**ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY**

# AN ASSESSMENT OF BUILDING INFORMATION MODELING IMPLEMENTATION FOR THE TURKISH TRANSPORTATION INFRASTRUCTURE INDUSTRY

**M.Sc. THESIS**

**Feyza YİĞİTER**

**Department of Civil Engineering**

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**JULY 2020**

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**Thesis Advisor: Prof. Dr. Ali Osman ATAHAN**

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**İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ**

# YAPI BİLGİ MODELLEMESİ UYGULAMASININ TÜRK ULAŞTIRMA ALTYAPI SEKTÖRÜ İÇİN BİR DEĞERLENDİRMESİ

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**Date of Submission : 03 June 2020**
**Date of Defense : 13 July 2020**

***To my family,***

**FOREWORD**

Primarily, I would sincerely like to express my appreciation and thanks to my thesis advisor Prof. Dr. Ali Osman ATAHAN, for his valuable guidance in every step of this study. The completion of my thesis would not have been possible without his experience and support.

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June 2020

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(Civil Engineer)

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## ABBREVIATIONS

| | |
|---|---|
| **AEC** | : Architecture, Engineering, Construction |
| **AGC** | : Associated General Contractors of America |
| **BCA** | : Building and Construction Authority |
| **BDS** | : Building Description System |
| **BIM** | : Building Information Modeling |
| **BSI** | : British Standards Institute |
| **bsK** | : buildingSMART Korea |
| **CAD** | : Computer-Aided Design |
| **CIC** | : Construction Industry Council |
| **CIM** | : Civil Information Modeling |
| **COBIM** | : Common BIM Requirements |
| **CSC** | : Certificate of Successful Completion |
| **EFA** | : Exploratory Factor Analysis |
| **EUPPD** | : European Union Public Procurement Directive |
| **IFC** | : Industry Foundation Classes |
| **ISO** | : International Organization for Standardization |
| **IT** | : Information Technologies |
| **KMO** | : Kaiser–Meyer–Olkin |
| **NBIMS-US** | : United States National Building Information Model Standard |
| **NIBS** | : National Institute of Building Sciences |
| **O&M** | : Operation and Maintenance |
| **PCA** | : Principal Component Analysis |
| **ROI** | : Return on Investment |
| **VDC** | : Virtual Design and Construction |

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**AN ASSESSMENT OF BUILDING INFORMATION MODELING IMPLEMENTATION FOR THE TURKISH TRANSPORTATION INFRASTRUCTURE INDUSTRY**

## SUMMARY

Transportation infrastructure, which includes highways, railways, bridges, airports, and tunnels, is an integral part of the socio-economic development of a country. There is a great need for innovative techniques and technologies that increase productivity and efficiency in terms of time, cost, and quality for the design, construction, operation, and maintenance of transportation structures due to the growing population and the increasing demand for transportation. Building Information Modeling (BIM), an innovative technology widely adopted in the construction industry, has the potential to revolutionize the transportation infrastructure industry due to the knowledge-based nature of transportation infrastructure projects.

BIM enables the creation of a 3D object-based and parametric model of a structure, and the BIM model supports collaborative working and interoperability among all disciplines via a digital information-sharing platform. It aims to ensure that all the information generated through the lifecycle of a project is accurately and efficiently stored, shared and used, thereby to make the decision-making and problem-solving processes easier, quicker and more accurate based on the information, and ultimately to minimize the possible time, cost and quality losses of the project.

While the initiatives and investments are increasing in Turkey, as with the other countries in the world, BIM is not widely implemented in the Turkish transportation infrastructure industry. Although the implementation and adoption of BIM in the Turkish transportation infrastructure industry are inevitable, the process is slow due to the challenges and limitations.

Various strategies have been developed worldwide for the adoption of BIM. Although there are many studies around the world that aim to reveal the challenges and propose preventative strategies to the challenges regarding the implementation of BIM in construction projects in general, the studies that conduct this research for transportation infrastructure projects are very limited.

The aim of this study is (1) to identify the challenges of BIM implementation for the Turkish transportation infrastructure industry, and (2) to propose preventative actions to the identified challenges. To achieve this aim, firstly, a literature review was conducted in order to obtain available information related to BIM and its implementation within the transportation infrastructure industry, both worldwide and in Turkey, and identify the common challenges and preventative actions to these challenges regarding BIM implementation. In light of this information, a questionnaire survey was designed with 13 challenge items and 11 preventative action items to collect data and conduct quantitative statistical analysis by applying the aforementioned questionnaire amongst BIM professionals who have experience in

transportation infrastructure projects in Turkey to investigate their perceptions regarding the challenges to BIM implementation and preventative actions to these challenges for the Turkish transportation infrastructure industry. The results of this survey were digitized and analyzed with descriptive statistics and exploratory factor analysis (EFA) methods by using a statistical analysis program named SPSS.

