong *et al.* 2009; Zhu *et al.* 2006a). These studies made analyzes by adding innovation attributes such as relative advantage, compatibility, complexity and so on. However, TOE has environmental factors differently from Diffusion of Innovation Theory (DOI). Therefore, it explains better intra-firm innovation diffusion (Hsu *et al.*, 2006; Oliveira and Martins, 2011). Furthermore, TOE framework has a positive association with Institutional Theory (INT) in the literature. There are many researches that are combining with TOE and INT (Gibbs and Kraemer 2004; Li 2008; Soares-Aguiar and Palma-Dos-Reis 2008).

2.5.3.5. Technology Acceptance Model (TAM). Davis (1985) proposed the technology acceptance model (TAM) in order to make understanding user acceptance towards new technological or innovative systems. In fact, this theory is an adaptation of Theory of Reasoned Action (TRA) that was developed by Fishbein (1967), and The Theory of Planned Behavior (TPB) which was introduced by Ajzen (1991). According to theory, there are two main attributes for adoption of technology, namely perceived usefulness (PU) and perceived ease of use (PEU) (Davis, 1989; Davis *et al.*, 1989). Also, Davis (1989) defined perceived usefulness as “the degree to which a person believes that using a particular system would enhance his or her job performance”. According to (Bhattacherjee, 2001), perceived usefulness is the term that refers to users’ opinions towards the advantages of IT utilization. Perceived ease of use is described as “the degree to which a person believes that using a particular system would be free of effort” (Davies, 1989). In the model, these two attributes are directly influence on user‘s attitude towards the usage of new technology or innovation system. Besides, perceived ease of use has an impact on perceived usefulness. This is because, if the degree of ease of usage of a system rise, undoubtedly it is more valuable (Venkatesh and Davis, 2000). Moreover, when it is considered the transition process, Hameed et al. (2012) suggested that due to TAM is directly related to the usage of new technological systems, it should be evaluated at the post-adoption stage. It is widely known that TAM is a beneficial model, but it needs to be combined more extensive models which have various factors such as human-related and social factors (Legris *et al.*, 2003). For example, Yuan *et al.* (2019) integrated TAM with TOE framework to anticipate project’s owner BIM adoption behavior.

3. RESEARCH METHODOLOGY

BIM is a state-of-the-art technological development for the construction industry in the world, especially in emerging countries (e.g., Turkey). Integrating BIM to construction organizations is generally painful since it is needed to invest in technology and people. However, the factors that affect the BIM transition process can vary from country to country, organization to organization, and people to people. From this point, the main aim of this thesis is to determine influential factors of the BIM transition process for the AEC companies.

For this purpose, in this research, 93 papers that were published all over the world were examined. In the light of an extensive literature review, an inclusive framework has been developed for the BIM transition process. This framework consists of 6 stages, and 3 characteristics, 6 components, and 46 factors that influence these stages.

After generating a framework and specifying the corresponding factors, online interviews have been conducted to identify the most effective factors according to the Turkish AEC firms. In order to evaluate 46 factors, interviewees are asked to designate the importance level of the relevant factors on a 1 to 5 Likert scale (5 corresponds to very important) based on participants' own experiences during the BIM transition process.

3.1. Literature Review

For academic studies, it is highly important to review previous researches that are related to the content of the study. The findings of these former studies assist the researchers to conduct new studies. According to Kitchenham and Charters (2007), the gaps and proposed opportunities for future studies can be realized with the systematic literature review. Likewise, in this research, the findings of prior research papers were examined, and the BIM transition framework was developed with the help of them.

First of all, an extensive literature review was conducted in order to find the papers which have similar topic with this thesis. Moreover, Building Information Modeling (BIM) can be evaluated as a revolutionary innovation in the construction industry (Ullah *et al.*, 2019). Since BIM is also an innovative system, for the examination of the BIM transition process, the studies that are persistent to innovation adoption, implementation, and diffusion were also reviewed. Furthermore, this research also aims to identify the determinants which affect to the BIM transition process. Therefore, in order to find the determinants, relevant papers were analyzed. In the end, 46 factors have been determined as the result of the review process.

In the beginning, previous studies which are related to "Innovation Adoption", "IT Adoption", "Innovation Diffusion", "BIM Adoption", "Technology Adoption", "BIM Transition", "BIM Diffusion" terms were reviewed, and frameworks, models and theories that were used in these papers was noted down.

3.1.1. Transition Characteristics

After deeply examining transition structures, 3 types of transition characteristics have been determined, and these 3 types characteristics have 12 determinants in total. These determinants have been specified according to papers that are pertaining to innovation adoption and diffusion, technology adoption and diffusion, IT adoption and diffusion, and BIM adoption and diffusion.

<u>3.1.1.1. Innovation/Technology Characteristics.</u> Zhu *et al.* (2004) explained the technological context as both internal and external technologies that are related to the company. These technologies can be available inside the company or existing in the industry. Innovation or technology characteristics compose of 4 determinants including relative advantage, compatibility, technological factors, perceived usefulness. While constructing these characteristics, it was drawn on from both IDT and TAM. As it is mentioned above, Rogers (2003) indicated that innovation characteristics are the great catalyst for adopting an innovation. In addition, Hameed *et al.* (2012) claimed that

TAM plays a crucial role in users' attitude towards an innovation.

3.1.1.2. Internal/Organizational Characteristics. Organizational context is one of variable of TOE framework introduced by Tornatzky and Fleischer (1990). According to Baker (2011), the organizational contexts are pertaining to firm's characteristics and resources such as relationship among employees, communication process with other firms, and amount of available resources. Internal characteristics have a positive impact on both adoption and implementation of an innovation with several ways (e.g., organizational structure, communication behavior). Based on the literature review, 6 characteristics have been determined, including leadership, organizational readiness, economic factors, organizational culture, communication behavior, and willingness.

3.1.1.3. Leadership. According to Ozorhon (2013), leadership plays an important role in obtaining any type of innovation in the construction industry. Tatum (1989) also stated that leadership is one of the most significant management characteristics for achieving successful innovation. Moreover, if a manager has positive attitude and openness characteristics, this increases the creativity and innovation (Farid *et al.*, 1993). From this perspective, a firm that represents effective leadership, it is more likely to promote the innovation (Ozorhon, 2013). Also, Nam and Tatum (1997) found that leadership is crucial for innovation. In BIM literature, there are various studies that were examined leadership for BIM adoption and implementation. Liu *et al.* (2016) pointed out that the construction industry needs for people who have leadership feature to provide collaborative work environment to project teams and thereby, these leaders help the teams work collaboratively. Ma *et al.* (2020) found that leadership is one of the key drivers for BIM implementation. Liao and Teo (2019) claimed that if there is no person who has the vision of implementing BIM and leadership characteristics inside an organization, adopting new work processes will remain inconclusive.

3.1.1.4. Organizational Readiness. Iacovou *et al.* (1995) determined organizational readiness as whether an organization has available resources in order to adopt the technology. In addition, organizational readiness has been indicated as a significant determinant by Zhu *et al.* (2003) in technological adoption. Organizational readiness contains the availability of knowledge, skills, and expertise that is related to the technology in the organizations which aim to adopt it (Thong and Yap, 1995). It is noted that many researchers pointed out that companies which do not provide training and education to their employees to gain skills and expertise in a technology, cannot adopt properly into their organizations (e.g., Bosch-Sijtsema *et al.*, 2017; Tsai *et al.*, 2014; Won *et al.*, 2013). In addition to these studies, organizational readiness is also significant for adopting BIM (Ahmed and Kassem, 2018; Chen *et al.*, 2019). Juan *et al.* (2016) stated that when organization's readiness level increased, the possibility of adopting BIM technology grows.

3.1.1.5. Economic Factors. It is widely known that construction projects are mostly complex and therefore they need much money to complete (Tatum, 1987). Moreover, although the construction industry is one of the least innovative sectors in the world. Construction firms can increase their innovative capabilities by investing in new innovative technologies and R&D (Teece and Pisano, 1994). Besides, cost-effective solutions cannot be obtained all the time. Therefore, firms should consider that risk level of adopting an innovation is high, and in the long term returns of their investment might be attained (Ozorhon and Oral, 2017). From BIM perspective, financial investments are also highly important to maintain BIM environment continuity (Munir et al., 2019). According to Sawhney and Singhal (2014), high cost of BIM implementation (e.g., hardware, software, training) is important barrier. Amuda-Yusuf (2018) also pointed out that the significance of the cost of required tools for BIM changes depends on firms' turnover. Furthermore, Jamal *et al.* (2019) indicated that although BIM has a positive effect on cost savings, cost of BIM-related tools can generate a barrier for companies.

3.1.1.6. Organization Culture. Organizational culture can be defined as the reflection of organization's values and beliefs into organization's practices and goals, and it assists the members of organizations to understand organization's functions (Lewis and Boyer, 2002). Organizational culture has an impact on how company makes decisions

(Zammuto and O'Connor, 1992). In the literature, there are several studies that are related to how organizational culture affects innovation adoption (Khazanchi *et al.*, 2007; Stock *et al.*, 2007). Furthermore, there are researches that were examined the relationships of organizational culture and BIM (Becerik-Gerber *et al.*, 2012; Lu *et al.*, 2013; Wu *et al.*, 2018; Ahankoob *et al.*, 2018; Koseoglu *et al.*, 2019). Ahankoob *et al.* (2018), for example, contended that organizational culture can play a great role in improving the advantages of BIM, if it is open to changes and innovations.

3.1.1.7. Willingness. Willingness towards an innovation facilitates its adoption and implementation. However, Peansupap and Walker (2005) indicated that willingness can be affected negatively by the lack of top management support or organizational commitment, especially during implementation stage. Top managers or potential users can exhibit unwilling attitude within organization. Suebsin and Gerdsri (2009) pointed out that motivation to accept changes is influenced by the ease of use and usefulness of new technology. Also, it is important to say that if individuals do not accept the changes, organization will not reap the benefits of new idea. Therefore, the innovation should be understood clearly for both potential users and top management. Otherwise, this situation leads to resistance within organization (London and Singh, 2013; Xu *et al.*, 2014). Furthermore, competitiveness has also impact on organization's attitude (Takim *et al.*, 2013). According to Alshawi *et al.* (2010), companies of the AEC industry tend to adopt new technologies in order to gain a competitive advantage over their rivals.

3.1.1.8. Communication Behavior. Communication behavior demonstrates how information flow manages productively within organizations. Also, communication behavior has an impact on relationships with other project participants (Mom *et al.*, 2014). Ahmed and Kassem (2018) contended that communication behavior is a critical factor for decision-making process. Therefore, decision-makers can take action to enhance communication behavior by developing the strong relationships within the firm and with other firms. From this point of view, BIM can make great effect on this deficiency because BIM improves collaboration among multiple team members (Nanjakar, 2014).

BIM also has a positive impact on the concept of integrated project delivery (IPD) which is a novel project delivery approach to merge people, systems, etc., in order to decrease waste and increase productivity in the all stages of the project (Glick and Guggemos, 2009). Moreover, Eadie *et al.* (2013) indicated that collaboration plays an important role in BIM implementation. On the other hand, lack of collaboration creates obstacle for BIM implementation (Ding *et al.*, 2015; Liu *et al.*, 2017).

3.1.1.9. External/Environmental Characteristics. According to Institutional Theory (INT), environmental factors play an important role in adopting innovations for organizations. DiMaggio and Powell (1983) proposed three type of pressures that guide institutional isomorphism. These are coercive, mimetic and normative pressures that were explained in above section. In the BIM literature, there are many researches that investigates relationships between BIM environment and isomorphic pressures (Cao *et al.*, 2014; Ahmed and Kassem, 2018; Saka *et al.*, 2020).

3.1.2. Transition Components

In the literature, there are various studies that examine the factors that impact innovation process from AEC sector's perspective (Lu *et al.*, 2008; Won *et al.*, 2013; Tsai *et al.*, 2014; Ozorhon and Karahan, 2016; Antwi-Afari *et al.*, 2018). Moreover, Ozorhon (2013) generated framework by grouping influential factors into 6 components and adding project participants. The framework is depicted in Figure 3.1. According to the framework, components are linked to each other. These components are drivers, inputs, enabler, barriers, benefits, and impacts.

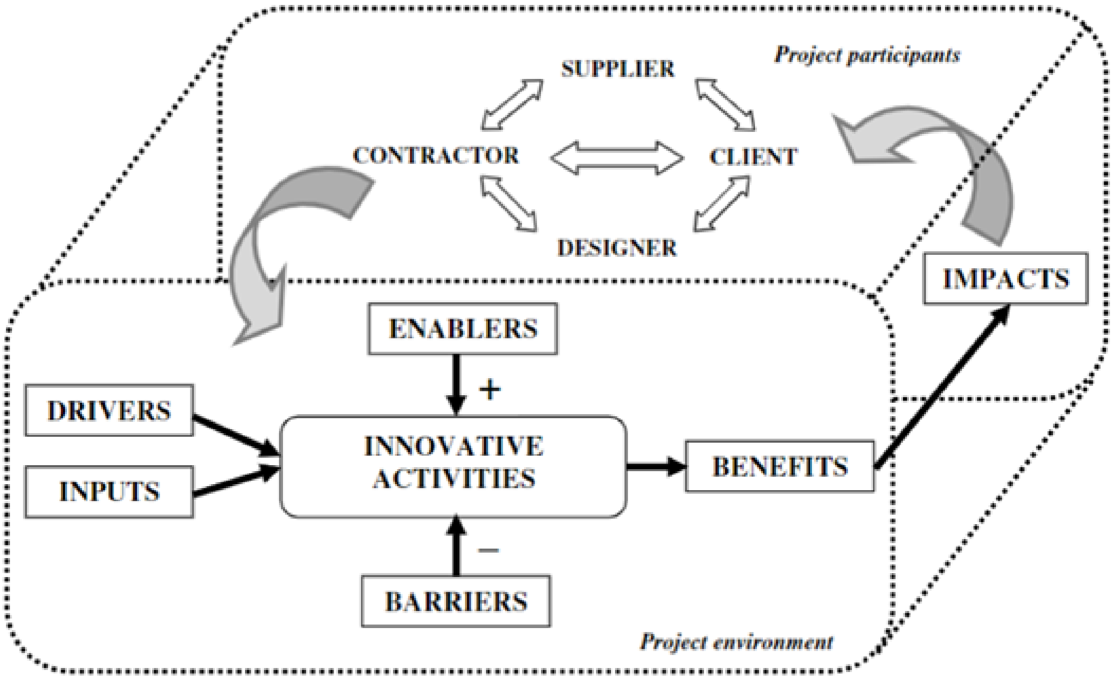

Figure 3.1. The Proposed Innovation Framework (Ozorhon, 2013).

Drivers can be described as the factors that provoke firms to embrace the innovation. Inputs can be defined as the requirements (e.g., resources, tools) that are needed for adoption and implementation of innovation. Enablers represents the factors that promote and accelerate the rate of innovation. Barriers are the challenging factors that make innovation process difficult. Benefits are beneficial outputs in project level after innovation. Impacts refer to the achievements of the firm for innovations in company level (Ozorhon, 2013).

Aside from the components, project participants also take part in the framework. According to Ozorhon (2013), each participant can affect the innovations and take advantage from them. In addition, the framework is shown within a loop since participants can transfer their knowledge and experience to the future projects.

3.1.3. BIM Transition Framework

In order to understand comprehensively innovation transition process, developing framework and determining factors that affect the transition process are critical. For the framework, innovation decision process that was developed by Rogers (2003) taken as a basis. As it is seen from the Figure 3.5, the framework composes of three parts, including pre-transition, transition, and post-transition. These three parts consist of 6 stages, namely awareness, intention, adoption decision, implementation, confirmation, and BIM diffusion. During these stages, two decision periods are occurred. At the end of the periods, there is a decision moment for acceptance or rejection of BIM. Rejection or disapproval leads the framework to discontinuance. In addition, there are 6 components that affect the parts and phases of the transition framework (interaction zone 2). These are motivations, inputs, obstacles, enablers, benefits, and impacts. Moreover, components are linked with three type of characteristics, including innovation/technological characteristics, internal/organizational characteristics, and external/environmental characteristics (interaction zone 1). In the following parts, the proposed BIM transition framework will be explained.

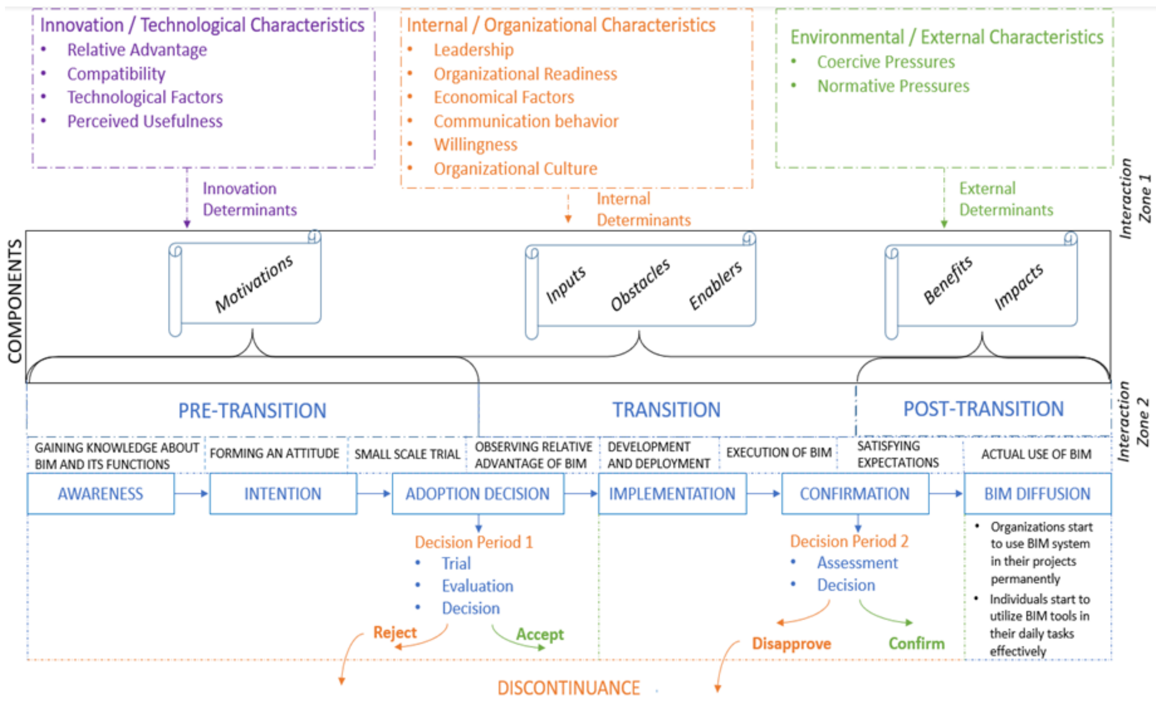

Figure 3.2. Proposed BIM Transition Framework.

<u>3.1.3.1. Components.</u> After the critical factors have been determined at the end of the literature review, these factors categorizing into 6 different components namely, motivations, inputs, enablers, obstacles, benefits, and impacts. These components will

explain in the following.

3.1.3.2. Motivations. Motivations can be defined as factors that express the motivation of companies to switch to the BIM system. These factors play an active role in the pre-transition period. According to the literature review, 8 motivations for the interviews were determined.

(i) "Client Requirement" is a motivational factor that pushes the project participants (e.g., contractor, sub-contractor) BIM in construction projects.

(ii) "Design Productivity Improvement" is an important factor that motivates organizations to improve their unproductive design processes. It is obvious that most construction firms suffer from construction wastes, especially in design related issues (Bernstein and Pitman, 2004; Aranda-Mena *et al.*, 2009). However, BIM usage can reduce these wastes by eliminating errors and reworks in design, by providing a better understanding of project details. Moreover, clash detection can be made by using BIM software, and thus design productivity can be increased (Eadie *et al.*, 2013).

(iii) "Project Performance Improvement" is the factor that drives companies to better construction management. Since the construction industry is one of the least innovative sectors in the world because of its traditional work processes, companies mostly try to boost their performances. BIM can provide this performance enhancement to the construction companies. BIM has positive effect on reduction in cost of project, better scheduling, and effective decision-making process (Ghaffarianhouseini *et al.*, 2017).

(iv) "Government Push" is another factor that can push the construction industry to utilize BIM. In the world, many countries have launched BIM mandate program to spread BIM usage (e.g., England, Singapore) (Eadie *et al.*, 2013; Liao and Teo, 2018).

(v) "To improve communication, collaboration and coordination" is the factor that instigates the construction industry to create a collaborative work environment. In this point, BIM can help organizations to work together, collaboratively (Coates *et al.*, 2010; Arayici *et al.*, 2011; Ozorhon and Karacigan, 2020).

(vi) "Corporate Organization Push" is a determinant that shows organizations' attitude towards BIM technology. In the construction industry, competition between firms is high. Therefore, most of them try to find a way to gain competitive advantage against their rivals, and BIM can make real this goal (Henderson *et al.*, 2012; Lee *et al.*, 2015; Yuan *et al.*, 2019).

(vii) "To Gain Competitive Advantage" is the factor that refers to protect social image. Within the construction industry, prestige can be significant for some companies. Therefore, they try to maintain their good images or gain prestige. From this perspective, since BIM is a prestigious development, these companies use BIM to carry on their images (Singh and Holmstrom, 2015; Rogers *et al.*, 2015; Cao *et al.*, 2016).

(viii) "To Gain Prestige" is the factor that refers to protect social image. Within construction industry, prestige can be significant for some companies. Therefore, they try to maintain their good images and gain prestige. From this perspective, since BIM is a prestigious development, these companies use BIM to carry on their images (Venkatesh and Davies, 2000; Aranda-Mena, 2007; Cao *et al.*, 2017; Ozorhon and Karacigan, 2020).

<u>3.1.3.3. Inputs.</u> Inputs represent steps taken by organizations in the transition process. Inputs play an active role in pre-transition and transition periods. As a result of the literature review, 7 inputs were determined for the interviews.

(i) "BIM Education and Training for Employees" is the factor that prepares workers for the BIM system. Before implement BIM, it is needed to train and educate users about BIM (Abbasnejad *et al.*, 2016; Ozener *et al.*, 2020; Chiu and Lai, 2020).

(ii) 'Generating Plan, Strategy, and Policy for BIM Execution" is a critical determinant that guides companies for BIM implementation. Most BIM-implemented projects created a plan and determined a strategy before BIM execution. In this way, implementation process can be managed much more effective, and accurately

(Krygiel and Nies, 2008; Karahan, 2015; Koseoglu *et al.*, 2019).

(iii) "Investment in Hardware and Software" is the factor that is a requirement before BIM transition. To generate a model and integrate the information into the model, there is the need for software and hardware. Therefore, in the beginning, investment in software and hardware is crucial (Jin *et al.*, 2017; Ahuja *et al.*, 2018; Sacks *et al.*, 2018; Hamma-Adama and Kauider, 2019).

(iv) "Taking Consulting Support" is another determinant that represents taking advice from outside. Companies might not be sufficient infrastructure in terms of knowledge. Therefore, to eliminate the risks that can be occurred during implementation, these companies can take help from outside (Bryde *et al.*, 2013; Takim *et al.*, 2013; Rogers *et al.*, 2015).

(v) "Using 3D Library" refers to utilizing specific object models for the projects during BIM implementation (Arayici *et al.*, 2011; McGraw Hill Construction, 2014; Jin *et al.*, 2017).

(vi) "Business Process Reengineering" is the factor that illustrates to review and adjust current workflows comply with BIM (Cao *et al.*, 2015; Amuda-Yusuf, 2018; Liao and Teo, 2019).

(vii) "Hiring Experienced/Qualified Staff" is the factor that supports the organizations during the BIM transition process. Skillful experts guide the organizations with their knowledge and experience about BIM processes (Aranda-Mena, 2007; Ku and Taiebat, 2011; Karahan, 2015; Gokuc and Arditi, 2017).

3.1.3.4. Enablers. Enablers refers to the factors that make transition process easier. In the framework, enablers play an active role in pre-transition and transition periods. As a result of the literature review, 8 enablers have been specified for interviews.

(i) "Top Management Support" is the factor that facilitates the BIM transition process. Managers of the companies can provide opportunities to accelerate the BIM transition process (e.g., training, incentives, etc.) (Wu and Chen, 2014; Son *et al.*, 2015; Chen *et al.*, 2019; Yuan *et al.*, 2019; Chiu and Lai, 2020).

(ii) "Having Dynamic, Collaborative, Supportive Work Environment" is the factor that refers to having strong and innovative organization culture. These kinds of companies can easily integrate new systems into their organizations and perform them effectively (Peansupap and Walker, 2005; Arayici *et al.*, 2012; Ahankoob *et al.*, 2018; Koseoglu *et al.*, 2019).

(iii) "Availability of Experienced/Qualified Staff in Company" is the factor that demonstrates whether organization is ready for the transition, or not. It is obvious that the organizations that have know-how are much more powerful compared to those who have not (Tsai *et al.*, 2013; Abubakar *et al.*, 2014; Suprun and Stewart, 2015; Ozener *et al.*, 2020).

(iv) "Having Adequate Level Technological Infrastructure" is the factor that represents the availability of BIM-related tools (e.g., software, hardware, etc.). If an organization has strong technological infrastructure, transition to BIM for this organization much less painful (Coates *et al.*, 2010; Mom *et al.*, 2014; Ghaffarianhouseini *et al.*, 2017).

(v) "Positive Attitude of Workers Towards BIM" is the factor that shows the interest of employees in the BIM system. Workers who open to new ideas simplify the BIM transition process (London and Singh, 2013; Xu *et al.*, 2014; Kim *et al.*, 2015; Ahuja *et al.*, 2018).

(vi) "Having Collaborative Project Delivery System" refers to BIM-enabled integrated project delivery system (IPD). IPD is a new collaborative procurement process (Sacks *et al.*, 2018). When it uses with BIM, its effectiveness increases. Therefore, a firm that implements IPD to its projects adopts and performs BIM much easier than those which have not (Bryde *et al.*, 2013; Lee *et al.*, 2015; Luo *et al.*, 2018).

(vii) "Compatibility with Values, Beliefs, and Practices" is the factor that expedites the BIM transition process. Generally, when a new system emerges, companies want to compare it with their existing working system, practices, beliefs, etc. If they decide this new system is compatible with theirs, transition process will be painless (Venkatesh and Bala, 2008; Suebsin and Gendsri, 2009; Hameed *et al.*, 2012; Saka *et al.*, 2020).

(viii) "Advanced R&D Capability of Company" demonstrates better integration and development. Having R&D capability for a company enables to adopt and implement BIM (Mitropoulos and Tatum, 2000; Waarts *et al.*, 2002; Singh and

Holmstrom, 2015; Ozorhon and Karahan, 2016).

3.1.3.5. Obstacles. Obstacles can be described as the factors that make the transition process difficult. Obstacles play a critical role in pre-transition and transition periods. As a result of the literature review, 11 obstacles have been specified for interviews.

(i) "The Resistance of Employees Towards the Change" refers to the act of defiance against BIM. Most people do not want to change their working habits. Therefore, these people approach to new systems unfriendly in their work environment. This makes the transition process harder (Hamada *et al.*, 2016; Alreshidi *et al.*, 2017; Olawumi *et al.*, 2018; Likita and Jelodar, 2019; Jamal *et al.*, 2019).

(ii) "Lack of Management Support" is the factor that impedes the BIM transition process. The absence of support of top managers decreases the willingness of employees towards BIM. Without manager support (financial support, incentives, etc.), it is difficult to use BIM (Chan *et al.*, 2019; Ullah *et al.*, 2019; Chiu and Lai, 2020).

(iii) "Lack of Experienced/Qualified Workforce inside Company" is the factor that represents the lack of organization's readiness. The firms that have qualified employees about BIM do not make mistakes during transition compared to those which have not because they can use BIM tools effectively. It is clear to say that the lack of these kinds of people makes the transition process difficult (Li *et al.*, 2017; Hosseini *et al.*, 2018; Sacks *et al.*, 2018; Hamma-adama and Kouider, 2019).

(iv) "Lack of BIM Awareness Among Stakeholders" is a determinant that makes it difficult to create a collaborative environment and is important because the benefits of BIM may go unnoticed due to the low level of awareness (Olawumi *et al.*, 2018; Terreno *et al.*, 2018; Li *et al.*, 2019; Koseoglu *et al.*, 2019).

(v) "Required high Initial Cost for BIM Transition" is a deterrent factor to scare decision-makers about BIM transition. BIM can be costly investment when thinking of software, hardware, etc. Also, there is need extra budget to maintain BIM technology. Therefore, in the beginning, firms can hesitate to implement the BIM system (McGraw Hill Construction, 2012; Elmualim and Gilder, 2014;

Bosh-Sijtsema *et al.*, 2017; Luo *et al.*, 2018; Ozener *et al.*, 2020; Deng *et al.*, 2020).

(vi) "Collaboration and Coordination Problems Among Different Parties" depicts unwillingness to share information and work together among distinct project participants. In addition, it is true that large BIM models cannot be control easily. Therefore, transition to BIM are affected negatively (Sacks *et al.*, 2018; Chan *et al.*, 2019; Deng *et al.*, 2020).

(vii) "Lack of BIM Education and Training for The Transition of BIM" is the determinant that indicates the importance of BIM education and training for BIM transition. It is significant to utilize BIM effectively in order to reap the benefits of BIM. Moreover, when it is considered to use BIM tools, work processes etc., education and training are highly crucial. Therefore, the lack of BIM training and education is an inhibitor for the transition process (Troshani and Doolin, 2005; Girginkaya and Maqsood, 2019; Ullah *et al.*, 2019; Chiu and Lai, 2020).

(viii) "The uncertainty of BIM's ROI" represents the financial impact on the BIM transition process. Generally, companies make their investments considering their financial gains. If a company sees vagueness for ROI, it is highly possible that the BIM transition process will be finalized as a failure (Mitropoulos and Tatum, 2000; Elmualim and Gilder, 2014; Hamma-adama and Kouider, 2019; Ullah *et al.*, 2019).

(ix) "Lack of Government Support" is the determinant that refers to external pressure for BIM transition. Governments can make an impact on BIM transition by publishing mandate programs in case of organizations evaluate BIM as unnecessary innovation. However, most countries in the world suffer from this deficiency (Suprun and Stewart, 2015; Karahan, 2015; Koseoglu *et al.*, 2019).

(x) "Lack of Standards, Laws and Regulations for BIM" represents privacy, security risks, managing data, sharing information, etc. Most company, due to the lack of legal framework, do not want to integrate BIM into their organizations (Likita and Jelodar, 2019; Deng *et al.*, 2020; Bouguerra *et al.*, 2020).

(xi) "Lack of Interoperability Among Software Applications" is the factor that illustrates technological characteristic. In the BIM environment, there are various software applications, and it is tremendously crucial that these distinct software applications must work together. If it does not, it cannot reap the benefits of BIM (Hosseini *et al.*, 2018; Li *et al.*, 2019; Jamal *et al.*, 2019).

3.1.3.6. Benefits. Benefits can be specified as the gainings that are obtained from the transition to BIM in the short-term. Benefits play an active role in the post-transition period. As a result of the literature review, 7 benefits have been designated for interviews.

(i) "Better Decision-making Process" is the positive determinant that is obtained in the result of BIM usage. Due to the fragmentation of the AEC industry, it can be said that it is not straightforward to make a decision. However, since BIM combines different project teams, it is possible to perform better decision-making process (Wu and Chen, 2014; Luo *et al.*, 2018; Ahn *et al.*, 2016; Acquah *et al.*, 2018; Chiu and Lai, 2020).

(ii) "Increasing in Collaboration and Coordination Among Project Parties" shows the impact of BIM on communication behavior of organization. There are a lot of AEC companies in the world that suffer from communication disputes between project teams. In this point, BIM can improve collaboration and coordination among project parties (Krygiel and Nies, 2008; Gu and London, 2010; Rogers *et al.*, 2015; Ozorhon and Oral, 2016; Liao and Teo, 2019).

(iii) "Effective Document Management" refers to one of the relative advantages of BIM compared to previous document management system. The construction projects are mostly complex and have various drafts, reports, etc. It is important to manage these documents productively because traditional document management is generally time-consuming and error-prone (Aranda-Mena and Wakefield, 2006; Yitmen, 2007; Coates *et al.*, 2010; Arayici *et al.*, 2011; InfoComm International, 2013; Sawhney and Singhal, 2014; Ozener *et al.*, 2020).

(iv) "Better Technical Office Works" demonstrates better monitoring and controlling process of project planning and cost issues. For example, BIM can also make impact on claims reduction caused by delays, discrepancy in quantities, etc. (Bryde *et al.*, 2013; Ghaffarianhouseini *et al.*, 2017; Acquah *et al.*, 2018; Sacks *et al.*, 2018; Koseoglu *et al.*, 2019; Ozorhon and Karacigan, 2020).

(v) "Client Satisfaction improvement" refers meeting client's needs. In every project, there are requirements that are demanded by the clients. When these necessities are accomplished, client satisfaction increases. However, this is not possible everytime with traditional construction methods. Therefore, BIM can make a difference which is about increasing of client satisfaction (Elmualim and Gilder, 2014; Nanajkar, 2014; Ozorhon and Oral, 2016; Ahn *et al.*, 2016; Chiu and Lai, 2020).

(vi) "Financial Performance improvement" is the key factor that represents reduction in lifecycle cost of the projects. BIM can increase financial performances by estimating accurately cost and time of the project (Aranda-Mena *et al.*, 2007; Tsai *et al.*, 2010; Eadie *et al.*, 2013; Oliveira *et al.*, 2014; Cao *et al.*, 2015; Saka *et al.*, 2020).

3.1.3.7. Impacts. Impacts illustrate the long-term achievements after firms start to use BIM in their daily works and projects, permanently. Therefore, impacts are directly related to post-transition period. As a result of the literature review, 5 impacts have been designated for interviews.

(i) "Formation of Company Knowledge" is the determinant that signifies generating archive about BIM within organization and gaining experience day by day about BIM (Coates *et al.*, 2010; Arayici *et al.*, 2012; Cao *et al.*, 2016; Sacks *et al.*, 2018).

(ii) "Improvement in Corporate Image of the Company" refers to gain a reputation in the market. BIM is not widely used by AEC industry. Therefore, firms that utilize BIM successfully can obtain competitive advantage and new business opportunities (Arayici *et al.*, 2011; Karahan, 2015; Ahn *et al.*, 2016; Ahankoob *et al.*, 2018).

(iii) "Increase in Company's Productivity" signifies the long-term gain for the firms. BIM have a great impact on companies' work processes, practices, etc. However, this effect cannot be evaluated accurately in the short-term. Thanks to BIM, organizations gain effective communication skills in the long-term and manages productively work processes in projects (Coates *et al.*, 2010; Arayici *et al.*, 2012; McGraw Hill Construction, 2012; Luo *et al.*, 2018).

(iv) "Increasing in ROI" illustrates enhancing financial performance by using BIM. In the beginning, BIM requires high investment in tools, workers, etc. However, when it is deemed the long-term usage of BIM, ROI will increase (Ghaffarianhouseini *et al.*, 2017; Amuda-Yusuf, 2018; Sacks *et al.*, 2018).

(v) "Expanding Company's Scope" refers that BIM helps organizations to solve the design problems of their complex projects and make them economically viable (Mitropoulos and Tatum, 2000; Cao *et al.*, 2014; Nanajkar, 2014; Sacks *et al.*, 2018).

<u>3.1.3.8. BIM Transition Phases.</u> During the literature review, various papers were examined and proper frameworks / models / theories and influential factors for the BIM transition process were determined. Then, based on the investigated frameworks/models/theories, transition phases were generated. In Figure 3.2, the elements of the BIM transition process are depicted. In accordance with the figure, the BIM transition framework has 6 stages, including awareness, intention, adoption decision, implementation, confirmation, and BIM diffusion. In the following section, these phases will be explained.

<u>3.1.3.9. Awareness Phase.</u> When an innovation emerged, organizations or individuals try to collect information about it in order to understand whether it is beneficial or not. Firms in the AEC industry can follow the same way, too. They can gain knowledge about BIM and its function through social events (e.g., seminars, conferences), academic publishes (e.g., books, papers), etc. In addition, when an organization participates a project, the client of the project can request from the organization to use BIM, or organizations have managers who give importance to innovative technologies. These people can raise awareness within the company. Otherwise, acquired information about BIM can be superficial.

3.1.3.10. Intention Phase. Companies that obtained knowledge about BIM evaluate the BIM system and start to develop a favorable or unfavorable attitude towards BIM. BIM plays a significant role in improving the design, project performance, and collaboration. Since most firms suffer from design problems, low project performance, and deficiency of collaboration, it is highly possible that a positive attitude towards BIM can be developed. On the other hand, BIM requires high initial investments, thus companies can hesitate to adopt BIM into their organizations and to implement BIM in their projects.

3.1.3.11. Adoption Decision Phase. If a company forms a favorable attitude towards BIM or has an intention to adopt it, it needs to make the decision of BIM usage. According to Rankin and Luther (2006), the decision process consists of three phases, including evaluation, trial, and adoption. It is true that during making decisions, organizations may want to try BIM in a pilot project before adopting it. Then, they can observe and assess the outcomes. As the result of the assessment, an organization can make its call. In this process, if the companies observe the relative advantage of BIM at the end of the trial session, they can accept to adopt BIM into their organizations. Organizations might accept BIM usage to gain a competitive advantage against their rivals, or they may discover that BIM is compatible with their values, beliefs, and practices. On the other hand, a rejection decision is also possible. They might do not want to use BIM due to the ambiguity of data ownership, privacy, insurance, etc. Moreover, employees might resist the change to protect their safe zones. To sum up, if the decision is acceptance, the implementation stage will begin, but if the decision is rejection, the process will not continue (see Figure 3.2).

3.1.3.12. Implementation Phase. After adoption decision, BIM implementation process begins. According to Rankin and Luther (2006), implementation process composes of some stages. These stages are:

- Learning BIM characteristics,
- Developing an execution plan for the implementation,

- Rebuilding jobs, processes, tasks, etc.

While taking these actions, organizations can invest in software, hardware, the internet, etc. to strengthen the technological infrastructure. Also, some firms can employ industry professionals who have experience in BIM. Moreover, companies can provide BIM education and training for employees. After this preparation and deployment process, organizations start to use BIM in their projects. However, some obstacles can impede the implementation of BIM, or slow down the process. For instance, in a construction project, there are several project participants. In order for BIM to be effective, these teams must communicate with each other, productively. In the case of the lack of collaboration and coordination, the implementation process can result negatively.

3.1.3.13. Confirmation Phase. At the end of the implementation stage, organizations can evaluate the implementation overcomes. This assessment session can be named as confirmation. In this phase, organizations evaluate whether their established goals are achieved or not. If their expectations are satisfied, it is probable that companies will confirm BIM. For example, if they observe effective document management, increasing client satisfaction, better decision-making process, etc. they will probably carry on BIM. Otherwise, organizations will not. When organizations disapprove BIM, the process will not continue. The reason for discontinuance can be collaboration difficulties. Moreover, BIM usage may be assessed as difficult or complex by organizations, or they may evaluate that it is difficult to measure BIM's impacts and benefits.

3.1.3.14. BIM Diffusion Phase. Diffusion of BIM refers to the actual use of BIM. In this phase, organizations start to utilize the BIM system in their projects, permanently, and individuals who are the members of organizations that are invested in BIM also commence to operate BIM tools in their daily tasks, effectively.

3.1.4. Interaction Zones of BIM Transition Framework

BIM transition framework consists of two interaction zones. These zones represent the relationships between components and characteristics, and between components and BIM transition phases. In the following, these zones will explain.

3.1.4.1. Interaction Zone 1. This zone refers to connection between components and characteristics. Characteristics and components have been clarified in the previous section. In this part, the relationship between characteristics and components will be described.

3.1.4.2. Motivations and Characteristics. To begin with Table 3.1, the characteristics of motivational factors and type of related characteristics have been represented. According to this table, "client requirement", "Government push", and "corporate organizations push" are categorized as coercive pressures in the environmental context (Cao *et al.*, 2014; Ahuja *et al.*, 2016; Ahmed and Kassem, 2018).

Secondly, it can be seen from the Table 3.1, "Design productivity improvement", "Project Performance improvement", and "to improve communication, coordination and collaboration" are labelled as the relative advantages in the innovation/technology context (Lee *et al.*, 2015; Kim *et al.*, 2015; Ahmed and Kassem, 2018).

Lastly, in the Table 3.1, "to gain competitive advantage", and "to gain prestige" are assigned as willingness in the internal/organizational context. It is a choice to remain competitive and want to have prestige (Moore and Benbasat, 1991; Waarts, 2002; Wang *et al.*, 2011; Ahmed and Kassem, 2018).

Table 3.1. Interaction between Motivations and Characteristics at the Zone 1.