In this regard, descriptive statistics were used to detect the most significant and critical challenges and preventative actions. According to the results of the descriptive statistics, it is concluded that (1) lack of regulations and contractual arrangements specified for BIM, (2) the resistance to the adversity of changing working culture and adapting to a new and unfamiliar system and (3) lack of demand and enforcement of BIM utilization from public authorities are the most critical challenges. As for the preventative actions, it is concluded that (1) BIM implementation in governmental agencies in order to lead the Turkish transportation infrastructure industry, (2) development of BIM-specific contracts and regulations by governmental authorities and (3) company incentives for employees to learn to work with BIM and its software are the most significant preventative actions. EFA was used to specify the underlying challenge and strategy factors of BIM implementation in the Turkish transportation infrastructure industry. According to the results of the EFA, three factors, named (1) organization, (2) initial stage, and (3) leadership, were identified for 13 challenge items of BIM implementation in the Turkish transportation infrastructure industry. As for the preventative actions, three factors, named (1) private sector, (2) government, and (3) education, were identified for 11 items of preventative actions to the challenges of BIM implementation in the Turkish transportation infrastructure industry.

Since all of the transportation infrastructure projects in Turkey are public projects, it is considered that leadership of the public institutions is the most effective strategy for the adoption of BIM in the Turkish transportation infrastructure industry. Accordingly, it is anticipated that the adoption of BIM primarily in the public institutions will effectively lead the adoption of BIM in the private sector and prevent the resistance to the adversity of changing working culture, which is determined as one of the most important challenges, for both public and private sectors, and eliminate many other organizational barriers. In addition, it is anticipated that supporting this transition progress with regulations, standards, and contractual arrangements will enable progressive and more conscious progress, facilitate and accelerate the transition, and ensure the most accurate and effective utilization of BIM. Besides, it is considered that to increase the awareness and knowledge of all project parties about the benefits of BIM, training and certification programs should be arranged and promoted by companies and public institutions. It is anticipated that training incentives will facilitate to overcome especially the organizational and initial stage related resistances and barriers.

In conclusion, this study is intended to facilitate further researches in this domain and to contribute to the studies and strategies to be developed for the implementation of BIM in Turkish transportation infrastructure projects.

## YAPI BİLGİ MODELLEMESİ UYGULAMASININ TÜRK ULAŞTIRMA ALTYAPI SEKTÖRÜ İÇİN BİR DEĞERLENDİRMESİ

## ÖZET


Ulaştırma altyapısı, karayolları, demiryolları, köprüler, havaalanları ve tüneller ile, bir ülkenin kalkınmasının ve sosyo-ekonomik gelişiminin ayrılmaz bir parçasıdır. Artan nüfus ve buna bağlı olarak büyüyen ulaşım talebi nedeniyle ulaştırma yapılarının tasarımı, yapımı, işletmesi ve bakımı için zaman, maliyet ve kalite gibi açılardan üretkenliği ve verimi artıracak yenilikçi teknik ve teknolojilere büyük ihtiyaç duyulmaktadır. İnşaat sektöründe geniş çapta benimsenmiş yenilikçi bir teknoloji olan Yapı Bilgi Modellemesi, ulaştırma projelerinin bilgi temelli doğası nedeniyle ulaştırma altyapı sektörü için bir devrim yaratma potansiyeline sahiptir.

Yapı Bilgi Modellemesi, bir yapının nesne tabanlı ve parametrik bir modelinin oluşturulmasını ve bu modelin dijital bir bilgi paylaşım platformunda projedeki tüm disiplinler tarafından yapının tüm yaşam döngüsü boyunca ortak olarak geliştirilerek kullanılmasını sağlayan bir çalışma sistemi ve tekniğidir. Temel olarak, yapının tasarım, inşaat, işletme ve bakım süreçlerinde oluşturulan tüm bilginin doğru ve verimli bir şekilde saklanması, paylaşılması ve kullanılması ile karar alma ve problem çözme süreçlerinin bilgiye dayalı hale getirilmesini ve böylelikle projenin olası zaman, maliyet ve kalite kayıplarının en aza indirilmesini hedeflemektedir.

Yapı Bilgi Modellemesi konseptinin gelişiminin temeli olarak kabul edilen ilk bilgisayar destekli tasarım (CAD) sistemleri 1960'ların başında gelişmeye başlamıştır. Bu sistemlerin büyük çoğunluğunun sadece dijital çizim ve geometrik modelleme araçları olmasına ve problem çözme süreçlerini neredeyse hiç desteklememesine rağmen, potansiyel avantajları bu yıllarda görülmeye başlanmıştır. 1970'lerde, Amerika Birleşik Devletleri ve İngiltere'den birkaç araştırmacı, inşaat sektörünün daha entegre ve birlikte çalışılabilir araçlara ihtiyaç duyduğunu fark etmiş ve bu ihtiyacın giderilmesi için prototip sistemler önermişlerdir. Yıllar içinde teknolojinin ilerlemesiyle özel yazılımların geliştirilmesi ve kişisel bilgisayarların kullanımlarının yaygınlaşması sonucunda bu sistemler geliştirilerek Yapı Bilgi Modellemesi adı altında hayata geçirilmiştir.

Yapı Bilgi Modellemesi, son yıllarda inşaat sektöründe yaygın olarak kullanılmaya başlanmış ve dünya çapında inşaat projelerinde geniş çapta benimsenmiştir. Amerika Birleşik Devletleri, İngiltere, Danimarka, Finlandiya ve Norveç Yapı Bilgi Modellemesi uygulamasının dünyadaki öncüleri olarak gösterilebilir. Dünya çapında ulaştırma altyapı inşaat projelerinde kullanımı ve benimsenmesi henüz bina projelerinde olduğu kadar yaygın hale gelmemiş olmasına rağmen, bina projelerindeki uygulamalar sonucunda görülen avantajlar ve elde edilen deneyimler, ulaştırma altyapı sektöründe Yapı Bilgi Modellemesi'nin uygulanması için hızlandırıcı ve kolaylaştırıcı bir etki oluşturmaktadır.

Dünya çapında Yapı Bilgi Modellemesi'nin yaygınlaşması ve bu teknolojiden en verimli şekilde yararlanılabilmesi için çeşitli stratejiler geliştirilmiştir. Hükümet ve kamu kuruluşları tarafından Yapı Bilgi Modellemesi'nin inşaat projelerinde kullanımının zorunlu hale getirilmesi, ulusal ve uluslararası Yapı Bilgi Modellemesi kılavuzlarının ve standartlarının geliştirilmesi ve Yapı Bilgi Modellemesi'ne yönelik eğitim ve sertifika programlarının düzenlenmesi bunlar arasında sayılabilir.

Türkiye'de de İstanbul Büyükşehir Belediyesi tarafından İstanbul'daki raylı sistemler projelerinde Yapı Bilgi Modellemesi kullanılması zorunlu hale getirilmiştir. Üniversitelerde Yapı Bilgi Modellemesi dersleri verilmeye ve sertifika programları düzenlenmeye başlanmıştır. Buna karşın Türkiye inşaat projelerinde Yapı Bilgi Modellemesi'nin benimsenmesi konusunda henüz erken aşamalardadır. Ayrıca ulaştırma altyapı inşaat projelerinde Yapı Bilgi Modellemesi'nin kullanımının dünya çapındaki öncü ülkelerde dahi erken aşamalarda olması da göz önüne alındığında, Türk ulaştırma altyapı sektöründe Yapı Bilgi Modellemesi'nin yaygınlaşması ve benimsenmesinin bu konuda giderek artan girişim ve yatırımlara rağmen çeşitli engellerle dolu zorlu bir süreç olduğu görülmektedir.

Yapı Bilgi Modellemesi'nin genel olarak inşaat projelerinde uygulanmasına yönelik zorlukları ortaya çıkarmayı amaçlayan dünya çapında birçok araştırma olmasına rağmen, bu konuda ulaştırma altyapı inşaat projelerine yönelik yapılan araştırmalar oldukça az sayıdadır. Bununla birlikte, Türk ulaştırma altyapı sektöründe Yapı Bilgi Modellemesi'nin uygulanmasının önündeki engelleri belirlemeyi ve bu engelleri ortadan kaldıracak stratejileri ortaya çıkarmayı amaçlayan araştırmaların sayısı oldukça sınırlıdır.