#	Motivation	Characteristics	Type of Charac.
1	Client Requirement	Coercive Pressure	E/E
2	Design productivity improvement	Relative Advantage	I/T
3	Project Performance improvement	Relative Advantage	I/T
4	Government push	Coercive Pressure	E/E
5	To improve communication, coordination, and collaboration	Relative Advantage	I/T
6	Corporate organizations push	Coercive Pressure	E/E
7	To gain competitive advantage	Willingness	I/O
8	To gain prestige	Willingness	I/O
E/E: External/Environmental; I/T: Innovation/Technological; I/O: Internal/Organizational			

3.1.4.3. Inputs and Characteristics. Table 3.2 depicts the relationship between inputs and characteristics. As it can be seen from the following table, "BIM education and training for employees", "generating strategy, plan, and policy for BIM execution", "Investment in software and hardware", "business process reengineering", and "hiring experienced/qualified staff" are labelled as organizational readiness in the internal/organizational context since these factor represents how ready the company is for the transition to BIM. "Taking outsourcing support" is evaluated as normative pressures in the external context. The reason is that normative pressures refer to professional consultation (Ahmed and Kassem, 2018). "Using 3D library" is related to the technology of BIM. Therefore, it is categorized as technological factor in the innovation/technological context.

Table 3.2. Interaction between Inputs and Characteristics at the Zone 1.

#	Inputs	Characteristics	Type
1	BIM education and training for employees	Organization Readiness	I/O
2	Generating strategy, plan, and policy for BIM execution	Organization. Readiness	I/O
3	Investment in software and hardware	Organization. Readiness	I/O
4	Taking outsourcing support	Normative Pressure	E/E
5	Using 3D library	Technological Factor	I/T
6	Business process reengineering	Organization. Readiness	I/O
7	Hiring experienced/qualified staff	Organization Readiness	I/O
E/E: External/Environmental; I/T: Innovation/Technological; I/O: Internal/Organizational			

3.1.4.4. Enablers and Characteristics. The relation between enablers and characteristics have been depicted in the Table 3.3. According to following table, "top management support" is classified as leadership characteristics in the internal/organizational context since it requires strong leadership skills. "Having dynamic, collaborative, supportive work environment" is related to the organization's culture. This kind of organizations discuss openly new ideas, and this needs strong culture. "Availability of experienced/qualified staff in company" and "Having adequate level technological infrastructure" are labelled as organizational readiness. Before executing BIM, companies need to make preparation i.e. hiring experienced people if they have not. However, they already have experienced employees. Therefore, it can be said that these factors refer to the organizational readiness. "Positive attitude of workers towards BIM" is a critical factor that refers to intention of employees about BIM usage. Therefore, it is categorized as willingness characteristic in the organizational context. "Having collaborative project delivery system" is related to the communication between stakeholders. For this reason, it is labelled as communication behavior characteristics. "Compatibility with values, beliefs, and practices" is classified as compatibility characteristic in the innovation context. "Advanced R&D capability of company" is an important factor to carry on the development of BIM within the organization. So, it can be evaluated as organizational readiness characteristic.

<u>3.1.4.5. Obstacles and Characteristics.</u> The relationship between obstacles and characteristics have been shown in the Table 3.4. According to this table, "Lack of experienced/qualified workforce inside company" and "Lack of BIM education and training for the transition of BIM" are labelled as organizational readiness. "Lack of government support" and "Lack of standards, laws, and regulations for BIM" are related to coercive pressures directly. "Lack of BIM awareness among stakeholders" is categorized as normative pressure (Ahmed and Kassem, 2018). "Lack of management support" is evaluated as leadership characteristics. "The resistance of employees towards the change" is classified as willingness characteristics. "Required high initial cost for BIM transition" and "the uncertainty of BIM's ROI" are assessed as economic factor characteristics in the organizational context. "Collaboration and coordination problems among different parties" is categorized as communication behavior. "Lack of interoperability among software applications" is labelled as technological factor in the innovation/technology context.

Table 3.3. Interaction between Enablers and Characteristics at the Zone 1.

#	Enablers	Characteristics	Type
1	Top management support	Leadership	Internal/organiza.
2	Having dynamic, collaborative, supportive work environment	Organization Culture	I/O
3	Availability of experienced/qualified staff in company	Organization Readiness	I/O
4	Having adequate level technological infrastructure	Organization Readiness	I/O
5	Positive attitude of workers towards BIM	Willingness	I/O
6	Having collaborative project delivery system	Communication Behavior	I/O
7	Compatibility with values, beliefs, and practices	Compatibility	I/T
8	Advanced R&D capability of company	Organizational Readiness	I/O
I/T: Innovation/Technological; I/O: Internal/Organizational			

Table 3.4. Interaction between Obstacles and Characteristics at the Zone 1.

#	Obstacles	Characteristics	Type
1	Lack of management support	Leadership	Internal/organiza.
2	Lack of experienced/qualified workforce inside company	Organizational Readiness	I/O
3	The resistance of employees	Willingness	I/O
4	Lack of BIM awareness towards the change	Normative Pressure	E/E
5	Required high initial cost for BIM transition	Economic Factor	I/O
6	Collaboration and coordination problems among different parties	Communication Behavior	I/O
7	Lack of BIM education and training training for the transition of BIM	Organizational Readiness	I/O
8	The uncertainty of BIM's ROI	Economic Factor	I/O
9	Lack of government support	Coercive Pressure	E/E
10	Lack of standards, laws, and regulations for BIM	Coercive Pressure	E/E
11	Lack of interoperability among software applications	Technological Factor	I/O
E/E: External/Environmental; I/T: Innovation/Technological; I/O: Internal/Organizational			

3.1.4.6. Benefits and Characteristics. Table 3.5 shows the relativity between short-term gains after BIM transition and characteristics. First of all, since these worthwhile factors are observed at the end of the implementation stage, they are all classified as perceived usefulness characteristics in the innovation/technology context.

Table 3.5. Interaction between Benefits and Characteristics at the Zone 1.

#	Benefits	Characteristics	Type
1	Better decision-making process	Perceived Usefulness	I/T
2	Increase collaboration and coordination among project parties	Perceived Usefulness	I/T
3	Effective document management	Perceived Usefulness	I/T
4	Project risk management improvement	Perceived Usefulness	I/T
5	Better technical office works	Perceived Usefulness	I/T
6	Increase client satisfaction	Perceived Usefulness	I/T
7	Increase financial performance	Perceived Usefulness	I/T
I/T: Innovation/Technological			

3.1.4.7. Impacts and Characteristics. Table 3.6 represents the relationship between long-term benefits and characteristics. According to the following table, the achievements that were obtained in the long-term after transition to BIM are classified as perceived usefulness characteristics in the innovation/technology context since perceived usefulness is more convenient to post-adoption period (Hameed *et al.*, 2012).

Table 3.6. Interaction between Impacts and Characteristics at the Zone 1.

#	Impacts	Characteristics	Type
1	Formation of company knowledge	Perceived Usefulness	I/T
2	Improvement in corporate image of the company	Perceived Usefulness	I/T
3	Increase in Company's productivity	Perceived Usefulness	I/T
4	Increase in ROI	Perceived Usefulness	I/T
5	Expanding Company's scope	Perceived Usefulness	I/T
I/T: Innovation/Technological			

3.1.4.8. Interaction Zone 2. Interaction zone 2 refers to the connection between periods and stages of the BIM transition process, and components. Transition periods and stages have been specified in the previous sections. In this part, this connection will be explained in the following.

3.1.4.9. The Relationship Between Motivations and BIM Transition Periods and Stages. Motivations influence the pre-transition period. This is because it is necessary to have motivation beforehand to shift to something, or to implement something, and the factors in the Table 3.7 below show these motivations. In addition, the pre-transition period consists of 2 stages, namely awareness, and intention. Table 3.7 also shows which motivations affect which stages during the transition to BIM.

To begin with, it can be said that "client requirement", "government push", and "corporate organizations push" affect both awareness and intention stages because if there is no awareness of BIM in the company, awareness may occur when the employer requests the use of BIM. If the company is aware of the existence of the BIM system but is not willing to use it due to some reasons (e.g., economic), the firm can switch to BIM at the request of the employer. Likewise, trading partners can make such an impact. When it is looked at from the perspective of the government, governments can establish committees and organize events to raise BIM awareness across the country. It can prepare a specific plan and program for transition to BIM (e.g., BIM mandate program) and force companies to transition to BIM.

Moreover, it can be seen from the Table 3.7 that “design productivity improvement”, “project Performance improvement”, “to improve communication, coordination and collaboration”, “to gain competitive advantage”, and “to gain prestige” affect the intention phase. The reason for this, for example, projects that are designed in 2D may cause problems in many ways in the construction phase (e.g., clashes). However, if the 3D BIM model of the project is created, possible problems can be avoided during the implementation phase. Considering that many companies suffer from this condition, they can develop a positive attitude towards BIM for design efficiency. In addition to this example, construction projects generally perform poorly. However, BIM can have a positive impact on performance in many ways, such as effective document management, and the ability to perform quantity take-off with a low error rate. So, this can lead companies to develop a positive attitude towards BIM. Furthermore, sometimes companies can switch to the BIM system to compete with their competitors or simply to gain prestige.

Table 3.7. . The Relationship Between Motivations and BIM Transition Periods and Stages in the Zone 2

#	Motivations	Period	Phase
1	Client Requirement	Pre-transition	AW - IN
2	Design productivity improvement	Pre-transition	IN
3	Project Performance improvement	Pre-transition	IN
4	Government push	Pre-transition	AW - IN
5	To improve communication, coordination & collaboration	Pre-transition	IN
6	Corporate organizations push	Pre-transition	AW - IN
7	To gain competitive advantage	Pre-transition	IN
8	To gain prestige	Pre-transition	IN
AW: Awareness; IN: Intention			

3.1.4.10. The Relationship Between Inputs and BIM Transition Periods and Stages. Inputs affect both transition and post-transition periods. The Table 3.8 shows the relationship between inputs, and BIM transition periods and stages. According to the following table, inputs affect both implementation and BIM diffusion phases.

To begin with, "BIM education and training for employees", "generating strategy, plan, and policy for BIM execution", "investment in software and hardware", and "using 3D library" have an influence in both implementation and BIM diffusion stages. The reason for this, before executing BIM to projects, a preliminary preparation is required. Performing BIM training, creating strategies and plans, investing in technological tools, and using 3D libraries can be evaluated within the scope of preliminary preparation. However, these preparations might not be enough because, after the transition to BIM, these actions should continue for certain periods in order to keep the users up to date with the developments.

In addition, "taking outsourcing support", "business process reengineering", and "hiring experienced/qualified staff" make impact on the implementation stage. To start with, some companies can get external consulting support before implementing BIM to make the implementation process more efficient, or instead of getting external support, they can hire people who have experience in BIM and benefit from the knowledge of these hired people.

Lastly, it is necessary to adjust work processes according to the BIM system to use it effectively. Therefore, in the transition period, in order to execute BIM, companies need to change their business processes.

Table 3.8. The Relationship Between Inputs and BIM Transition Periods and Stages in the Zone 2.

#	Inputs	Period	Phase
1	BIM education and training for employees	Transition and Post-transition	IM - DIF
2	Generating strategy, plan, and policy for BIM execution	Transition and Post-transition	IM - DIF
3	Investment in software and hardware	Transition and Post-transition	IM - DIF
4	Taking outsourcing support	Transition	IM
5	Using 3D library	Transition and Post-transition	IM - DIF
6	Business process reengineering	Transition	IM
7	Hiring experienced/qualified staff	Transition	IM
IM: Implementation; DIF: Diffusion			

3.1.4.11. The Relationship Between Enablers and BIM Transition Periods and Stages.

As can be seen from the table 3.9, enablers affect all phases of the BIM transition process. In addition, most of the facilitating factors also influence more than one stage.

To begin with, “top management support” is an extremely significant factor for transition to BIM, and it influences all BIM transition periods. For instance, if a company has visionary managers who follow technology and innovations, when a new system emerges, these managers can increase the company’s awareness of this system and make the company develop a positive attitude. They can then take the lead to integrate this system into the company. In addition, with the integration of the system into the company, they can support the implementation of this system in the company’s projects, and after the implementation, the results can be analyzed and they can confirm BIM to use in other projects and daily works permanently. Finally, over the years, they can take the lead to the renewal and development of the system within the company.

When it is looked at the Table 3.9, it can be said that both “having dynamic, collaborative, supportive work environment”, and “availability of experienced/qualified staff in company” affect implementation and BIM diffusion stages. The reason for this, for example, collaborative work environment and the presence of experienced people in BIM can make easier and effective the implementation of BIM to the projects. Moreover, these factors might help the company to advance the BIM system in the future.

Moreover, “having adequate level technological infrastructure” impacts intention, adoption decision, and implementation stages (Table 3.9). To exemplify, if a company has sufficient technological infrastructure for the BIM system, it may take a positive attitude towards BIM as it will not invest extra in technological infrastructure for BIM. Starting from this point, after adapting the BIM system to the company, it can implement BIM in its projects with this adequate technological infrastructure. Likewise, “the positive attitude of workers towards BIM” affects intention, adoption decision and implementation phases. However, this factor can also influence in confirmation stage because when employees observed the benefits of BIM at the end of the implementation process, they can help to implement BIM in future projects by approving the results.

Furthermore, both "having collaborative project delivery system", and "compatibility with values, beliefs, and practices" affect intention, adoption decision, and confirmation stages. BIM promotes different project teams to work with each other collaboratively. Therefore, if a firm has collaborative project delivery system, it might develop positive attitude towards BIM, and then it can make the adoption decision. After implementing BIM, in the confirmation stage, the firm can realize the advantages of having a collaborative work process thanks to BIM, and then, the firm can approve the BIM system to use it in its other projects. Compatibility is similar to a collaborative project delivery system. If a company observe that BIM is compatible with its existing practices, beliefs, and values, it is probably that company will use the BIM in its future projects.

Lastly, "Advanced R&D capability of company" influences BIM diffusion stage in the post-transition part (Table 3.9). If a company has an advanced R&D capability, it can make researches how to implement BIM more efficiently in projects and develop new methods for this.

Table 3.9. The Relationship Between Enablers and BIM Transition Periods and Stages in the Zone 2.

#	Enablers	Period	Phase
1	Top management support	Pre-transition, Transition and Post-transition	AW - IN - DE - IM - CO - DIF
2	Having dynamic, collaborative, supportive work environment	Transition and Post-transition	IM - DIF
3	Availability of experienced/qualified staff in company	Transition and Post-transition	IM - DIF
4	Having adequate level technological infrastructure	Pre-transition and Transition	IN - DE - IM
5	Positive attitude of workers towards BIM	Pre-transition and Transition	IN - DE - IM - CO
6	Having collaborative project delivery system	Pre-transition and Transition	IN - DE - CO
7	Compatibility with values, beliefs, and practices	Pre-transition and Transition	IN - DE - CO
8	Advanced R&D capability of company	Post-transition	DIF
AW: Awareness; IN: Intention; DE: Decision; IM: Implementation; CO: Confirmation; DIF: Diffusion			

3.1.4.12. The Relationship Between Obstacles and BIM Transition Periods and Stages. It can be seen from Figure 3.7, obstacles influence all three periods of the BIM transition process. In addition, most preventive factors also affect more than one stage (Table 3.9).

To begin with, it was mentioned in the previous section that top management support made the transition process much easier. Conversely, if there is no support from top management for the use of BIM within the company, the process can get stuck, and the company might postpone the transition to BIM. In addition, if there are no people experienced in BIM within the company, there may be problems while implementing BIM to the projects, or afterward the development of BIM within the company can be hampered. Moreover, the resistance of employees is one of the most important barriers in the BIM transition process. This resistance affects the pre-transition and transition periods of the BIM transition process. For example, since BIM brings a new arrangement to the way employees do business, after implementing BIM, they may resist executing BIM in other projects at the confirmation stage.

In addition, “lack of BIM awareness among stakeholders” is another impediment for transition to BIM. Although awareness of BIM increases recently, especially in developing countries, the rate of awareness of BIM is still low. It can be concluded that it is very difficult to develop a positive attitude towards BIM without sufficient level awareness. Also, financial issues can have a negative impact on the BIM transition. To exemplify, if a company’s technological infrastructure, workforce, and education level are insufficient to implement BIM, the company may need to invest heavily in these specified areas. After a firm collected information about BIM, it might think that BIM is costly investment. This perception may also affect firm’s adoption decision for BIM. Furthermore, the firm may not realize how costly BIM is until the implementation phase. When applying BIM to its project or preparing ahead of time, the firm may experience that BIM is very costly and then may not want to implement BIM in other projects. Similarly, the high initial cost of BIM and the ambiguity of BIM’s return on investment can also delay companies’ BIM transition plans.

Moreover, "lack of interoperability among software applications" affects both pre-transition and transition periods. Although interoperability problems among different software decrease after exchange data standards emerged (e.g., IFC), they remain since distinct companies use different software, and this situation may influence negatively from intention to confirmation phases. In addition, the absence of adequate standards and regulations for BIM can impede the implementation phase because there is the need for standards and regulations for executing BIM. What is more, collaboration difficulties can be observed during the implementation phase, and therefore, companies' decision-makers might not approve to utilize the BIM system for future projects.

Table 3.10. The Relationship Between Obstacles and BIM Transition Periods and Stages in the Zone 2.

#	Obstacles	Period	Phase
1	Lack of management support	Pre-transition, Transition & Post-transition	AW - IN - DE - IM - CO - DIF
2	Lack of experienced/qualified workforce inside company	Transition & Post-transition	IM - DIF
3	The resistance of employees owards the change	Transition & Post-transition	IN - DE - IM - CO
4	Lack of BIM awareness among stakeholders	Pre-transition	AW - IN
5	Required high initial cost for BIM transition	Pre-transition & Transition	IN - DE - CO
6	Collaboration and coordination & coordination problems among different parties	Transition	IM - CO
7	Lack of BIM education & training for the transition of BIM	Transition & Post-transition	IM - DIF
8	The uncertainty of BIM's ROI	Pre-transition & Transition	IN - DE - CO
9	Lack of government support	Pre-transition	AW - IN
10	Lack of standards, laws, and regulations for BIM	Transition	IM
11	Lack of interoperability among software applications	Pre-transition & Transition	IN - DE - IM - CO

3.1.4.13. The Relationship Between Benefits and BIM Transition Periods and Stages. The connection between beneficial factors, and BIM transition periods and stages has been represented in the Table 3.11. According to Table 3.11, all beneficial factors affect the post-transition period, and both confirmation and BIM diffusion phases. The reason for this is that benefits refer to short-term gains at the end of the implementation phase. Therefore, these factors are evaluated in the confirmation stage to use BIM in future projects, and employees might start to use BIM in their daily tasks and work processes in the BIM diffusion stage.

To begin with, once companies carry out BIM to their projects, they can reap many benefits. For example, the decision-making process may be better with BIM. To be more precise, companies can make clash detection analysis and generate what if scenarios to detect the design problems and assess design alternatives. In addition, performing clash detections and determining design alternatives might prevent project risks. Moreover, in a construction project, it is crucial to keep track of progress of projects from the perspectives of technical office. Thanks to BIM, technical office engineers can effectively monitor construction progress. For instance, if time overrun risk emerges, engineers can realize the risky situation early, and they can take precautions against poor scheduling.

In traditional construction work process, document coordination is mostly unproductive process. However, companies can perform high accuracy of model-based documentation through BIM, and project drawings can be produced rapidly through BIM model. Moreover, if you implement BIM in the project, you are unlikely to deceive the employer because you can present everything related to the project to the employer in a transparent way. This makes the employer feel safe. Furthermore, BIM can also increase collaboration and coordination between distinct project participants, which this generally do not observe in a construction projects managed with conventional way. Last but not least, it can be said that BIM can increase financial performances of the construction projects such as performing effective cost estimating, monitoring procurement processes, and reducing errors. These all affect the project costs positively.

Table 3.11. The Relationship Between Benefits and BIM Transition Periods and Stages in the Zone 2

#	Benefits	Period	Phase
1	Better decision-making process	Post-transition	CO - DIF
2	Increasing collaboration and coordination among project parties	Post-transition	CO - DIF
3	Effective document management	Post-transition	CO - DIF
4	Project risk management improvement	Post-transition	CO - DIF
5	Better technical office works	Post-transition	CO - DIF
6	Client satisfaction improvement	Post-transition	CO - DIF
7	Financial performance improvement	Post-transition	CO - DIF
CO: Confirmation; DIF: Diffusion			

3.1.4.14. The Relationship Between Impacts and BIM Transition Periods and Stages. Table 3.12 shows the relationships between long-term gains and BIM transition periods and phases. It can be seen from the following table, all impacts influence the BIM diffusion stage in the post-transition period of the BIM transition process. The reason for this is that these achievements can only be attained after BIM has been applied for a certain period of time.

First of all, as companies carry out BIM to their projects, they will have built up a certain amount of knowledge. This accumulation of knowledge will enable companies to use BIM more efficiently over time. In addition, the companies that are used the BIM system effectively in their projects can gain prestige in the market, and they can improve their corporate image. Moreover, constantly BIM usage has a tremendous impact on efficiency of companies' projects and work processes. So, in the end, it leads to increase in companies' productivity. Besides, as mentioned before, BIM needs a certain amount of investments. However, the return of BIM investment to the company is not something that will happen immediately. In the long run, the company's return on investment will increase. Lastly, BIM can bring various innovations to the companies. Then, companies may use this innovation to broaden their scope. For example, an architecture firm can perform energy analysis of the buildings through BIM model.

Table 3.12. The Relationship Between Benefits and BIM Transition Periods and Stages in the Zone 2

#	Impacts	Period	Phase
1	Formation of company knowledge	Post-transition	DIF
2	Improvement in corporate image of company	Post-transition	DIF
3	Company's productivity improvement	Post-transition	DIF
4	Increase in ROI	Post-transition	DIF
5	Expanding Company's scope	Post-transition	DIF

3.2. Interviews

After the framework and factors have been determined, interviews were conducted with 14 industry experts through online platforms (e.g., zoom, skype, etc.) to specify the factors that affect the BIM transition process based on their experiences. For this aim, a questionnaire form has been generated (Appendix A).

3.2.1. Questionnaire Form

In the first section of the form, there are questions to collect information about interviewees. (e.g., participant's experience in BIM, profession). In the second section of the form, there are questions which are related to participant's firm (e.g., company's field of operation, number of years that company used BIM). Next section, there are questions about the projects that are implemented BIM (e.g., which type of software utilized, BIM usage areas in the projects, etc.). In the fourth section, there are most common factors that are grouped according to component type and assessed by using the Likert scale technique.

3.2.2. Likert Scale

During the online interviews, participants are asked to evaluate the significance level of specified factors on a 1-5 Likert scale (1 corresponds to insignificant and 5 corresponds to very significant). Likert scale is one of the most prevailing utilized rating scales in the literature to measure attendees' attitudes. One of the advantages of it is that there is no yes or no answer. Therefore, the results can be analyzed easily. During the interview, it was asked to participants to evaluate the factors according to their component types, and respondents graded these factors based on their experiences.

Table 3.13. Meaning of Ratings in Likert Scale.

1	2	3	4	5
Insignificant	Less Significant	Moderate	Significant	Very significant

3.2.3. Interviewees' Profile

While choosing interviewees, some criteria were determined. Firstly, participants must have BIM experiences, and they must have experience in the BIM transition process in their firms. This is important because this study aims to understand how companies in the AEC industry start to use BIM and which factors have been effective during this transition process. Secondly, The Field of Operations of Firms and their BIM experience also are critical because in this thesis comparisons of transition process and effective factors will be made according to their operational fields and BIM experience level. Thirdly, although it is not as significant as other criteria, the occupation of interviewees has been also considered. To begin with, it can be seen from Figure 3.6. that participants' BIM experience level were categorized as less than 5 years, between 5 and 10 years, and more than 10 years. According to related figure, 4 participants have less than 5 years' experience in BIM, 5 participants have experience between 5 and 10 years in BIM, and 5 participants have more than ten years' experience in BIM.

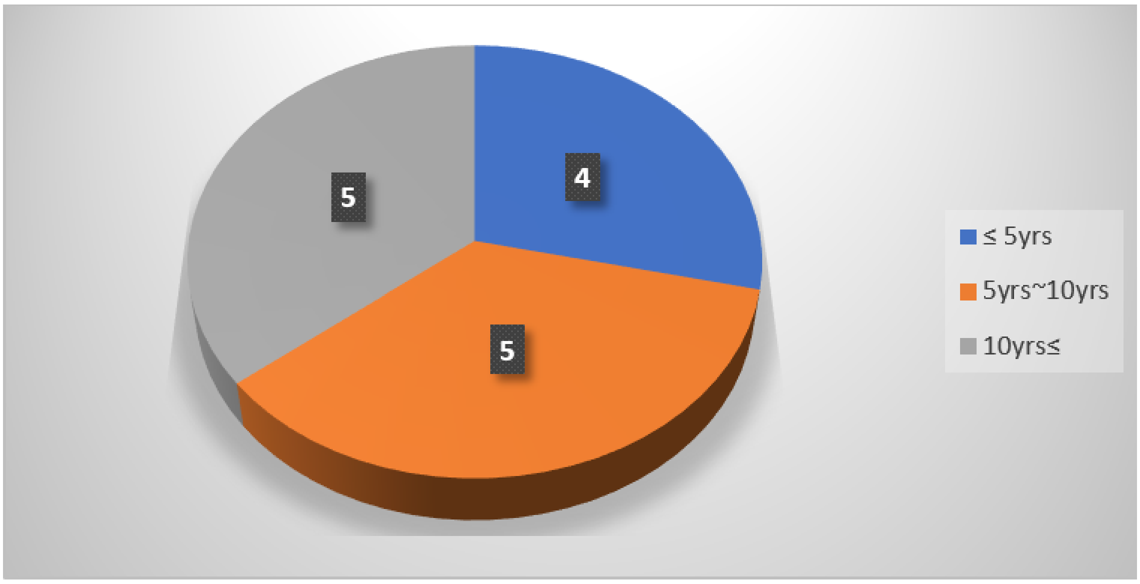

Figure 3.3. BIM Experience of the Participants.

In addition, it can be seen from Figure 3.7, half of respondents' occupation is architecture. There are 5 civil engineers and 2 mechanical engineers among participants.

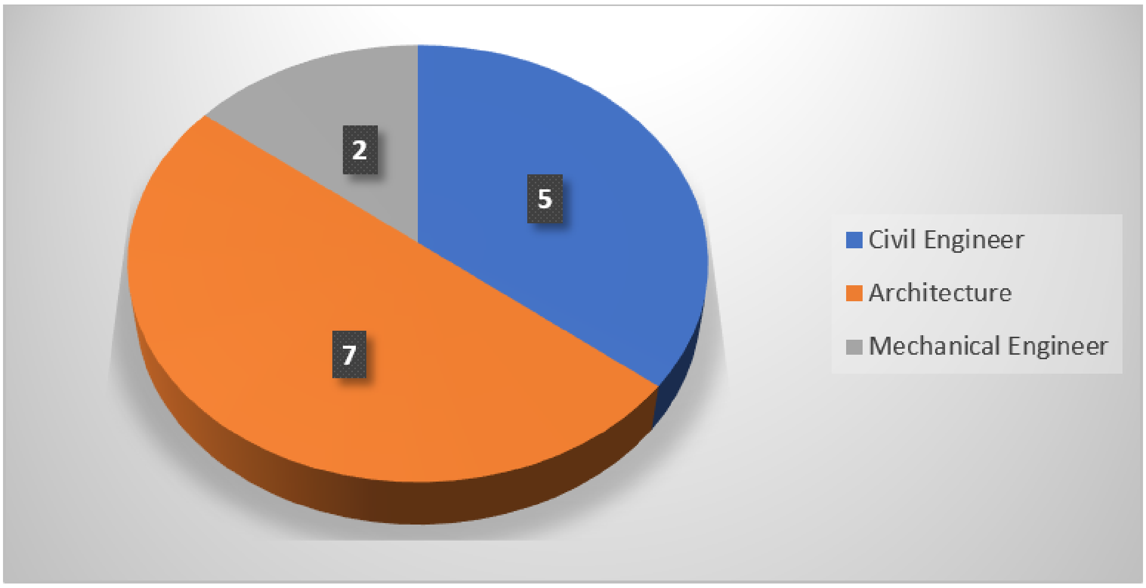

Figure 3.4. The Occupation of Participants.

3.2.4. Companies' Profile

When it is looked firms' profile from Figure 3.5, there are equally distributed the field of operations of firms. It is noted that although there are 14 firms in the interview, in total, there are 18. The reason is that some firms have operations more than one area. For example, company A have operations all the fields (see table 3.2.).

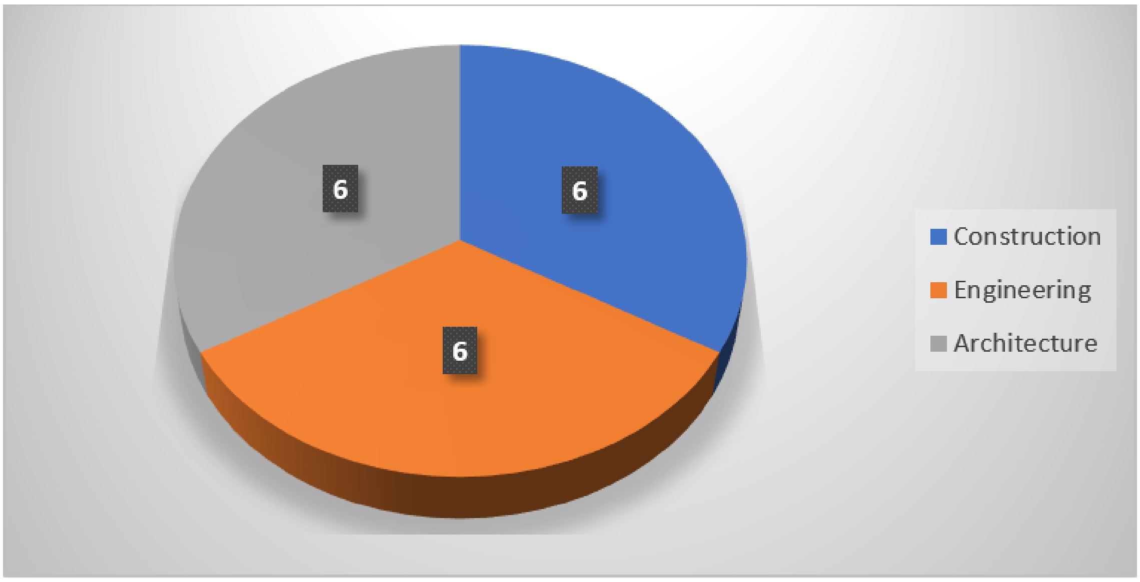

Figure 3.5. The Field of Operations of Firms.

Figure 3.6 depicts the BIM experience level of firms that participants work in. As illustrated in the following figure, the experiences of firms differ. However, half of the firms have experience in BIM between 5 and 10 years. One firm has experience in BIM for less than 1 year.

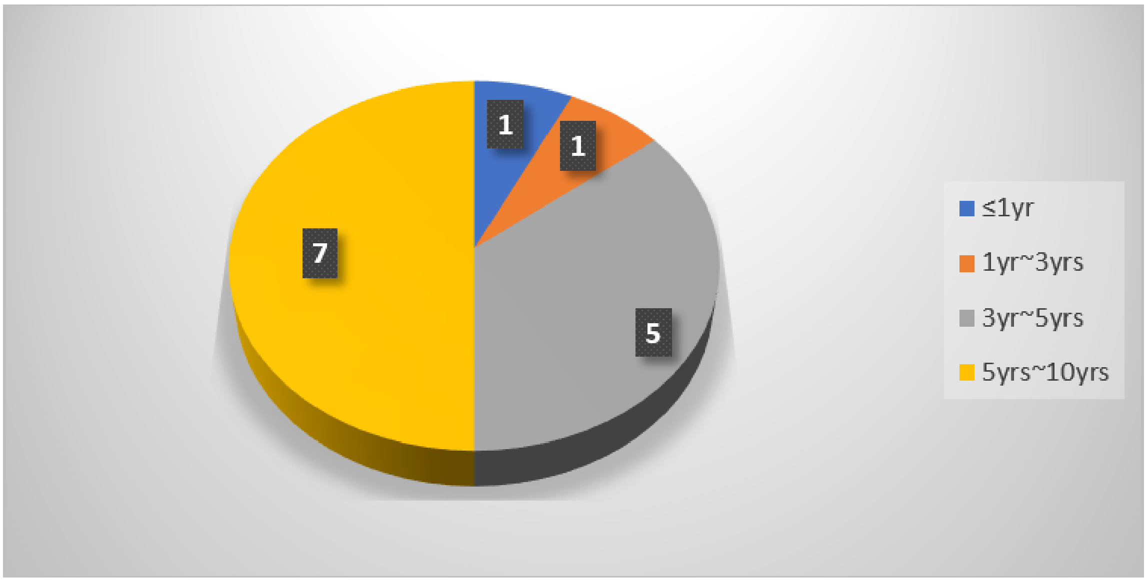

Figure 3.6. BIM Experience Level of Firms.

Table 3.14. Field of Operations of Companies.

#	Motivations	Average Rank
1	Client Requirement	4.43
2	To improve Collaboration & Coordination	4
3	Project Performance Improvement	3.43
4	Design Productivity Improvement	3.36
5	Corporate Organizations Push	3.36
6	To Gain Competitive Advantage	3.29
7	To Gain Prestige	2.93
8	To Government Push	2.43

Furthermore, during interviews, software types that are using asked to participants. The results depicted in the Figure 3.7. When it is looked at the figure below, Revit and Navisworks are using by all firms. Moreover, Allplan and Archicad are using by only one company.

In addition, BIM functions are asked to the interviewees in their projects. The figure 3.8 shows BIM usage fields in the projects according to the response of the participants. It can be seen from Figure 3.8, all firms are using BIM in terms of quantity take-off and clash detection. Nevertheless, energy analysis is not being used frequently by the firms.

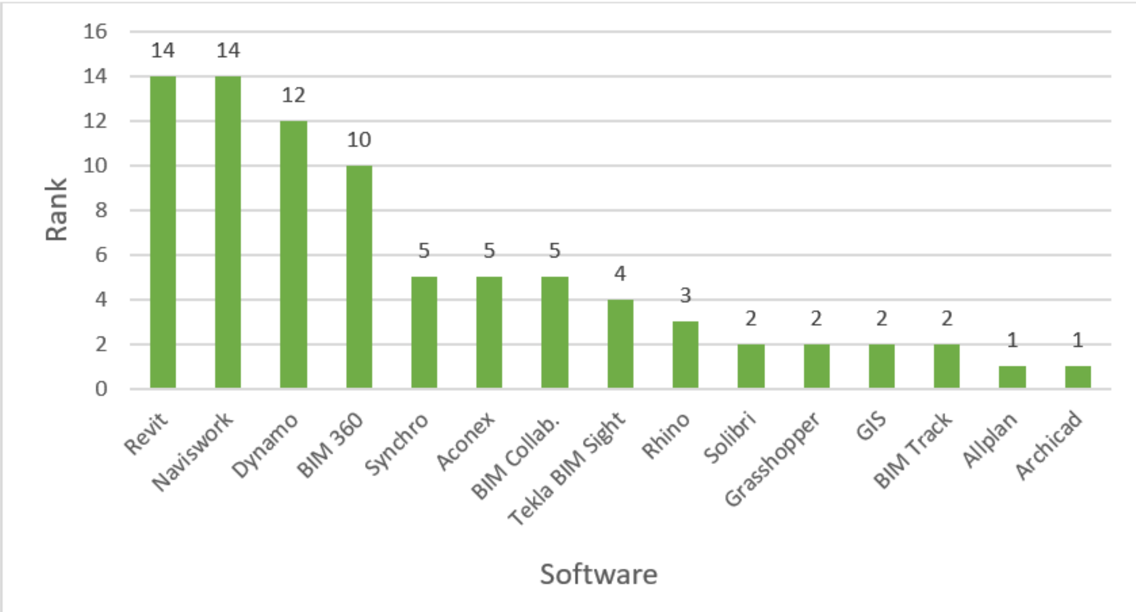

Figure 3.7. Usage of Software Types According to Responders' Evaluation.

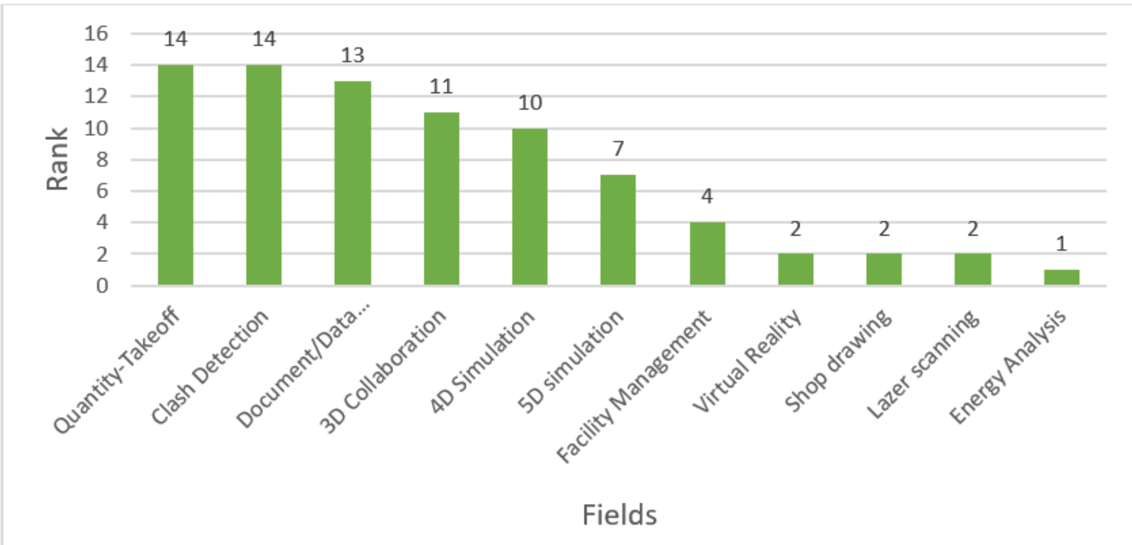

Figure 3.8. BIM Usage Fields According to Responders' Evaluation.

4. FINDINGS

In this chapter, the results of the interviews will be represented. First, the rankings of the factors will be shown for all participants' responses for each component. Second, the rankings of the factors will be demonstrated in terms of interviewees who are working in Architectural firms. After that, the results will be depicted from the perspectives of participants who are the members of Engineering firms. Then, the factor grades will be illustrated based on the response of participants who are working in the construction firms. Lastly, the most effective factors of related components will be represented according to the field of operation of companies.

4.1. The findings for BIM Transition Process in Terms of All Participants

In this section, the findings for each component will be shown based on all respondents' responses.

4.1.1. Motivations

Motivational factors represent the answer to the question of why companies have an intention towards the BIM system. Table 4.1 shows the ratings of motivations according to all participants' assessment.

As can be seen from the Table 4.1, the experts of the AEC sector evaluated "Client Requirement" as the highest ranked motivational factor. The second highest ranked factor for motivations is "To improve collaboration and coordination". The other factors are "Project Performance Improvement", "Design Productivity Improvement", "Corporate Organizations Push", "To Gain Competitive Advantage", "To Gain Prestige", and "To Government Push", respectively. According to results, it can be said that "government push" is the least effective factor to drive the companies to BIM.

Table 4.1. Rank of Motivations for BIM Transition Process Based on All Participants' Evaluation.

#	Motivations	Average Rank
1	Client Requirement	4.43
2	To improve Collaboration & Coordination	4.00
3	Project Performance Improvement	3.43
4	Design Productivity Improvement	3.36
5	Corporate Organizations Push	3.36
6	To Gain Competitive Advantage	3.29
7	To Gain Prestige	2.93
8	To Government Push	2.43

4.1.2. Inputs

Inputs demonstrate what firms did during the transition BIM transition process. The actions of firms can be defined as deployment for BIM transition. Table 4.2 depicts the inputs and their significance based on the interviewees' assessments.

According to the Table 4.2, the most important input is "investment in software and hardware". The second crucial input is "generating strategy, plan, and policy for BIM execution". After, "business process reengineering", "BIM education and training for employees", "hiring experienced/qualified staff", "using 3D library", and "taking outsourcing support" factors come, respectively. As can be seen from table 4.2, "taking outsourcing support" is labeled as the lowest ranked factor in total.

Table 4.2. Rank of Motivations for BIM Transition Process Based on All Participants' Evaluation

#	Inputs	Average Rank
1	Investment in software & hardware	4.36
2	Generating strategy, plan, and policy for BIM execution execution	4.29
3	Business process reengineering	4.07
4	BIM education and training for employees	4.00
5	Hiring experienced/qualified staff	3.71
6	Using 3D library	3.14
7	Taking outsourcing support	2.86

4.1.3. Enablers

Enablers can be defined as the factors that facilitate the BIM transition process. During interviews, responders graded the factors based on their experience. In table 4.3, these factors have been sorted in terms of their significance degree.