Buradan yola çıkılarak bu tez çalışması kapsamında, Yapı Bilgi Modellemesi'nin Türk ulaştırma altyapı sektöründe uygulanmasının önündeki engellerin tespit edilmesi ve bu engellere karşı alınabilecek önlemlerin ortaya çıkarılması amaçlanmaktadır. Bu amaç doğrultusunda öncelikle bir literatür taraması yapılmış ve çalışmanın temelini oluşturan konular sunulmuştur. Daha sonra, dünyada bu konuda yapılan çalışmalar ve Türk ulaştırma altyapı sektörünün mevcut durumu değerlendirilerek, Yapı Bilgi Modellemesi'nin Türk ulaştırma altyapı sektöründe uygulanmasının ve benimsenmesinin önündeki 13 adet engel maddesi belirlenmiş ve bu engellere karşı alınabilecek 11 adet önlem maddesi ortaya çıkarılmıştır. Bu engel ve önlem maddelerinin Türk ulaştırma altyapı sektörü için anlamlılığının sayısal olarak analiz edilmesi amacıyla, bu maddelerle birlikte Yapı Bilgi Modellemesi kullanımının sektördeki mevcut durumunu tespit etmeyi amaçlayan soruları da içeren bir anket araştırması hazırlanmıştır. Bu araştırma için, Yapı Bilgi Modellemesi ile çalışma deneyimi olan ve aynı zamanda Türkiye'de gerçekleşen bir ulaştırma altyapı inşaat projesinde tecrübe sahibi olan kişiler hedef grup olarak belirlenmiştir. Yapılan bu araştırmanın sonuçları sayısallaştırılmış ve SPSS adlı istatistiksel analiz programı kullanılarak betimsel istatistik ve açımlayıcı faktör analizi (EFA) yöntemleriyle analiz edilmiştir.

Bu bağlamda, betimsel istatistik analiz yöntemi kullanılarak, öne sürülen engel ve önlem stratejilerinden hangilerinin Türk ulaştırma altyapı sektörü için daha anlamlı olduğu tespit edilmiştir. Analiz sonuçlarına göre (1) Yapı Bilgi Modellemesi için belirlenmiş yönetmelik ve sözleşmesel düzenlemelerin eksikliği, (2) çalışma kültürünü değiştirmenin ve alışılmadık bir sisteme uyum sağlamanın getireceği sıkıntılı sürece karşı direnç ve (3) Yapı Bilgi Modellemesi kullanımı ile ilgili kamu kurumlarından gelen talep ve yaptırım eksikliği en önemli üç engel olarak belirlenmiştir. (1) Kamu kurumlarının Türk ulaştırma altyapı sektörüne liderlik etmek için Yapı Bilgi Modellemesi'ne geçiş sağlaması, (2) devlet yetkilileri tarafından özel Yapı Bilgi Modellemesi sözleşmelerinin ve yönetmeliklerinin geliştirilmesi ve (3) şirketlerin çalışanlarını Yapı Bilgi Modellemesi ve yazılımlarıyla çalışmayı öğrenmeye teşvik etmesi ise en önemli üç önlem stratejisi olarak belirlenmiştir. Daha sonra, bu maddelerin altında yatan asıl anlam ve sebeplerin tespit edilmesi ve maddeler arasındaki ortak anlamların ortaya çıkarılması amacıyla açımlayıcı faktör analizi kullanılmıştır. Analiz sonucunda elde edilen matris çıktıları yorumlanmış ve engel maddeleri için (1) organizasyon, (2) ilk aşama ve (3) liderlik adları altında 3 ana faktör, engelleri önleyici faaliyetler için ise (1) özel sektör, (2) hükümet ve (3) eğitim adları altında 3 ana faktör ortaya çıkarılmıştır. Engeller ve engelleri önleyici stratejiler bu faktörler altında gruplandırılarak incelenmiş ve yorumlanmıştır.

Türkiye'de ulaştırma altyapı projelerinin kamu projesi olması nedeniyle Yapı Bilgi Modellemesi'ne yönelik sektörel dönüşüme kamu kurumlarının liderlik etmelerinin en etkili faktör olduğu düşünülmektedir. Bu bağlamda, Yapı Bilgi Modellemesi sisteminin öncelikle kamu kurumlarında benimsenmesine yönelik adımların atılmasının, Türk ulaştırma altyapı projelerinde Yapı Bilgi Modellemesi'nin uygulanmasını sağlamak adına en önemli stratejilerden biri olacağı ve özel sektörde Yapı Bilgi Modellemesi'nin benimsenmesine etkin bir biçimde öncülük edeceği öngörülmektedir. Bunun hem kamu hem de özel sektör için Yapı Bilgi Modellemesi kullanımının önündeki en önemli engellerden biri olarak belirlenen çalışma kültürünü değiştirmeye karşı direncin önüne geçilmesi ve bunun dışındaki birçok organizasyonel engelin ortadan kaldırılması için en kritik önleyici faaliyetlerden biri olacağı düşünülmektedir. Ayrıca bu dönüşümün yönetmelikler, standartlar ve sözleşmesel düzenlemelerle desteklenmesinin de Yapı Bilgi Modellemesi'ne aşamalı olarak ve daha bilinçli adımlarla geçişi sağlayacağı, geçiş sürecini kolaylaştırıp hızlandıracağı ve Yapı Bilgi Modellemesi'nden en doğru ve etkin bir biçimde faydalanılabilmesine olanak tanıyacağı öngörülmektedir. Ayrıca şirketler ve kamu kurumları tarafından Yapı Bilgi Modellemesi eğitim ve sertifika programlarının düzenlenmesinin ve teşvik edilmesinin Yapı Bilgi Modellemesi'nin sağlayacağı faydalarla ilgili farkındalığı ve bilgi seviyesini artıracağı ve böylelikle organizasyon ve ilk aşama ile ilgili bariyerlerin aşılmasında önemli bir rol oynayacağı düşünülmektedir.

Son olarak, bu tez çalışmasından elde edilen verilerin ve sonuçların Türkiye'de ulaştırma altyapı sektöründe Yapı Bilgi Modellemesi'nin uygulanması ve benimsenmesini konu alacak olan araştırmaların gelişimine yardımcı olması ve sektörel değişimin sağlanması adına atılacak olan adımlara ve geliştirilecek stratejilere katkı sağlaması amaçlanmaktadır.

# 1. INTRODUCTION

Transportation infrastructure is a crucial component of the social and economic growth of a country by providing mobility and accessibility with highways, railways, bridges, airports, and tunnels. The transportation infrastructure industry, as with the other industries, has been affected by the advancement of technology and digitalization. As a consequence of the information-based nature of this industry, digitalization has the potential to make a revolution in the planning, design, construction, operation, and maintenance phases of the transportation infrastructure projects.

Building Information Modeling (BIM) as an innovative technology has become popular in the construction industry in recent years (Eastman et al, 2011). BIM enables the creation of a 3D object-based parametric model of a structure and supports collaboration and interoperability among all disciplines via a digital information-sharing platform. BIM provides numerous benefits in different stages of the project lifecycle, including earlier and more accurate visualizations of design, increased collaboration in the project, the discovery of design omissions and errors before construction, improved structure performance and quality, improved sustainability, and energy efficiency, and more efficient operation and management of facilities (Sacks et al, 2018).

BIM has been widely adopted in building projects around the world. Although the implementation of BIM in transportation infrastructure projects has been relatively slow, the advantages and experiences gained from the implementation of BIM in building projects have become a driving force for BIM adoption in the transportation infrastructure industry. Thus, implementing BIM in transportation infrastructure projects is increasing rapidly around the world (Bradley et al, 2016). Dodge Data & Analytics (2017) conducted a study to measure the growth of BIM implementation in the transportation infrastructure industry. The study showed that while BIM was implemented on average 22% of transportation infrastructure projects in the US, UK, France, and Germany in 2015, the implementation rate reached 54% in 2017.

Currently, BIM is not widely implemented in the Turkish transportation infrastructure industry, however, initiatives and investments are increasing as with the other countries all around the world. Although the adoption of BIM in the transportation infrastructure industry is inevitable, the process is slow due to the limitations and challenges. There are some research studies aimed to specify the challenges to BIM implementation for construction projects. However, the research studies that aim to reveal challenges to BIM implementation in the Turkish transportation infrastructure industry, and to enhance preventative actions to these challenges are very limited.

## 1.1 Objective

The main objectives of this thesis are to analyze the challenges of BIM implementation for the Turkish transportation infrastructure industry and to propose preventative actions to the challenges. In this regard, it is aimed to detect the most critical challenges and preventative actions among the variables designed for the survey and specify the underlying factors of the challenges and the preventative actions. Hence, it is aimed to facilitate further researches in this domain and to contribute to the studies and strategies to be developed for the implementation of BIM in transportation infrastructure projects in Turkey.