Table 4.3 shows that "top management support" is assessed as the most effective enabler by interviewees. The factor that has the second-highest rank is "having dynamic, collaborative, supportive work environment". The others are "availability of experienced/qualified staff in the company", "having adequate level technological infrastructure", "positive attitude of workers towards BIM", "having collaborative project delivery system", "compatibility with values, beliefs, and practices", and "advanced R&D capability of the company", respectively. It can be seen from the following table 4.3, the enabler that has the least importance is the "advanced R&D capability of the company".

Table 4.3. Rank of Enablers for BIM Transition Process Based on All Participants' Evaluation.

#	Enablers	Average Rank
1	Top management support	4.71
2	Having dynamic, collaborative, supportive work environment	4.36
3	Availability of experienced/qualified staff in the company company	4.29
4	Having adequate level technological infrastructure	4.29
5	Positive attitude of workers towards BIM	4.07
6	Having collaborative project delivery system	3.79
7	Compatibility with values, beliefs, and practices	3.57
8	Advanced R&D capability of the company	3.36

4.1.4. Obstacles

Obstacles are the factors that prevent or decelerate the BIM transition process. Due to obstacles, both adoption and implementation of BIM become much more difficult. According to Table 4.4, "lack of management support" is the most powerful barrier. Moreover, both. Moreover, both "lack of experienced/qualified workforce inside the company" and "the resistance of employees towards the change" were graded as the second effective obstacles. Furthermore, the least forceful factor is "lack of interoperability among software applications" based on the responders' evaluation. The others are "lack of BIM awareness among stakeholders", "required high initial cost for BIM transition", "collaboration and coordination problems among different parties", "lack of BIM education and training for the transition of BIM", "the uncertainty of BIM's ROI", "lack of government support", "lack of standards, laws and regulations for BIM", and "lack of interoperability among software applications", respectively.

Table 4.4. Rank of Obstacles for BIM Transition Process Based on All Participants' Evaluation.

#	Obstacles	Average Rank
1	Lack of management support	4.00
2	Lack of experienced/qualified workforce inside company	3.86
3	The resistance of employees towards the change	3.86
4	Lack of BIM awareness among stakeholders	3.79
5	Required high initial cost for BIM transition	3.57
6	Collaboration and coordination problems among different parties	3.57
7	Lack of BIM education and training for the transition of BIM	3.36
8	The uncertainty of BIM's ROI	2.93
9	Lack of government support	2.86
10	Lack of standards, laws, and regulations for BIM	2.79
11	Lack of interoperability among software applications	2.57

4.1.5. Benefits

Benefits are the outputs that are obtained as the result of BIM usage. Table 4.5 illustrates benefits that were ranked by participants.

As can be seen from the Table 4.5, "better decision-making process" is the highest ranked advantage. "increasing collaboration and coordination among project parties" is the second significant output for interviewees. On the other hand, "financial performance improvement" is not evaluated as observing output. The other factors are "effective document management", "project risk management improvement", "better technical office works", and "client satisfaction improvement", respectively.

Table 4.5. Rank of Benefits for BIM Transition Process Based on All Participants' Evaluation.

#	Benefits	Average Rank
1	Better decision-making process	4.43
2	Increasing collaboration and coordination among project parties	4.36
3	Effective document management	4.07
4	Project risk management improvement	3.79
5	Better technical office works	3.79
6	Client satisfaction improvement	3.64
7	Financial performance improvement	3.14

4.1.6. Impacts

Impacts refer to long-term gains through BIM usage. Table 4.6 shows these acquisitions regarding their significance degree that is given by the interviewees.

According to the results, "formation of company knowledge" is seen as the biggest acquisition in the long-term for AEC experts. Conversely, "expanding company's scope" is the lowest ranked impact based on the respondents' assessment. Apart from these, the other impacts are "improvement in corporate image of the company", "increase in company's productivity", and "increase in ROI", respectively.

Table 4.6. Rank of Impacts for BIM Transition Process Based on All Participants' Evaluation.

#	Impacts	Average Rank
1	Formation of company knowledge	4.64
2	Improvement in corporate image of the company	4.29
3	Increase in Company's productivity	4.21
4	Increase in ROI	3.86
5	Expanding Company's scope	3.36

4.2. The Findings for BIM Transition Process in Terms of Architecture Firms

After interviews, the results have been arranged according to each company type. In the following parts, the findings in the perspective of Architecture firms will be represented.

4.2.1. Motivations

In the Table 4.7, the motivational factors have been written according to their ranks based on the answers of participants who work in the Architecture firms.

It can be seen from the table; Architecture firms evaluated the factor of "to improve collaboration and coordination" as the most effective motivational factor. On the other hand, "government push" was labeled as insignificant factor by Architecture companies.

Table 4.7. Rank of Motivations for BIM Transition Process from the Perspective of Architecture Firms

#	Motivations	Average Rank
1	To improve collaboration & coordination	4.33
2	To gain competitive advantage	4.00
3	Client Requirement	3.83
4	Project Performance improvement	3.83
5	Design productivity improvement	3.83
6	To gain prestige	3.50
7	Corporate organizations push	3.33
8	Government push	1.33

4.2.2. Inputs

The Table 4.8 depicts the inputs according to their significance degrees that were assessed by the Architecture firms. When it is looked at the table, from the perspective of Architecture firms, "generating strategy, plan, and policy for BIM execution" is the most important input for the BIM transition process. However, as can be seen from the table 4.8, "taking outsourcing support" is not preferred a lot by Architecture firms compared to other factors.

Table 4.8. Rank of Inputs for BIM Transition Process from the Perspective of Architecture Firms.

#	Inputs	Average Rank
1	Generating strategy, plan, and policy for BIM execution	4.33
2	Investment in software & hardware	4.17
3	Business process reengineering	3.67
4	BIM education and training for employees	3.50
5	Hiring experienced/qualified staff	3.33
6	Using 3D library	3.00
7	Taking outsourcing support	2.83

4.2.3. Enablers

In the Table 4.9, the factors that accelerate the BIM transition process were ranked from the perspective of Architecture firms. It can be seen easily from the Table 4.9, the most effective facilitator according to Architecture firms is “top management support. Adversely, “advanced R&D capability of the company” were ranked as the lowest among enablers.

Table 4.9. Rank of Enablers for BIM Transition Process from the Perspective of Architecture Firms.

#	Enablers	Average Rank
1	Top management support	4.67
2	Availability of experienced/qualified staff in company	4.17
3	Compatibility with values, beliefs, and practices	4.17
4	Having dynamic, collaborative, supportive work environment	4.00
5	Having adequate level technological infrastructure	4.00
6	Positive attitude of workers towards BIM	4.00
7	Having collaborative project delivery system	4.00
8	Advanced R&D capability of the company	3.00

4.2.4. Obstacles

In the Table 4.10, the factors that hamper the BIM transition process were graded by the Architecture firms. When it is looked at the Table 4.10, both “collaboration and coordination problems among different parties” and “lack of BIM education and training for the transition of BIM” are the most preventive factors according to Architecture firms. In addition, “lack of interoperability among software applications”, “lack of standards, laws, and regulations for BIM”, and “the uncertainty of BIM’s ROI” are not seen as big problems from the perspective of Architecture firms.

Table 4.10. Rank of Obstacles for BIM Transition Process from the Perspective of Architecture Firms.

#	Obstacles	Average Rank
1	Collaboration and coordination problems among different parties	3.67
2	Lack of BIM education and training for the transition of BIM	3.67
3	Lack of BIM awareness among stakeholders	3.50
4	Lack of experienced/qualified workforce inside company	3.33
5	The resistance of employees towards the change	3.33
6	Required high initial cost for BIM transition	3.00
7	Lack of government support	3.00
8	Lack of management support	2.83
9	The uncertainty of BIM's ROI	2.67
10	Lack of standards, laws, and regulations for BIM	2.67
11	Lack of interoperability among software applications	2.67

4.2.5. Benefits

Table 4.11 shows the ranked beneficial outputs based on the assessment of Architecture firms. When it is looked at the table 4.10, it can be said that "better decision-making process" is the most advantageous outputs according to Architecture firms. On the other part, "financial performance improvement" is seen as the least effective short-term gain.

Table 4.11. Rank of Benefits for BIM Transition Process from the Perspective of Architecture Firms.

#	Benefits	Average Rank
1	Better decision-making process	4.50
2	Increasing collaboration and coordination among project parties	4.33
3	Effective document management	4.17
4	Project risk management improvement	4.17
5	Better technical office works	4.00
6	Client satisfaction improvement	3.33
7	Financial performance improvement	3.17

4.2.6. Impacts

As it can be seen from the Table 4.12, both "formation of company knowledge" and "improvement in corporate image of the company" were ranked as the most important acquisitions by Architecture firms. In addition, both "increase in ROI" and "expanding company's scope" are seen as the least significant impacts from the perspective of Architecture firms.

Table 4.12. Rank of Impacts for BIM Transition Process from the Perspective of Architecture Firms.

#	Impacts	Average Rank
1	Formation of company knowledge	4.67
2	Improvement in corporate image of the company	4.67
3	Increase in Company's productivity	4.17
4	Increase in ROI	3.67
5	Expanding Company's scope	3.67

4.3. The Findings for BIM Transition Process in Terms of Engineering Firms

In the following parts, the findings from the perspective of Engineering firms will be represented.

4.3.1. Motivations

As it can be seen from the Table 4.13, the most influential motivation from the perspective of the Engineering firms is "client requirement" in the result of the interviews. Besides, "government push" was assessed as the least critical motivation for Engineering firms.

Table 4.13. Rank of Motivations for BIM Transition Process from the Perspective of Engineering Firms.

#	Motivations	Average Rank
1	Client Requirement	4.33
2	To improve collaboration and coordination	3.67
3	Corporate organizations push	3.33
4	To gain competitive advantage	3.17
5	To gain prestige	3.17
6	Project Performance improvement	3.00
7	Design productivity improvement	2.67
8	Government push	1.83

4.3.2. Inputs

According to the Engineering firms in the Table 4.14, the input that was ranked as the highest is "investment in software and hardware". On the other hand, "taking outsourcing support" is seen by the Engineering firms as the least significant input.

Table 4.14. Rank of Inputs for BIM Transition Process from the Perspective of Engineering Firms.

#	Inputs	Average Rank
1	Investment in software and hardware	4.33
2	Generating strategy, plan, and policy for BIM execution	3.83
3	Hiring experienced/qualified staff	3.67
4	Business process reengineering	3.50
5	BIM education and training for employees	3.33
6	Using 3D library	2.67
7	Taking outsourcing support	2.50

4.3.3. Enablers

In the Table 4.15, the factors that simplify the BIM transition process were evaluated by Engineering firms. It can be seen from the Table 4.15, the most important facilitator is "top management support" for Engineering firms. In addition, engineering firms indicated that "having a collaborative project delivery system" does not accelerate the process.

Table 4.15. Rank of Enablers for BIM Transition Process from the Perspective of Engineering Firms.

#	Enablers	Average Rank
1	Top management support	4.50
2	Positive attitude of workers towards BIM	4.33
3	Having dynamic, collaborative, supportive work environment	4.17
4	Having adequate level technological infrastructure	4.17
5	Availability of experienced/qualified staff in company	4.00
6	Compatibility with values, beliefs, and practices	3.83
7	Advanced R&D capability of the company	3.83
8	Having collaborative project delivery system	3.67

4.3.4. Obstacles

In the Table 4.16, preventive factors are depicted with their importance degrees that were given by the Engineering firms. From the perspective of the Engineering firms, the most powerful obstacle is “the resistance of employees towards the change”, and the factor that is seen as the lowest barrier is “lack of interoperability among software applications”.

Table 4.16. Rank of Obstacles for BIM Transition Process from the Perspective of Engineering Firms.

#	Obstacles	Average Rank
1	The resistance of employees towards the change	4.00
2	Required high initial cost for BIM transition	3.83
3	Lack of BIM awareness among stakeholders	3.67
4	Lack of management support	3.67
5	Collaboration & coordination problems among different parties	3.50
6	Lack of experienced/qualified workforce inside company	3.50
7	The uncertainty of BIM's ROI	3.50
8	Lack of BIM education and training for the transition of BIM	3.33
9	Lack of government support	3.17
10	Lack of standards, laws, and regulations for BIM	3.00
11	Lack of interoperability among software applications	2.67

4.3.5. Benefits

In the Table 4.17, short-term gains have been represented aligned with their rank based on the Engineering firms' assessment. It is clear that both "better decision-making process" and "increase collaboration and coordination among project parties" were the main benefits for the Engineering firms. However, the experts who work in Engineering firms indicated "financial performance improvement" as the least advantageous factor.

Table 4.17. Rank of Benefits for BIM Transition Process from the Perspective of Engineering Firms.

#	Benefits	Average Rank
1	Better decision-making process	4.33
2	Increase collaboration and coordination among project parties	4.33
3	Effective document management	4.17
4	Project risk management improvement	3.67
5	Better technical office works	3.50
6	Client satisfaction improvement	3.33
7	Financial performance improvement	2.67

4.3.6. Impacts

The Table 4.18 shows long-term gains that were ranked by the Engineering firms. It can be seen from the table that "formation of company knowledge" was assessed as the most crucial impact. Nevertheless, the experts of Engineering firms indicated "expanding company's scope" as the least important impact.

Table 4.18. Rank of Impacts for BIM Transition Process from the Perspective of Engineering Firms.

#	Impacts	Average Rank
1	Formation of company knowledge	4.67
2	Improvement in corporate image of the company	4.33
3	Increase in Company's productivity	4.00
4	Increase in ROI	3.50
5	Expanding Company's scope	3.00

4.4. The Findings for BIM Transition Process in Terms of Construction Firms

In the following parts, the findings of the interviews will be illustrated from the perspective of Construction firms.

4.4.1. Motivations

In the Table 4.19, drivers have been demonstrated in terms of Construction firms. When it is looked at the table 4.19, the most influential factor is "client requirement" from the perspective of the construction firms. Besides, the construction firms evaluated "to gain prestige" as the lowest effective motivational factor.

Table 4.19. Rank of Motivations for BIM Transition Process from the Perspective of Construction Firms.

#	Motivations	Average Rank
1	Client Requirement	4.50
2	To improve collaboration & coordination	4.17
3	Corporate organizations push	3.50
4	Project Performance improvement	3.50
5	Design productivity improvement	3.33
6	Government push	3.33
7	To gain competitive advantage	3.00
8	To gain prestige	2.83

4.4.2. Inputs

Table 4.20 depicts the inputs that were ranked by the construction firms. It can be seen from the Table 4.20, there are 4 factors that were ranked with the same value from the perspective of the construction firms. These are "generating strategy, plan, and policy for BIM execution", "investment in software and hardware", "business process reengineering", and "BIM education and training for employees". These factors are the most critical inputs according to the construction firms. On the other hand, "taking outsourcing support" was ranked as the lowest input.

Table 4.20. Rank of Inputs for BIM Transition Process from the Perspective of Construction Firms.

#	Inputs	Average Rank
1	Generating strategy, plan, and policy for BIM execution	4.50
2	Investment in software and hardware	4.50
3	Business process reengineering	4.50
4	BIM education and training for employees	4.50
5	Hiring experienced/qualified staff	4.17
6	Using 3D library	3.50
7	Taking outsourcing support	3.17

4.4.3. Enablers

In the Table 4.21, the factors that enable the BIM transition were evaluated by the construction firms. According to Table 4.21, the highest ranked facilitator in terms of construction firms is "top management support". From the viewpoint of the construction firms, both "compatibility with values, beliefs, and practices" and "advanced R&D capability of company" were evaluated as the lowest ranked enablers.

Table 4.21. Rank of Enablers for BIM Transition Process from the Perspective of Construction Firms.

#	Enablers	Average Rank
1	Top management support	4.83
2	Having dynamic, collaborative, supportive work environment	4.67
3	Availability of experienced/qualified staff in company	4.50
4	Having adequate level technological infrastructure	4.50
5	Positive attitude of workers towards BIM	4.17
6	Having collaborative project delivery system	3.83
7	Compatibility with values, beliefs and practices	3.33
8	Advanced R&D capability of company	3.33

4.4.4. Obstacles

The factors that prevent the BIM transition process were ranked by the construction companies in the Table 4.22. When it is looked at the table, "lack of experienced/qualified workforce inside company" is the highest ranked obstacle. Also, "lack of interoperability among software applications" was graded as the lowest ranked obstacle from the perspective of the construction firms.

Table 4.22. Rank of Obstacles for BIM Transition Process from the Perspective of Construction Firms.

#	Obstacles	Average Rank
1	Lack of experienced/qualified workforce inside company	4.67
2	The resistance of employees towards the change	4.50
3	Lack of management support	4.17
4	Collaboration and coordination problems among different parties	4
5	Required high initial cost for BIM transition	3.83
6	Lack of BIM awareness among stakeholders	3.67
7	Lack of standards, laws and regulations for BIM	3.67
8	Lack of BIM education and training for the transition of BIM	3.50
9	The uncertainty of BIM's ROI	3.33
10	Lack of government support	3.17
11	Lack of interoperability among software applications	3.00

4.4.5. Benefits

From the viewpoint of the construction firms, benefits have been assessed in the Table 4.23. According to the table, both "better decision-making process" and "increase collaboration and coordination among project parties" were assessed as the most beneficial factors. In addition, "financial performance improvement" was evaluated as the lowest ranked benefits.

Table 4.23. Rank of Benefits for BIM Transition Process from the Perspective of Construction Firms.

#	Benefits	Average Rank
1	Better decision-making process	4.33
2	Increase collaboration and coordination among project parties	4.33
3	Client satisfaction improvement	4.00
4	Effective document management	3.67
5	Project risk management improvement	3.50
6	Better technical office works	3.50
7	Financial performance improvement	3.17

4.4.6. Impacts

In the interview, construction firms ranked the impacts according to their experiences. The Table 4.24 depicts the results. As can be seen from the table, "formation of company knowledge" was ranked as the most effective long-term gain. On the other hand, "expanding company's scope" was graded as the least effective long-term gain.

Table 4.24. Rank of Impacts for BIM Transition Process from the Perspective of Construction Firms.

#	Impacts	Average Rank
1	Formation of company knowledge	4.67
2	Improvement in corporate image of the company	4.17
3	Increase in Company's productivity	4.17
4	Expanding Company's scope	3.50
5	Increase in ROI	3.33

5. DISCUSSION

In this part, the findings that were represented in the previous section will be analyzed and discussed. In addition to the findings, some influential quotes from the interviewees will be provided. Firstly, the findings will be discussed by comparing the results from the perspectives of the AEC firms according to each component. Secondly, the findings will be compared according to the BIM experience level of firms.

5.1. Discussion on Components

In this section, 6 components and 46 factors will be debated based on the findings of the interview.

5.1.1. Comparison of Motivations in Terms the Turkish AEC Industry

In this section, motivations are compared according to the AEC firms. As can be seen from Figure 5.1, although both Engineering and Construction firms evaluate "client requirement" as very significant motivation, Architecture firms label "to improve collaboration and coordination" as the key motivational factor. During the interview, BIM manager of Company I indicated that "client requirement is insignificant factor for our motivation to use BIM because we had shifted to BIM before clients realized it. In fact, many clients do not even know that we are using BIM. However, the most significant motivation for us was to improve collaboration and coordination". In addition, Ahuja *et al.* (2016) found similar results by investigating the effective factors for BIM adoption from the perspectives of Indian Architectural firms.

Secondly, both Architectural and Engineering firms pointed out that government push is the least effective driver even though Construction companies indicated that "to gain prestige" is an unimportant motivation. BIM specialist of Company A stated that "For us, government does not force companies to use BIM. On the other hand, we think that one of the biggest deficiencies is that the government does not force to use BIM.

Eventually, transition to BIM for companies will be with government push because BIM will bring an extra burden to companies that can run their business with their own methods. At this point, the government's attitude will be decisive". Contrarily, the BIM manager of company J claimed that "we are a company involved in the government's metro projects, and BIM has started to be included in the specifications of the Ministry of Transport. Therefore, this situation has been a very driving force for our company".

Moreover, when it is looked at the Figure 5.1, gaining competitive advantage is an important motivation for Architectural companies compared to Engineering and Construction companies. The reason can be that most of the Architectural firms interviewed they do business abroad and BIM is generally used in projects there. Because, both BIM manager of company K and BIM coordinator of company F said that "BIM generally includes in the specifications of abroad projects. Therefore, competing with other companies, and gaining competitive advantage against them is a significant driver for us".