## 1.2 Research Methodology

The research methodology was chosen to satisfy the research objectives. First of all, a literature review regarding BIM and its implementation within the transportation infrastructure industry, both worldwide and in Turkey, was conducted to obtain available information. In light of this literature review, common challenges, and preventative actions to the challenges regarding BIM implementation were identified to design a questionnaire survey. A quantitative research methodology was adopted by applying this questionnaire amongst BIM professionals who have experience in transportation infrastructure projects in Turkey. The survey aimed to investigate their perceptions regarding the challenges to BIM implementation and required preventative actions to the challenges for the Turkish transportation infrastructure industry. The data obtained from the survey were analyzed using statistical analysis methods which are descriptive statistics and exploratory factor analysis (EFA). Descriptive statistics were used to detect the most significant and critical challenges and preventative actions among the variables, and EFA was used to identify the underlying challenge factors of BIM implementation in the Turkish transportation infrastructure industry and the underlying preventative action factors to the challenges.

### 1.3 Organization of the Thesis

Section 2 includes definitions of BIM, the historical development of BIM, global strategies for BIM implementation. Global strategies for BIM implementation are collected under the following headings: (1) leadership in the public and private sectors, (2) national and international guides and standards and (3) BIM education, training and research. At the end of Section 2, the current situation of BIM implementation in Turkey is presented. In Section 3, BIM implementation for the transportation infrastructure industry is evaluated by comparing BIM for building projects and transportation infrastructure projects and assessing BIM from the point of transportation infrastructure types. Section 4 presents the research methodology by describing the data collection method, target population, and questionnaire design and development. Section 5 presents the analysis methods and the results of the survey in detail. In the final chapter, all the findings are composed and discussed.

# 2. BUILDING INFORMATION MODELING (BIM)

The previous section provided the introductory details for the study of the thesis. This section is aimed to present further information about Building Information Modeling (BIM) based on the relevant sources of literature. Hence, definitions and historical development of BIM, global strategies for BIM implementation, and current situation of BIM in Turkey were reviewed. In light of this information obtained from the research, a basis was provided for the preparation of the questionnaire.

## 2.1 Definitions of BIM

In the literature, a lot of various definitions have been used for BIM with different perspectives.

As described by the United States National Building Information Model Standard (NBIMS-US) Project Committee, BIM "is a digital representation of physical and functional characteristics of a facility. As such, it serves as a shared knowledge resource for information about a facility, forming a reliable basis for decisions during its life cycle from inception onward." (NIBS, 2015). The Associated General Contractors of America (AGC) describes BIM as "a data-rich, object-oriented, intelligent and parametric digital representation of the facility, from which views and data appropriate to various users' needs can be extracted and analyzed to generate information that can be used to make decisions and improve the process of delivering the facility." (AGC, 2006).

BIM approach has various dimensions, each of which is extended versions of their sub-dimensions with one extra variable. The dimensions of BIM approach can be distinguished as follows (Czmoch & Pekala, 2014):

- BIM 3D - Virtual parametric model
- BIM 4D – Scheduling (Time)
- BIM 5D – Estimating (Cost)
- BIM 6D - Sustainability
- BIM 7D - Facility management

According to Eastman et al. (2011), models created using BIM technology comprise intelligent and parametric characteristics besides three-dimensional (3D) data and graphic visualization. The intelligent objects allow integration and analysis, and the parametric feature prevents the formation of incorrect views of the model. Costin et al. (2018) also support this view by stating that considering BIM as an only 3D model of a structure with functions is misleading. BIM is expected to incorporate the 3D computer-aided-design (CAD) model of a structure with all the information related to the planning, design, product information, schedule sequencing, construction, and operation of the structure rather than to comprise the only visualization. In other words, the 3D function of the BIM models is just the figuration of the information that is incorporated into the model. 3D visual data models are the storage of information and data throughout the lifecycle of a real-life object and the models represent the physical and functional features of that object (Costin, 2016).

Bradley et al. (2016) suggested the idea that BIM produces a productive and innovational environment for a project by courtesy of its 4 key elements and the interaction of these 4 elements with each other. The mentioned elements were stated as “collaboration”, “representation”, “process” and “lifecycle” as shown in Figure 2.1.

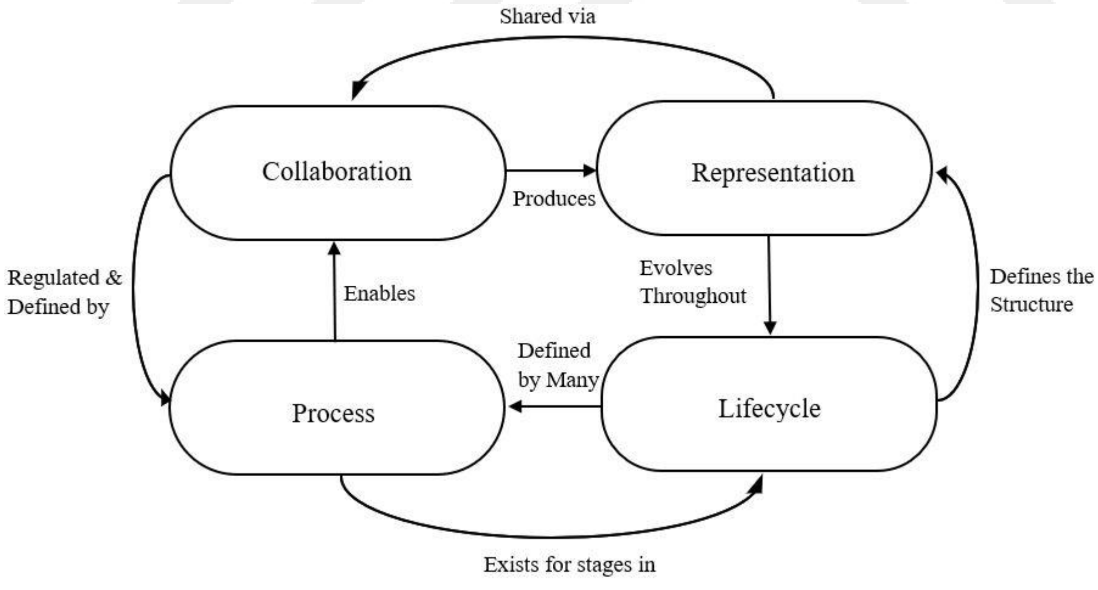


**Figure 2.1 :** 4 key elements of BIM (Bradley et al, 2016).

## 2.2 Historical Development of BIM

The initial CAD systems, which can be considered as the basis of the development of the BIM concept, started to develop in the early 1960s. Despite the fact that the vast majority of the systems are only draughting and geometric modeling tools in digital form, and do not support for the problem-solving process, their potential advantages for design began to be realized in these years. In the 1970s, a few leading researchers from Great Britain and the United States recognized the fact that the architecture, engineering and construction (AEC) industry needed more integrated and interoperable tools; and proposed extensive integrated prototype design systems that could be utilized throughout the entire design process (Björk, 1995).

Successful one of these projects was the Building Description System (BDS) developed by Charles M. (Chuck) Eastman who is currently a Professor at the Georgia Tech School of Architecture. BDS was the first software that has a library of elements that could be used and manipulated in different models (Quirk, 2012). Eastman suggested that BDS would work as a coordination and analyzation tool capable of performing visual and quantitive analyses for the drafting process and for detecting clashes, using a single integrated database, and thus BDS would provide significant time and cost efficiency for the projects designed utilizing this system (Eastman, 1975). However, due to this program was developed a long time before the personal computers got wide popularity, it could not become widespread (Dobelis, 2013).

ArchiCAD, the first BIM software that could be used on personal computers, was developed in 1982 in Budapest, Hungary. Although it was not used in large scale projects due to the industrial and technological challenges, the development of this program can be considered as the real beginning of BIM in the sense that it is perceived today. In the following years, as a result of the efforts to develop a software that could handle more complex projects than ArchiCAD, Revit software program was developed in 2000. The development of Revit was revolutionary because it enables to simulate the construction process, and produce construction schedules, real-time cost estimation and material quantities due to its fourth dimension of time (Quirk, 2012).

## 2.3 Global Strategies for BIM Implementation

In this section, BIM implementation strategies followed by the countries in the world are collected under the following subsections: (1) leadership in the public and private sectors, (2) national and international guides and standards, and (3) BIM education, training and research.

### 2.3.1 Leadership in the public and private sectors

One of the key strategies needed for successful BIM implementation is leadership in the public and private sectors. Leadership is a critical driver for cultural change to adopt collaboration culture, dealing with the organizational barriers and initial stage related difficulties of BIM implementation.

It is an outstanding example of leadership that the European Union Public Procurement Directive (EUPPD) leads all the 28 European Member States to encourage, specify or mandate the implementation of BIM for their public construction projects. It is expected that this strategy will boost the global competitiveness of the European Union construction industry (Autodesk, 2014).