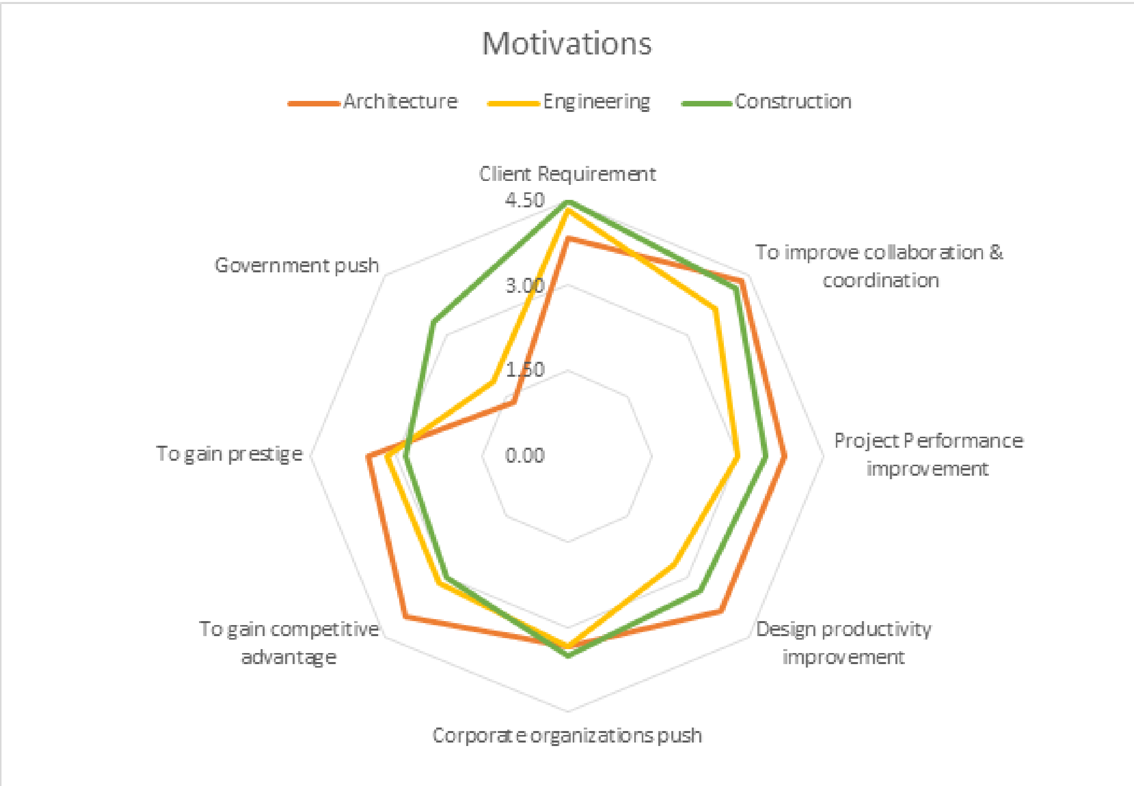

Figure 5.1. The Comparison of Motivations According to Firms.

In the figure above, “design productivity improvement” was ranked by Engineering companies as one of the least motivational factors. For instance, BIM manager of company K stated that “Design improvement was not our first priority, because we were not responsible for the design of the projects, we involved in”.

In conclusion, firstly, Client requirement is significant motivation to use BIM, especially Engineering and Construction firms in Turkey. Most of companies indicated that without client requirement BIM usage level will be low. Secondly, government can play a crucial role in BIM usage, especially in public projects (e.g., metro projects) by adding BIM into the specification of projects. This situation can be seen mostly in the construction firms that do business with the government. In the literature, Jin *et al.* (2017) found that both client requirement and government push are critical driver for BIM implementation in the Chinese AEC industry. In addition, the BIM implementation rate of firms can increase gradually with client requirement even if the government has no intention to force companies to use BIM. Thirdly, gaining competitive advantage is an important driver for the companies that do business abroad. This is because, commonly, BIM usage is a requirement in abroad. Lastly, improving collaboration is assessed by the AEC industry in Turkey as a significant catalyst. Likewise, Ahmed and Kassem (2018) found similar results in UK from the perspective of Architectural sector.

5.1.2. Comparison of Inputs in Terms of the Turkish AEC Industry

In this section, inputs are compared according to the AEC firms in Turkey. As can be seen from the following figure, construction companies in Turkey give importance to 4 inputs equally, including “investment in software and hardware”, “generating strategy, plan, and policy for BIM execution”, “business process reengineering”, and “BIM education and training for employees”. Although “investment in software and hardware?, and “generating strategy, plan, and policy for BIM execution” were ranked almost equal by firms, “business process engineering”, and “BIM education and training for employees” were evaluated by construction firms much higher than both Architecture and Engineering companies. Likewise, Mutai (2009) examined success factors for

BIM in US leading construction firms, and he founded similar results. Senior information management lead in company H stated that “Apart from the BIM department, departments such as design, planning, etc. need to have BIM awareness. At this point, BIM education and training plays an important role in raising this awareness.” BIM and Technology Coordinator of company M pointed out that “Our BIM team did not receive BIM or software training. We hired a few people who are experienced in BIM to transfer their knowledge, and we continued to learn as the project progressed.” Besides, BIM manager of company L said that “If the business processes are not structured in accordance with BIM, then the processes cannot proceed smoothly and at some point, they become blocked”.

As the result of the interviews, Architectural companies assessed “generating strategy, plan, and policy for BIM execution as the most effective input. BIM manager of company F claimed that “it is very important to create a BIM execution plan before starting the project. Because this plan becomes your user guide after the project starts and you do not deviate from it until the project is completed”.

Furthermore, “taking outsourcing support” was evaluated significant input by some companies, but some of them sees it as insignificant. Nevertheless, overall, “taking outsourcing support” was graded as the least important input. For instance, BIM manager of company D said that “Companies that will start to implement BIM should definitely get consultancy support from people who are competent in this field. Because this kind of support is important for rapid progress”. Contrarily, senior information management lead in company H indicated that “We initially received consultancy support, but it did not contribute much to us. Therefore, we do not think that this kind of support is inconsequential”.

Consequently, it can be said that Construction companies give importance to inputs much more than Engineering and Architectural companies do. Architectural companies in Turkey believe that creating execution plan has a great impact on performing BIM processes, accurately. Secondly, from the perspective of Engineering firms, it is crucial to investment in software and hardware. Thirdly, giving their employees BIM education and training and arranging their work processes, tasks, etc. according to BIM is more significant for construction firms than others. Last but not least, outsourcing support like consultancy is not assessed by the AEC industry in Turkey as an effective input.

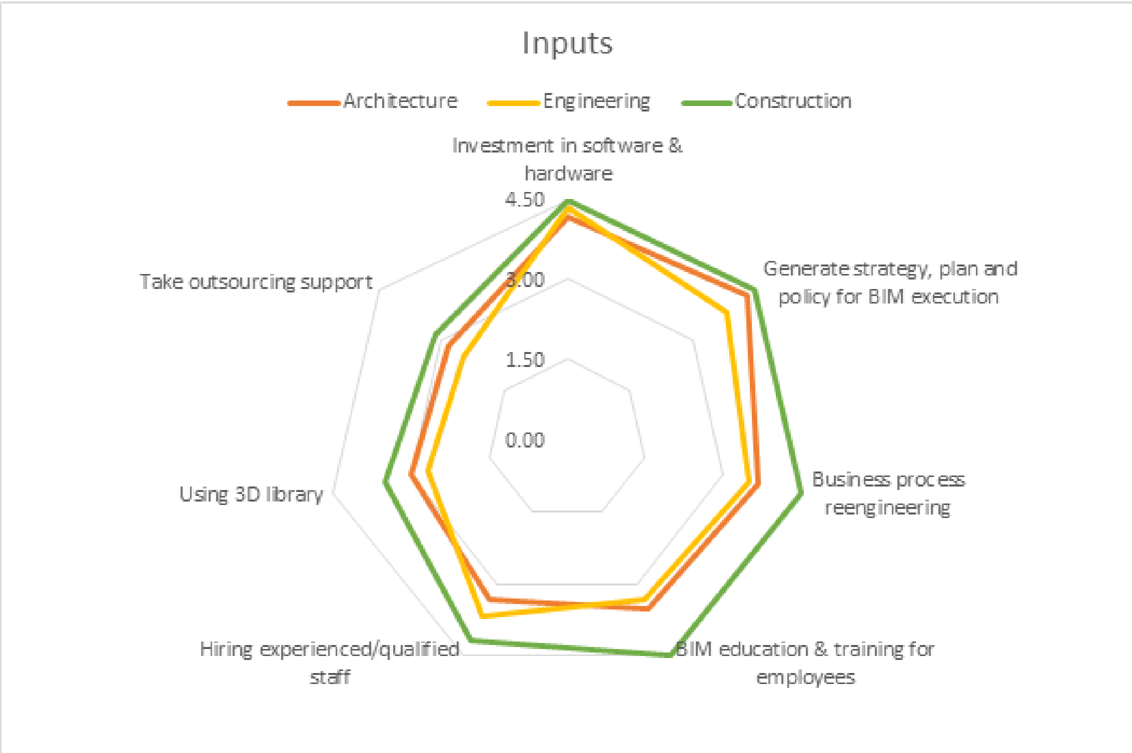

Figure 5.2. The Comparison of Inputs According to Firms.

5.1.3. Comparison of Enablers in Terms of the Turkish AEC Industry

In this section, enablers are compared according to the Turkish AEC firms. As can be seen from Figure 5.3, "top management support" plays a tremendous role in simplifying the BIM transition process in the Turkish AEC Industry. During the interview, all firms without exception indicated that management support is vital to shift the BIM system. Likewise, Yuan *et al.* (2019) found that top management support is one of the critical success factors for BIM adoption and implementation in Chinese AEC industry. BIM and technology coordinator of company M stated that "Our managers played a crucial role in the transition to the BIM system. It must be accepted that support from top management enables the process to proceed faster and easier". In addition, the BIM manager of company J indicated that "for the transition to BIM, the top-down approach should be embraced because within the company there can be employees who are unwilling to utilize BIM. To convince these people, top managers can play a crucial role".

Moreover, the availability of experienced staff within the company is seen as the second important enabler by the AEC industry in Turkey. BIM manager of company D claimed that "The presence of experienced people in BIM within the company is a factor that facilitates the transition to BIM. However, if your company is financially strong, it can offer you the necessary resources without the need for experienced people".

Furthermore, "compatibility with existing values, beliefs and practices" was also ranked as significant enabler by the AEC industry in Turkey. To exemplify, BIM manager of company D said that "Unless you create something suitable for the company's system, you cannot exist in that system. Because you change the tools the employees use, and if you change the system that has been used for a long time, the acceptance of the new system becomes more difficult".

On the other hand, "R&D capability of company" was ranked as the least significant enabler for the BIM transition process by Architectural and Construction firms in Turkey. For instance, BIM manager of company G told that "it would be nice if we could do R&D work. However, we cannot spare time for such activities because of the busy schedule. In addition, we do not prefer it much because it brings a financial burden". Contrarily, BIM manager of company D indicated that "it is very important that the BIM department and the R&D department work together. As a team, we do R&D work on a certain day of the week".

Last but not least, from the perspective of Engineering firms, "having collaborative project delivery system" is seen as the least critical facilitator for the transition process. BIM coordinator of company C stated that "Since the integrated project delivery (IPD) approach did not exist in the projects we have been involved in until now, it did not have much effect".

All in all, top management support sees as the most effective facilitator to shift BIM in the Turkish AEC industry. It is obvious that powerful leadership for a company during the transition process can prevent potential problems and overcome existing barriers. Besides, the presence of people who have knowledge about BIM also can accelerate the transition. Because these people can lead the transition process and prevent the problems that will arise with their experiences. Compatibility is another critical issue. If BIM is suitable to current work system of company, it is much easier to break the resistance of employees towards BIM. Lastly, although some firms indicated that R&D works have a positive impact on productivity of BIM processes, overall R&D capability of company is not as much substantial as others. However, when it is compared the companies in terms of R&D, it can be said that Architectural firms give much less importance to R&D activities than the others.

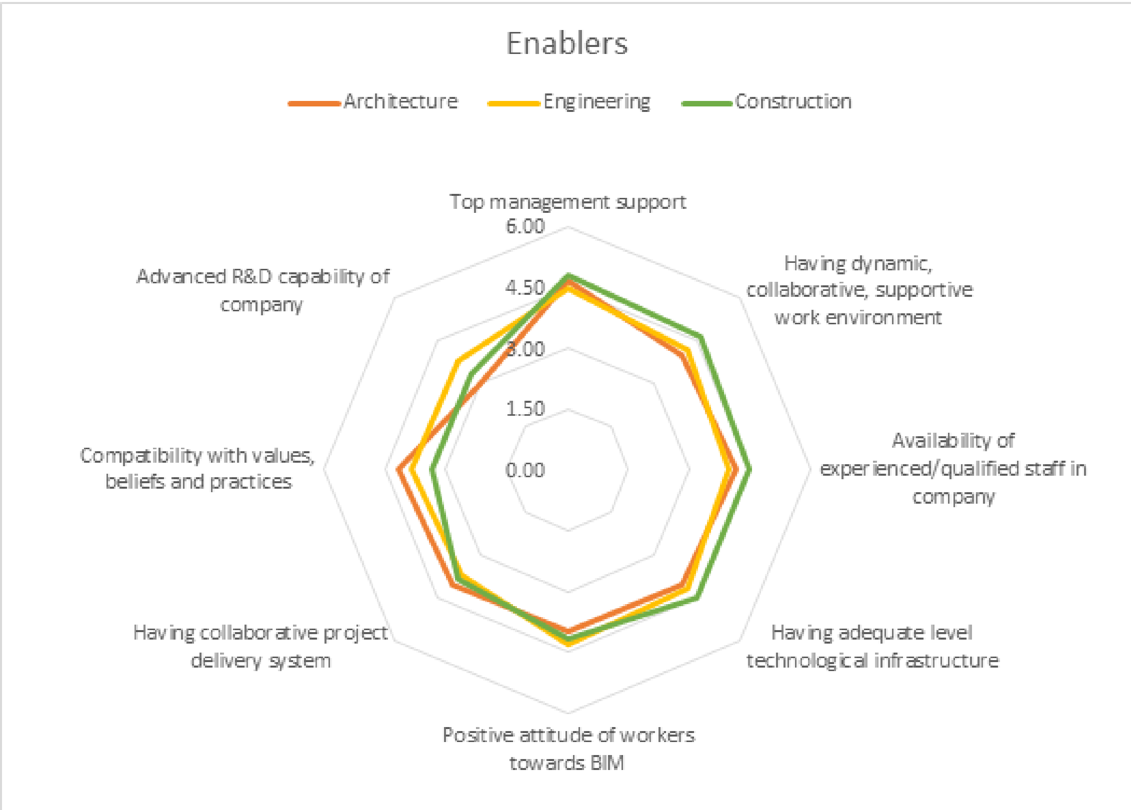

Figure 5.3. The Comparison of Enablers According to Firms.

5.1.4. Comparison of Obstacles in Terms of the Turkish AEC Industry

In this section, obstacles are compared according to the Turkish AEC firms. First of all, in Figure 5.4, collaboration and coordination difficulties between project stakeholders and the lack of BIM education and training for BIM transition are assessed as the biggest obstacles by Architectural firms. Girginkaya and Maqsood (2019) also indicated that poor communication and training issues about BIM are the important barrier in Pakistan Architecture firms. BIM manager of company G said that "In the beginning, if the role of project participants in BIM is not clearly stated in the contract, some companies do not want to use BIM, thinking that it brings a financial burden, and in the end, this causes collaboration problems in the project". Moreover, BIM manager of company I articulated that "I do not think that anyone knows what BIM is in Turkey. Therefore, I believe that BIM education and training are not given adequately in Turkey" In addition, Architectural firms do not think that the ambiguity of BIM's ROI affects negatively to BIM transition process. Besides, they do not believe that lack of standards and regulations is the obstacle for BIM transition. Most Architectural firms' experts indicated that there are various international BIM standards. Furthermore, lack of interoperability among software applications was not assessed as the barrier by Architectural companies because there are exchange data standards in the market (e.g., IFC).

When it is looked at the perspectives of Construction firms, "lack of experienced/qualified workforce inside the company" and "the resistance of employees towards the change" are the most effective impediments. Construction firms think that it is hard to find people who are experienced in BIM in Turkey. There is similar situation in Australian Construction firms. Newton and Chileshe (2012) stated that trained/experienced staff is hard to find within the Australian construction industry. BIM manager of company D explained that "Lack of experienced people in BIM is a serious problem. For example, you may want to train your employees yourself. However, this is a process that requires a serious investment and time". BIM specialist of company A claimed that "Since we are a company that has been operating in the sector for many years, there are people who are working for 30 years inside the company, too. So, it is not easy to change the system that these people have been accustomed to, known, and implemented for years". Moreover, Construction companies have the same thoughts on the ROI of BIM. BIM manager of company A stated that "BIM's return on investment isn't actually uncertain. If you apply it correctly in all processes, you will have achieved gains of %20 and %25. Considering that the operating time of a construction is too long, the real return on investment is obtained in the facility management part. Furthermore, construction companies have the idea that is that lack of government support is not an important obstacle.

It can be seen from the figure below, the most critical impediment is resistance to change from employees in Engineering firms. BIM and technology coordinator of company M expressed that "Employees' attitude is very important at this point. It happens if the individual wants. Because after a certain age, after a certain level of experience, it becomes difficult for people to change their way of doing business". Olawumi *et al.* (2018) studied obstacles for BIM with AEC industry experts from various countries, and they found that resistance to change is highly significant impediment. Engineering firms also labelled "high initial cost for transition to BIM" as the second significant barrier. The BIM coordinator of company C stated that "to implement BIM, you need to purchase software, set up server, change your computer maybe. These all cause a certain degree cost". On the other hand, Engineering firms do not believe anymore that interoperability problem among software applications prevents transition to BIM.

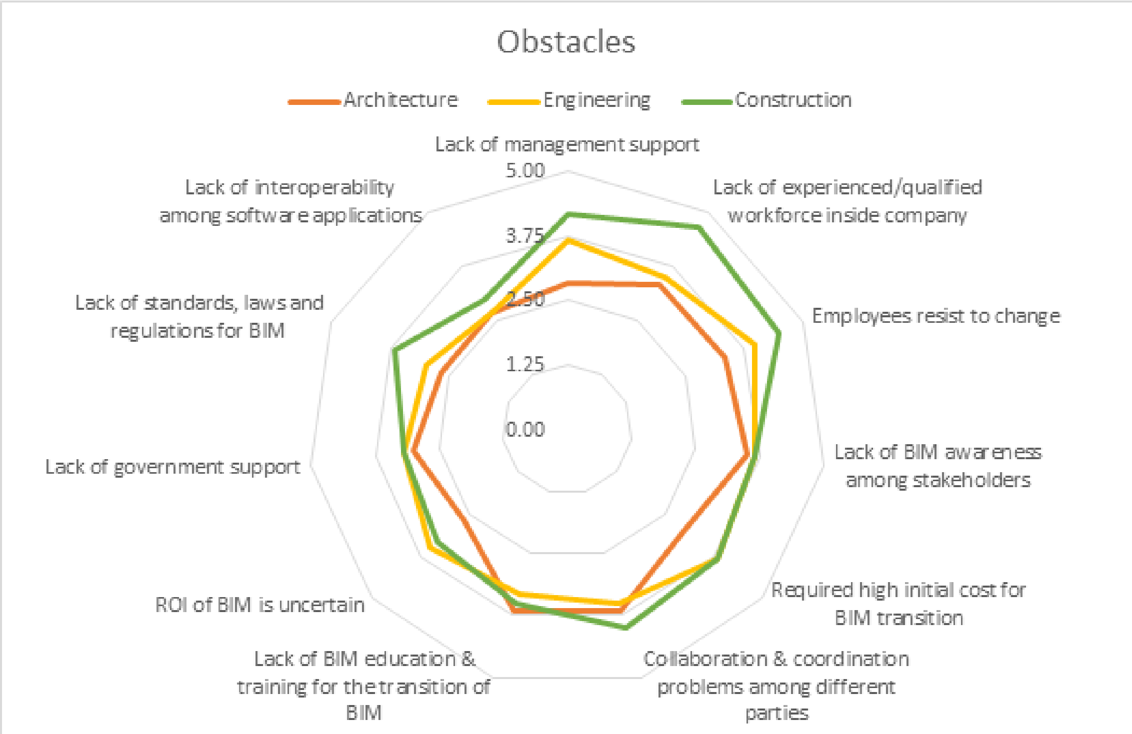

Figure 5.4. The Comparison of Obstacles According to Firms.

In conclusion, while Architecture companies faced the collaboration problems and lack of BIM education, Engineering firms experienced employees' resistance, and Construction firms felt the deficiency of experienced workforce during transition to BIM. Architecture and Engineering companies do not think that lack of standards, laws, and regulations is a barrier because even if there is no standard specified in the project, companies can create their own standards in accordance with the project. In addition, all companies said that interoperability issue among software applications do not generate problem because of the data exchange standards and cloud system.

5.1.5. Comparison of Benefits in Terms of the Turkish AEC Industry

In this section, benefits are compared according to the Turkish AEC firms. As can be seen from Figure 5.5, all firms indicated that the most important benefit from BIM usage is obtaining better decision-making process. This observation shows the similarity with other studies. For example, Chiu and Lai (2020) indicated that BIM helps practitioners to better decision-making. In addition, both Engineering and Construction companies claimed that BIM usage increases collaboration and coordination among project parties. For example, BIM can help to create what if scenarios during design phases, and users can make their decision according to these options. VR technology and clash detections can be utilized for this. In Figure 3.8, there are 2 firms that are using VR technology in some projects, or at least trying to utilize it. When it is looked at these companies' answers, they said that better decision-making process is the most significant benefit. In addition, it can be seen from Figure 3.8, all companies use BIM for clash detection in Turkey. This also might affect the result. Furthermore, there are 11 companies out of 14 that do 3D collaboration by using BIM model (see Figure 3.8). Therefore, it is logical that firms think that BIM increase collaboration and coordination.

Moreover, Construction firms have thought that client satisfaction increases with BIM compared to the others. BIM manager of company D claimed that "when you implement the project via the BIM model, you cannot fool the employer in any way. Because you present everything to the employer transparently. Even, before the project starts, the employer sees what will happen when the project is finished. In this sense, the employer feels safe and satisfied". Furthermore, project risk management improvement is evaluated by Architectural companies as beneficial factor more than the others. BIM manager of company G explained that "risks which cannot be predicted in 2D can be detected and mitigated easily with the help of 3D model. Accordingly, the problems that may occur in the site can be prevented before the project has not started yet". What is more, Engineering and Architectural firms compared to Construction firms assess "effective document management" as more significant output of BIM usage.

On the other hand, "financial performance improvement" is labelled as the least advantageous factor by all firms. The reason is maybe due to the low financial return of BIM in the short term. In fact, financial performance means reducing life cycle costs, and better planning and scheduling. However, companies that are inside the Turkish AEC industry may have no experience adequately to observe these benefits. Because it is not simple to obtain profit when breakthrough changes happened. Setting up the system takes time, and it must be understood by all individuals. Ma *et al.* (2019)

pointed out that BIM usage is scarce at individual level. For this reason, organizations fail to reap the benefits of BIM. Likewise, BIM manager of company J said that "BIM needs to be evaluated financially in the long term. From this point of view, the initial high cost of BIM does not matter". Besides, BIM manager of company D stated that "it is necessary to use BIM in all processes from the concept design phase to the operation phase in order to measure how much BIM provides profit in the entire construction process. However, there are very few companies in the market that can do this".

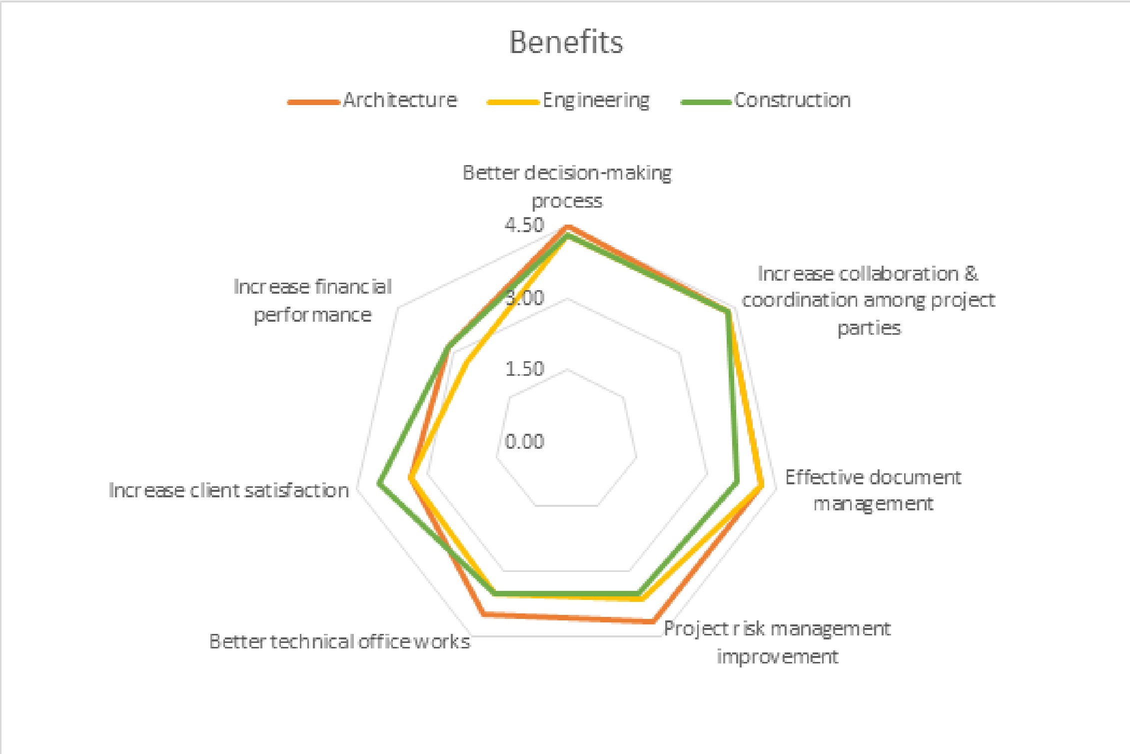

Figure 5.5. The Comparison of Benefits According to Firms.

5.1.6. Comparison of Impacts in Terms of the Turkish AEC Industry

In this section, impacts are compared according to the Turkish AEC firms Figure 5.6, shows that "formation of company knowledge" is the most significant long-term effect of BIM in the AEC industry. For instance, BIM manager of company D indicated that "Over time, know-how is formed within the company. In addition, a project archive is created about the projects we have done, which you can utilize in future projects". Arayici *et al.* (2012) investigated BIM in a case study in UK, and they found similar result. This is how BIM can evolve within the company, and this is very important for BIM to achieve its purpose. Moreover, Architectural firms think more than the others that BIM improves the corporate image of the company in the long-term. The reason may be that Architecture companies generally are subcontractor in a construction project. Therefore, they might see “improvement of corporate image” as one of the most effective impacts to remain competitive.

Figure 5.6. The Comparison of Impacts According to Firms.

On the other hand, when it is looked at Figure 5.6, companies in the Turkish AEC industry ranked “expanding scope of companies” and “increase in ROI” as the least effective long-term gains. BIM coordinator of company C explained that “If a company does not know the project management, it will not learn it after transition to BIM. They are doing project management and now they will continue to do it, but in a different way”. Moreover, BIM manager of company D explains that the positive impact of BIM for return on investment (ROI) can be seen mostly in the field of facility management. However, only 4 companies out of 14 stated that they are using BIM for facility management. So, it is not surprising that companies do not think that BIM increases ROI.

5.2. Discussion on BIM Experience Level of Firms

In this section, the findings of interviews will be discussed according to companies' BIM experience level. However, it is more convenient to make this comparison for the post-adoption part of the BIM transition process because companies can evaluate only benefits (short-term gains) and impacts (long-term gains) according to their BIM experiences. Because in the purposed BIM transition process, it is said that you must first apply it to get benefits from something. After gaining experience, evaluations can be made on the results.

5.2.1. Comparison of Benefits According to BIM Experience Level of Firms

In Figure 5.7, beneficial factors were compared in accordance with the experience of firms in BIM. During the interview, as mentioned before, interviewees evaluated these factors based on their experiences.

As can be seen from Figure 5.7, "increasing collaboration and coordination among project participants" is a more important short-term gain for companies that have experienced less than 5 years in BIM than those that have more than 5 years of experience. The reason can be that in the beginning, companies have the motivation of improving collaboration and coordination. In the short-term, companies can enhance communication behavior and reap the benefits of it. However, over the years and as long as to increase firms' experience in BIM, other benefits might have gained importance (e.g., technical office works).

Moreover, "effective document management" and "project risk management improvement" ranked nearly equal by companies regardless of BIM experience. In addition, companies evaluate "better decision-making process" as the most critical benefit regardless of BIM experience.

Furthermore, according to Figure 5.7, as long as firms' experience level increases, they give more importance to client satisfaction and technical office works (e.g., scheduling, quantity take-off). On the other hand, companies ranked "financial performance improvement" as the least effective benefit regardless of the BIM experience of firms. It can be said that in the Turkish AEC industry, firms are not sure exactly about the financial benefits of BIM compared to other factors.

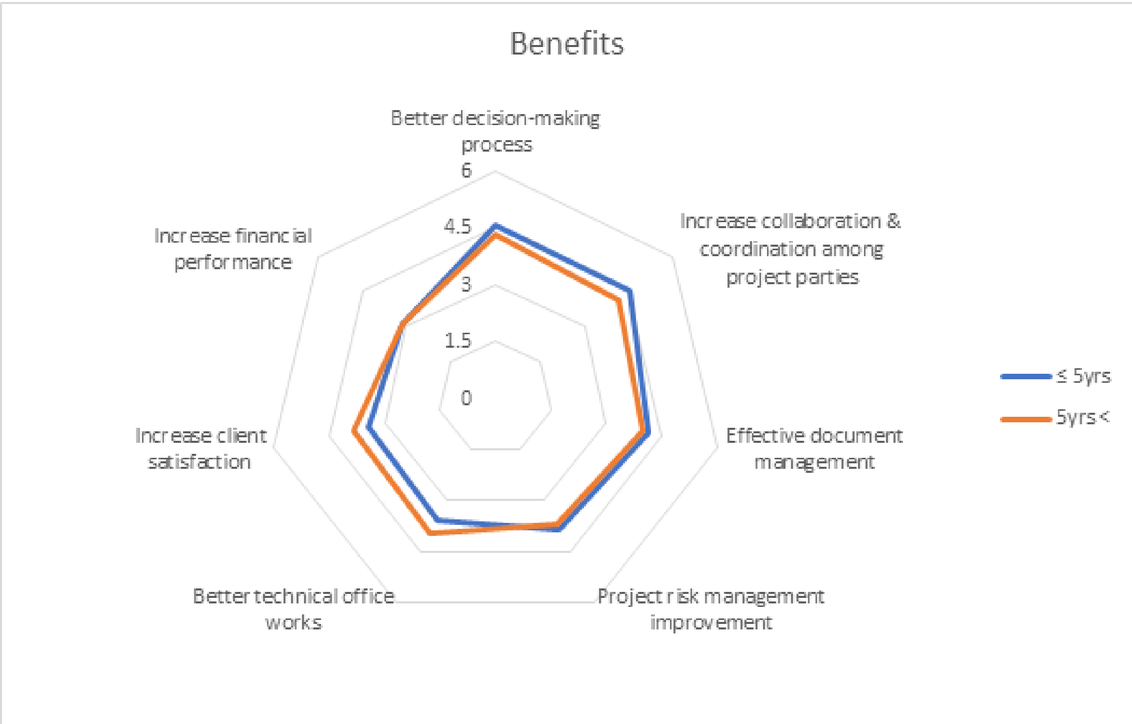

Figure 5.7. The Comparison of Benefits According to Firms' BIM Experience Level.

5.2.2. Comparison of Impacts According to BIM Experience Level of Firms

In Figure 5.8, long-term gains were compared according to the experience of companies in BIM. During the interview, as mentioned before, interviewees evaluated these factors based on their experiences.

As can be seen from Figure 5.8 that firms with more than 5 years of experience feel that the increased return on investment of BIM is a stronger effect compared to those with less than 5 years of experience. On the other hand, new adopters observe that BIM plays more significant role in the corporate image of the company. The reason may be that these companies evaluate "gaining prestige" as the important driver for transition to BIM. Because, the companies that ranked gaining prestige as an important motivation also said that improvement in the corporate image of the company is a crucial long-term gain.

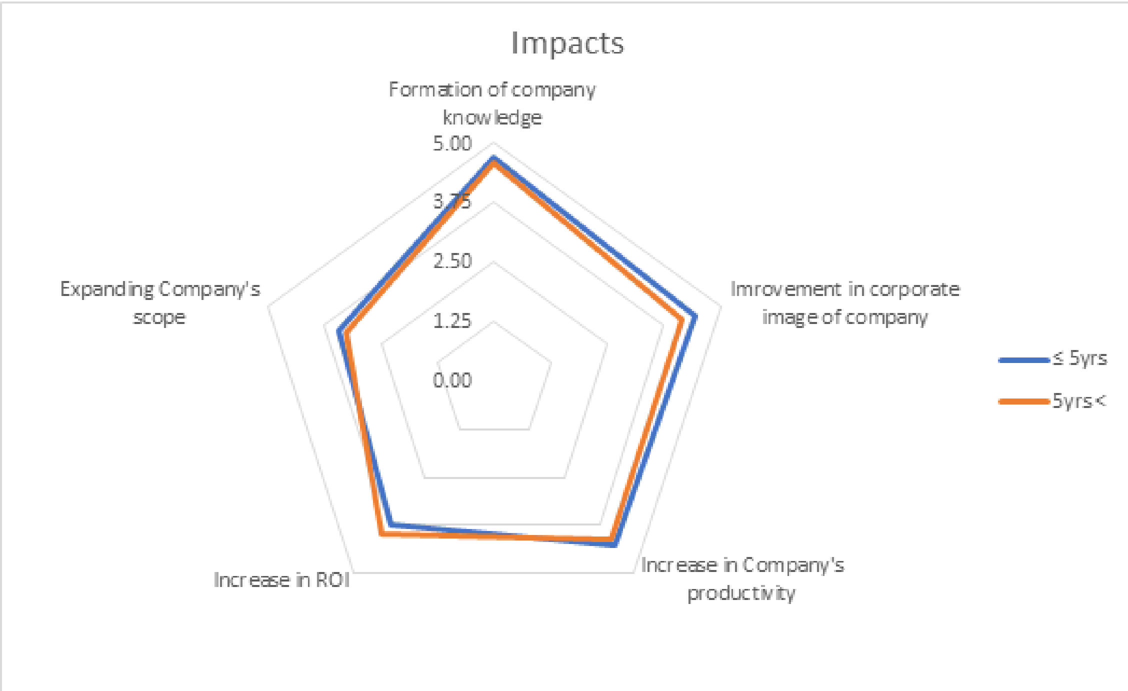

Figure 5.8. The Comparison of Impacts According to Firms' BIM Experience Level.

6. CONCLUSION

As the main aim of this thesis, the BIM transition process and the effective determinants have been examined from the perspective of the Turkish AEC industry. The first goal in this study was to determine frameworks, models, and theories for the BIM transition process through extensive literature review. The second objective was to identify and classify the factors that impacts the transition process via an extensive literature review. The third aim was to assess the factors' significance via online interviews by grouping companies' fields of operations. The last objective was to discuss the findings of interviews to elucidate the BIM transition process by comparing determinants according to the answers of the AEC companies and then comparing these answers according to firms' BIM experience level.

6.1. Conclusion Based on Research Findings

Although BIM awareness has increased in the Turkish AEC industry compared to 10 years ago, BIM usage still is very low. It is important to show the benefits and impacts of BIM to the potential users. However, this is not enough to convince the firms to shift BIM. It is needed to represent how to adopt and implement BIM, and to identified critical success factors for smooth transition.

This thesis, differently from other studies in the literature, has been proposed the BIM transition framework that consists of 3 parts and 6 stages. In addition, 6 different components that affect to transition process have been specified.

After framework and components have been identified in the result of extensive literature review, and then, most effective factors have been determined by interviewing with the Turkish AEC industry experts.

For Architecture companies based on the interviews, the most important motivation is "to improve collaboration and coordination among project participant", the main input is "generating strategy, plan and policy for BIM execution", the most facilitator factor was "top management support", the most powerful impediments were "collaboration and coordination difficulties" and "the lack of BIM education and training for transition to BIM", the main benefit was "better decision-making process", and the most critical impacts are "formation of company knowledge" and "improvement of corporate image of company" (see Table 6.1).

Table 6.1. The Most Powerful Factors for Architecture Companies.

Components	Factors
Motivation	To improve collaboration and coordination among project participant
Inputs	Generating strategy, plan, and policy for BIM execution
Enablers	Top management support
Obstacles	Collaboration and coordination difficulties
	The lack of BIM education and training for transition to BIM
Benefits	Better decision-making process
Impacts	Formation of company knowledge
	Improvement of corporate image of the company

For Architecture companies, by looking at the Table 6.1, it can be said that "top management support" and "to improve collaboration and coordination among project participant" play a critical role in pre-transition process. Maybe Architecture firms are aware of the BIM system because of their managers who give importance to innovative and technological developments. Then, they might start to positive attitude since they have intention to improve collaboration with other stakeholders. After BIM adoption decision has been made, they develop strategies and make execution plan before implementing BIM. However, during transition process, Architecture companies can suffer from the lack of BIM education and training, and they might have difficulties in collaboration and coordination with project participants. Afterwards, at the end of the implementation process, Architecture companies can obtain better decision-making process. Furthermore, in the long-term, Architectures generate their know-how and archive of knowledge which are about their previous projects. By doing this, Architecture companies improve their corporate image.

For Engineering companies based on the interviews, the most important motivation is “client requirement”, the main input is “investment in software and hardware”, the most facilitator factor is “top management support”, the most powerful impediments are “the resistance of employees towards the change”, the main benefit is “better decision-making process” and “increase collaboration and coordination among project parties”, and the most critical impact is “formation of company knowledge” (see Table 6.2).

Table 6.2. The Most Powerful Factors for Engineering Companies.

Components	Factors
Motivation	Client Requirement
Inputs	Investment in software and hardware
Enablers	Top management support
Obstacles	The resistance of employees towards the change
Benefits	Increase collaboration and coordination among project parties
	Better decision-making process
Impacts	Formation of company knowledge

When it is looked from the perspective of Engineering firms, it can be said that client requirement leads to create awareness towards BIM, and willingness of top managers persuade company to adopt BIM, or vice versa. After Engineering firms made their decision to adopt BIM, they invest in software and hardware to establish adequate infrastructure to implement BIM. On the other hand, during the transition period, it can be said that employees resist to change their working habits because of BIM, and they do not want to use it. Moreover, when implementation process finished, Engineers acquire better decision-making process and they realize that BIM improve their collaboration and coordination skills with other project parties. Last but not least, when it is looked at the long-term, engineering firms generate knowledge archive from their previous projects and experiences.

For Construction companies based on the interviews, the most important motivation is "client requirement", the main input is "business process reengineering" and "BIM education and training for employees", the most facilitator factor is "top management support", the most powerful impediments are "lack of experienced/qualified workforce inside company", the main benefit is "better decision-making process" and "increase collaboration and coordination among project parties", and the most critical impact is "formation of company knowledge" (see Table 6.3).

Table 6.3. The Most Effective Factors for Construction Companies.

Components	Factors
Motivation	Client Requirement
Inputs	Business process reengineering
	BIM education & training for employees
Enablers	Top management support
Obstacles	Lack of experienced/qualified workforce inside company
Benefits	Increase collaboration & coordination among project parties
	Better decision-making process
Impacts	Formation of company knowledge

When it is compared to Construction and Engineering companies, it can be seen that they experience similar things during the BIM transition process. To become aware of BIM, or to develop a positive attitude towards BIM, top managers' support and client requirement are effective. After the adoption decision has been made, construction firms need to change their business processes and provide their employees BIM education and training before using BIM in their projects. At the end of the implementation process, construction firms think that they improve their communication skills thanks to BIM and reap the benefits of a better decision-making process. Besides, in the long-term, construction companies can build important knowledge archives from their prior BIM projects to develop the BIM implementation process for future projects, similarly with Architecture and Engineering companies.

6.2. Recommendations

It is widely known that BIM brings about a paradigm shift in the AEC industries in the world. This innovation has also started to affect the Turkish AEC industry since last decade. However, in the Turkish AEC industry, BIM development proceed slowly when it is compared to most developed countries that use BIM. Therefore, the AEC industry in Turkey try to close this gap recently. This thesis may be shed light on the AEC firms in Turkey, and other AEC firms in developing countries like Turkey for their transition process.

6.2.1. Strategy Matrix

In the light of the findings of this thesis, a strategy matrix has been generated to make the BIM transition process much easier and more efficient for companies that want to use BIM in their projects. As it can be seen from Table 6.4 the strategy matrix composes of 4 different stakeholders, namely government, client, company, and non-governmental organization. In the rows of the figures, there are recommendations according to each stakeholder, in the columns of the figures, the periods and phases of the BIM transition process have been written. In addition, the transition stage and transition period, these suggestions affect, are marked in the figures below. The aim of creating a strategy matrix is to give advice to each stakeholder for each period and phase in order to facilitate the BIM transition process.

6.2.1.1. Government. During interviews, some company experts emphasized the potential of government impact on BIM usage in Turkey. Also, there are many researches in the literature that were indicated the government's role in BIM use (Hamma-adama and Kouider, 2019; Saka *et al.*, 2020). Therefore, it can be said that government should play important role in the BIM transition. For example, government can provide financial aid to small medium companies that are willing to use BIM. Since BIM requires high initial cost, the rate of BIM adoption in these firms is much less than the others.

Moreover, government can publish a BIM mandate program by targeting specific date on the purpose of promoting BIM usage within the construction industry. In addition, government should generate standards and make regulations by law to address liability, privacy, and security issues about BIM. Furthermore, government should publish a national BIM guide for the construction industry by working closely academy and the construction sector because it can be said that there is the need for a handbook about BIM usage in Turkey according to the findings of the interview.

Last but not least, government should establish BIM education center for new graduates. Establishing a state-supported training center can contribute positively to the industry in many ways. First of all, companies can hire these educated people, thereby they will not also spend extra money for their adaptation and BIM training. Secondly, trained, and knowledgeable people might accelerate the transition process. Lastly, technology is developing, and the use of big data has become widespread in the world. In other words, every piece of information can be transferred to the digital. However, the use of big data for buildings and cities has not become widespread. Nevertheless, it will become increasingly important in the coming years. Therefore, we need to raise generations that can implement this in the future.

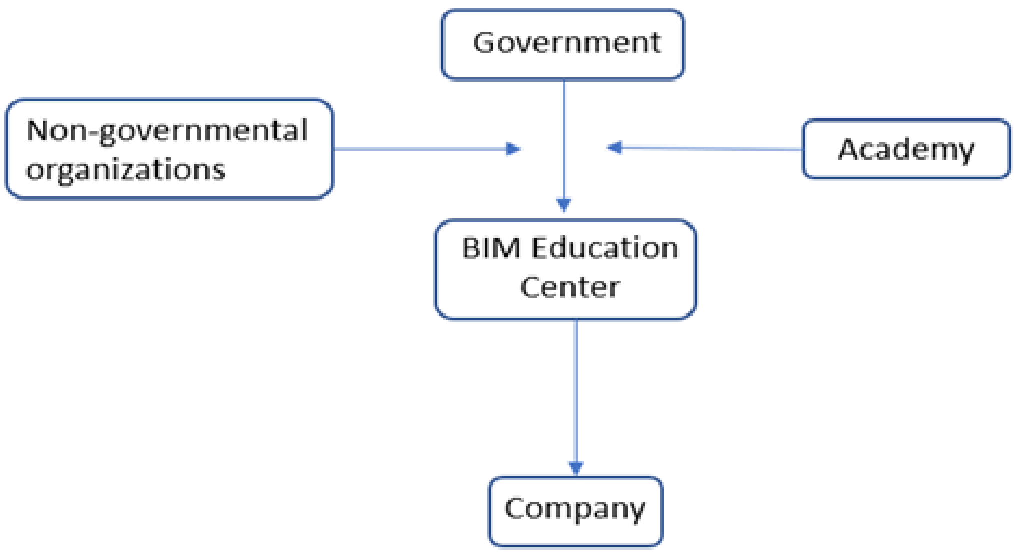

Figure 6.1. Recommended BIM Education System.

6.2.1.2. Client. Even though BIM plays an important role in multi-disciplinary collaboration among project teams, some significant problems can emerge. Therefore, client may generate information sharing protocols among project participants to ensure collaboration. Moreover, especially in big projects, there might be a lot of companies. These companies also need to work in a certain harmony within themselves. So, in order to communicate both inside the company and with other project participants productively, all work processes should be standardized and regulated. These standards and regulations can be thought as common language for project stakeholders.

Furthermore, in some cases, companies working together may not have sufficient knowledge and experience on BIM or these companies may use different programs within the BIM system. Although there are standards for data exchange (e.g., IFC), incomplete transfer can be made when converting the model to IFC data, thus the client might force project participants for using the same program to prevent erroneous conversion to IFC data.

When it is looked at the findings of the interviews, it is obvious that client requirement is the most effective driver in the Turkish AEC industry. The reason high likely is that companies hesitate to use BIM by thinking that BIM brings extra financial burden. Therefore, to enable stakeholders to use BIM in the project, client should contractually oblige the use of BIM. In addition, inexperienced companies about BIM, while the project proceeds, can change their work processes to traditional way since they think that BIM has a negative effect on the firms' economy. Therefore, to avoid these problems, everyone's role in the contract should be clearly stated at the beginning. Furthermore, BIM knowledge and experience levels of the companies should be measured before they enter the tender, and they should be allowed to participate in the tender accordingly.

6.2.1.3. Company. Collaboration is also one of the keystones in a successful project. In the Turkish AEC industry, firms have a considerable motivation to improve collaboration and coordination with other stakeholders. The reason is that the AEC industry suffers from the weakness of communication throughout the all processes of the projects. BIM can make tremendous effect on enhancing collaboration. For instance, project participants can work together on VR model. Another example is that companies can boost coordination and collaboration by using BIM-enabled cloud platforms. Cloud technology provides real-time collaboration to the companies.

To establish technological infrastructure is one of the critical milestones before implementing BIM. However, as long as technology develops, technological tools (e.g., software and hardware) inside BIM environment enhance accordingly. This advancement also brings the high cost because it is needed to renew software and hardware in time. Therefore, there must be people within the company who can follow general trends and new software and identify weaknesses by examining every newly released program. In short, there is a need for people who can see the big picture from a broader perspective. The presence of these people will make it easier to choose suitable software and hardware for the company and the project. In the end, selecting the right technological tools will benefit the company financially.

Top management support has a great impact on the BIM transition process in the Turkish AEC industry. It can be concluded that without this support, companies or individuals most likely do not use BIM. To exemplify, it is mentioned in the previous section that client requirement is the most powerful trigger for BIM transition in Turkey. However, even if there is no BIM request by the employer, managers who have BIM vision can promote employers to use BIM. When a new innovation which has a potential to change the system emerged, in the beginning, people try to protect their safe zones, and they show resistance towards the innovation. In Turkey, there is the same issue towards BIM. In order to overcome this defiance, top management support is tremendously crucial, because top managers have an opportunity to provides necessary resources.

Figure 6.2 represents proposed top managers' influence diagram. As can be seen from the diagram, Top managers play an important role in breaking the resistance of employees towards BIM. However, before do that, senior managers might decide to hire experienced people in BIM, or to take consultancy support from outside. If they decide to recruit experienced people in BIM, this person should have a strong communication skill and be a social person in order to make a facilitating effect on breaking the resistance of those who show defiance. Shortly, top managers should choose the right person to manage the transition process. On the other hand, top managers can also pressure employees to use BIM tools in their daily works, but this option might not be appropriate and sustainable. Nevertheless, companies may give incentives (e.g., rewards) for employees to break their resistance towards BIM.

On the other hand, top managers can decide to take consultancy support for the BIM transition process. It might be true that firms can get through the transition process in a less painful way by getting consultancy support. However, the significant thing that needs to pay attention in here is that people who have been consulted should have a high level of knowledge and experience about BIM. Otherwise, consultancy process will not be efficient and useful.

Once employees begin to develop a positive attitude towards BIM, they may need to undertake BIM training to understand the BIM system. In addition, it is necessary to raise the BIM awareness of different departments within the company with training. If BIM is considered as a tool that enables more efficient execution of business processes, it is necessary to explain the BIM system to departments, such as design, planning, etc. After employees accept to use BIM and are educated about BIM, the business processes should be rearranged to comply with the BIM environment to proceed with the process, effectively.

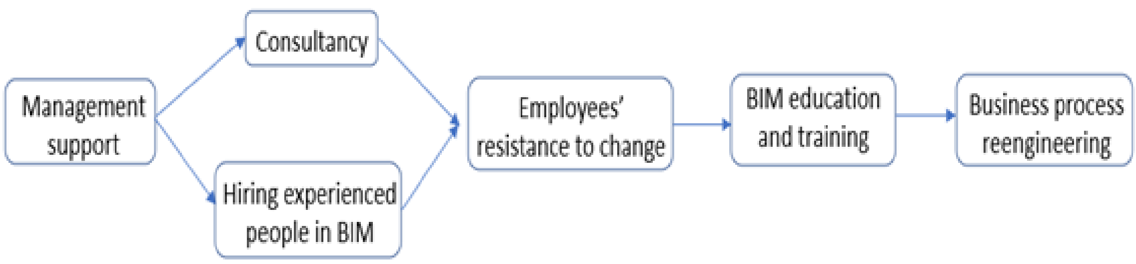

Figure 6.2. The Impacts of Senior Management on BIM Transition.

It is understood during the interview that companies should prepare BIM execution plan and determine a strategy to carry out BIM to the projects, properly. In addition, although the BIM model and the plans created over this model are made in the offices, the application will be on the construction site. Therefore, there should be engineer/s who are experienced or at least, have knowledge about BIM at the construction site. Another observation during interview is that when new systems emerge, firms that do business with many companies in Turkey and abroad become aware of these innovations earlier. Therefore, companies might expand social network to aware of new ideas earlier.

6.2.1.4. Non-governmental Organizations. Non-governmental organizations can have a great impact on the BIM transition in Turkey. First of all, BIM awareness can be increased through various ways such as social events (conferences, seminars, etc.). So, Non-governmental organizations may organize seminars and conferences to increase awareness and to enable people to develop a positive attitude towards BIM. However, the important point in these organizations is that while introducing the BIM system to increase awareness in Turkey, BIM benefits, especially in scheduling and cost estimating, should be emphasized. Because, generally, firms give importance to finish the project on time within its budget.

Additionally, as it is indicated that non-governmental organization can play a great role in raising awareness inside the AEC industry. These kinds of organizations compose of industry experts, and these people can develop strategies and plans for BIM transition. Nevertheless, they cannot do this without the help of the government. Non-governmental organizations can lead to increase BIM transition rate by working with government closely. They can together establish a committee to determine a roadmap for BIM transition.

Moreover, together with academy, non-governmental organizations can help government to develop convenient and sustainable training program. It is obvious that the quality of education is highly crucial for transition to BIM. Nevertheless, teachers who give BIM education in Turkey generally are not familiar with the AEC industry and its dynamics. Therefore, BIM training is often theoretical. To increase the qualification of BIM education and training, academy and the AEC industry should work together, and develop convenient and sustainable training program. Secondly, BIM education in Turkey is mostly related to software that are used in BIM environment (e.g., Revit), but BIM is not a software. So, the scope of education should also be expanded.

All in all, BIM's return on investment should be considered in the long term. It is not realistic to expect immediate benefits from a system that causes such a big change in a sector far from technology. This is a development that will happen with the gradual integration of all project stakeholders into the BIM system. This process also will get better with the lessons learned by companies in projects. In addition, although the top-down approach is necessary and more convenient method for BIM transition (Figure 6.3), the bottom-up approach may also be deemed. Because, engineers and architectures regardless of their managers' attitude, or government push should want to use BIM in the projects. They can also convince top managers and clients by representing BIM benefits.

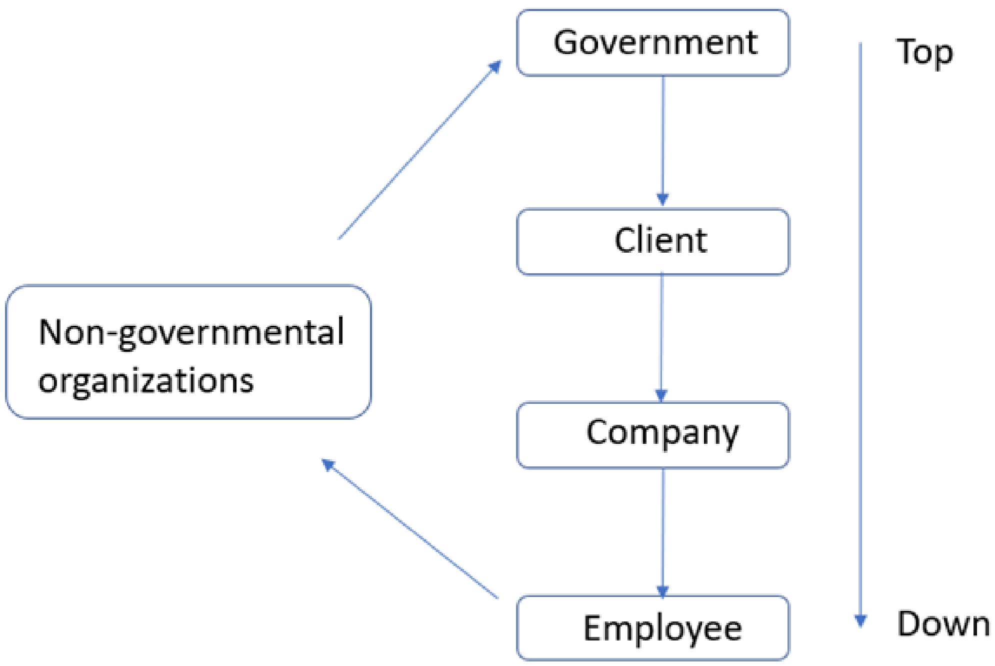

Figure 6.3. BIM Transition Mechanism in the Industry Level.

Table 6.4. Strategy Matrix for BIM Transition.

	BIM TRANSITION PERIODS	Pre-Transition Period		Transition Period		Post-Transition	
	BIM TRANSITION STAGES	Awareness	Intention	Adoption Decision	Implementation	Confirmation	BIM diffusion
STAKEHOLDERS	RECOMMENDATIONS						
Government	Government should publish BIM mandate program to promote BIM usage within construction industry	x	x	x			
	Government should provide financial aid to the companies that are willing to BIM usage		x	x	x		
	Government should generate standarts and make regulations by law to address liability, privacy, and security issues about BIM				x		x
	Government should establish BIM Education center for new graduates		x	x	x		x
	Government should publish national BIM guide for construction industry by working closely academy and construction sector	x	x		x		x
Client	Client should contractually oblige the use of BIM in the project	x	x	x	x		
	Client should clearly define project participants' role in the contract to implement BIM more efficiently				x		
	Client may generate information sharing protocals among Project participants to ensure collaboration				x		
	Client should measure BIM knowledge of companies that will enter to tender				x		
	The client might force Project participants for using the same program to prevent erroneus conversion to IFC data				x	x	

Table 6.4. Strategy Matrix for BIM Transition (cont.).

	BIM TRANSITION PERIODS	Pre-Transition Period		Transition Period		Post-Transition	
	BIM TRANSITION STAGES	Awareness	Intention	Adoption Decision	Implementation	Confirmation	BIM diffusion
STAKEHOLDERS	RECOMMENDATIONS						
Company	During the transition to BIM, senior management support within company should be a must	x	x	x	x	x	x
	Companies might use BIM-enabled technological tools(e.g. VR,						
	Cloud plaatforms) to increase collaboration				x	x	
	Companies should determine a strategy and prepare BIM execution plan before implementing BIM, if it is not available in the project				x		
	Companies can hire visionary/experienced people to make strategic decisions				x	x	x
	There should be engineer/s who are experienced or at least, have knowledge about BIM at the construction side				x		
	Companies may give incentives for employees to break the resistance towards BIM		x	x	x	x	x
	Companies might expand social network aware of new ideas earlier	x	x	x			
	Companies may take consultancy support to make BIM transition process easier				x		
Non-govermantal Organization	Non-govermantal organization should lead to establish committies about BIM usage with government together Non-govermantal organization may organize seminars and conferences to increase awareness and to enable people to develop a positive attitude towards BIM	x x					
	Together with academy, non-govermental organizations can help governement to develop convenient and sustainable training program				x		x

6.3. Future Research and Limitation

This thesis tries to explain the BIM transition process and its effective factors from the perspective of the Turkish AEC industry. It can be said that this study investigates the BIM transition process in terms of organizational level. However, the findings might change when the BIM transition process is examined from the perspective of the individual level. Besides, three parts of the BIM transition process might be scrutinized separately, and each stage can be investigated in more detail.

Moreover, the BIM transition mechanism can be investigated at the industry level as it is recommended and developed to generate roadmaps. Also, each component's role (e.g., non-governmental organizations) can be defined, thereby a BIM transition guide may be developed for everyone.

In addition, it is a fact that top management support is vital for companies to make the transition to BIM. Therefore, top managers' roles can be studied within a company at the organizational level for a smooth BIM transition. As it is proposed in the section 6, what steps should be taken by companies which are willing to use BIM can be investigated, deeply.

Furthermore, in the post-transition part, recent advancements in technology may be investigated to implement the construction projects through BIM. Blockchain and smart contracts, for example, can be examined in a case study. Another example is artificial intelligence, and health and safety environment implementations can be investigated in a pilot project. In addition, Internet of Things implementation through BIM can be scrutinized in the scope of facility management.

Even though this research is a comprehensive study, there is a limitation of the study since the number of participants is low. The number of respondents can be increased by conducting an extensive online questionnaire survey. If more people participate the study, more accurate results can be obtained.

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APPENDIX A: INTERVIEW FORM

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

	Thesis	:
	Student	:
	Professor	:
	General Information (Interviewee)	
1	Interviewee	:
2	Profession	:
3	Your position in your company	:
4	Your experience in construction industry	:
5	Your experience in BIM	:
	General Information (Company)	
1	Company name (not obligatory)	:
2	Number of years that your company has been operating	:
3	Field of operation of your company	: ☐ Engineering ☐Architecture ☐Construction
4	Your company's expertise areas	: ☐ Buildings ☐Infrastructure ☐Transportation ☐Diğer
5	Total number of projects that your company involved in	: ☐<10 ☐ 10-30 ☐30-50 ☐50<
6	How long has BIM been used in your company? (year)	: ☐ <1 ☐ 1-3 ☐3-5 ☐5<
7	Total number of projects that your company utilized BIM	:
	General Information (Projects)	
1	What is the average cost of your BIM applied projects?	: ☐<20Mn ☐ 20Mn-100Mn ☐100Mn-500Mn☐500Mn<
2	What is the average completion time of your BIM applied projects?	: ☐<12 ☐12-24 ☐ 24-36 ☐36<
3	Number of employees in your BIM team	:
4	What are the software programs you use within the scope of BIM?	: Revit/3D Studio Max/ArchiCAD/Dynamo/ GIS/Aconex/BIM Track/BIM360/Tekla BIM Sight/ Allplan/BlueBIM/Navisworks/Synchro/ITWO/Solibri/BIM collab./grasshopper/Rhino
5	On which subject has BIM been used in your poroject?	: 3D Collaboration/Clash Detection/4D Simulation/5D Simulation/Energy Analysis/Facility Management/Quantity Take-off/Document Management

Figure A.1. Interview Form 1.

Motivations

		1	2	3	4	5
1	Client Requirement					
2	Design productivity improvement					
3	Project Performance improvement					
4	Government push					
5	To improve collaboration & coordination					
6	To gain competitive advantage					
7	Corporate organizations push					
8	To gain prestige					

Inputs

		1	2	3	4	5
1	BIM education & training for employees					
2	Generate strategy, plan and policy for BIM execution					
3	Investment in software & hardware					
4	Take outsourcing support					
5	Using 3D library					
6	Business process reengineering					
7	Hiring experienced/qualified staff					

Enablers

		1	2	3	4	5
1	Top management support					
2	Availability of experienced/qualified staff in company					
3	Having dynamic, collaborative, supportive work environment					
4	Having adequate level technological infrastructure					
5	Positive attitude of workers towards BIM					
6	Compatibility with values, beliefs and practices					
7	Having collaborative project delivery system					
8	Advanced R&D capability of company					

Figure A.2. Interview Form 2.

Obstacles

		1	2	3	4	5
1	Required high initial cost for BIM transition					
2	Lack of standards, laws and regulations for BIM					
3	Lack of experienced/qualified workforce inside company					
4	ROI of BIM is uncertain					
5	Employees resist to change					
6	Lack of interoperability among software applications					
7	Lack of management support					
8	Lack of government support					
9	Collaboration & coordination problems among different parties					
10	Lack of BIM education & training for the transition of BIM					
11	Lack of BIM awareness among stakeholders					

Benefits

		1	2	3	4	5
1	Increase financial performance					
2	Increase collaboration & coordination among project parties					
3	Effective document management					
4	Project risk management improvement					
5	Increase client satisfaction					
6	Better technical office works					
7	Better decision-making process					

Impacts

		1	2	3	4	5
1	Increase in ROI					
2	Imrovement in corporate image of company					
3	Expanding Company's scope					
4	Increase in Company's productivity					
5	Formation of company knowledge					

Figure A.3. Interview Form 3.