All around the world, there are many governments and other public institutions that mandate the utilization of BIM on their construction projects to lead the construction industry and benefit from the advantages of BIM, and therefore enhance the quality and efficiency of the projects. These mandates have been effective for the implementation and adoption of BIM in the national construction industries since the vast majority of large-scale building projects and transportation infrastructure projects are public projects.

In 2007, Norway, Denmark, and Finland announced the BIM mandates on public construction projects. In the United States, the US General Services Administration (GSA) mandated the use of BIM on all its projects in 2008. From that year forward, over 15 countries in the world have mandated the use of BIM or declared a mandate plan. Although the mandates had very limited requirements and have become more comprehensive over time, the main objectives of them can be summarized as follows: (1) to enable decision-makers to make informed decisions through the lifecycle of a project based on BIM data, accordingly, (2) to raise the quality of building and transportation infrastructure projects, and ultimately, (3) to increase the productivity of the construction industry (Sacks et al, 2018). It can be stated that due to the increasing competition caused by the mandates, it is inevitable that the private companies need to implement BIM and improve their capabilities according to the specified requirements.

Smith (2014) stated that while leadership needs to be driven primarily by government agencies, there is a great need for the support of the private sector and the collaboration with the private organizations. If the leadership and incentives are supported by BIM standards and protocols, more stable, progressive, and effective BIM implementation strategies can be followed.

### 2.3.2 National and international guides and standards

While the term “BIM Guide” states a document evolved best practices for implementing BIM efficiently, the term “BIM Standard” expresses a protocol, information requirements or a guide that are certified by an international standard organization (Sacks et al, 2018).

The first BIM guides were published in 2006 by the Associated General Contractors of America (AGC) and Denmark (AGC, 2006; bips, 2007). In the United States, the General Services Administration (GSA) published the BIM Guide Series, the American Institute of Architects (AIA) published contract guidelines and National BIM Standard (NBIMS-US), which is later internationally recognized, was published by the National Institute of Building Sciences (NIBS) in 2007 (GSA, 2007; AIA, 2007; NIBS, 2007). In the same year, BIM Requirements for Architectural Design, which later became a basis for the Common BIM Requirements (COBIM), were published by the Senate Properties of Finland (buildingSMART Finland, 2012). From that year forward, Singapore, China, Australia, South Korea, Japan, and Taiwan have also published BIM-related guides. BIM guides have been affected by each other and updated many times. The GSA BIM Guide series, the NBIMS-US and the COBIM series are the most extensive guides and, those influenced many other guides (Sacks et al, 2018). Industry Foundation Classes (IFC), which is documented as an international standard (ISO 16739:2013), was developed by buildingSMART as a common data format to facilitate management and transmission of information (Bradley et al, 2016).

BIM guides and standards support to ensure the utilization of BIM most beneficially by transferring experiences and best practices and, play an essential role in the adoption and productive use of BIM.

### 2.3.3 BIM education, training and research

Due to the fact that BIM is a non-traditional system and manner of work, all parties of the project should be trained at a sufficient level according to their roles and responsibilities on the project. The process of the training basically aims to increase awareness and overall understanding of BIM technology, system, tools, processes, and benefits; and to improve technical knowledge and skills for the people who utilize the collaborative BIM tools actively (buildingSMART Australasia, 2012).

There are a lot of certification and training programs offered by public and private organizations in the world. Some significant certification programs are listed in Table 2.1. In addition to these, all around the world, many large companies have conducted internal BIM training programs by organizing periodic workshops and generating internal resources for sharing knowledge among employees. Also, many universities have incorporated BIM in their curriculum, education programs, Master of Science programs, or research studies especially in the US, South Korea, Hong Kong, Israel, Brazil, and Estonia (Sacks et al, 2018).

**Table 2.1 :** Examples of certification programs around the world (Sacks et al, 2018).

| Region | Organization | Certification Program |
|---|---|---|
| US | Associated General Contractors of America (AGC) | AGC Certificate of Management - BIM |
| UK | British Standards Institute (BSI) | BSI Kitemark (1) for BIM Design and Construction; (2) for BIM Asset Management; (3) for BIM Objects |
| Korea | buildingSMART Korea (bSK) | bSK BIM Certificate Program |
| Singapore | Building and Construction Authority (BCA) | Certificate of Successful Completion (CSC) |
| Hong Kong | Construction Industry Council (CIC) | Certified BIM Expert Program |

## 2.4 Current situation of BIM in Turkey

In Turkey, the implementation of BIM has started in the building and transportation infrastructure projects in recent years, and the awareness of its potential and benefits has begun to increase.

In recent years, some efforts which affect the awareness and implementation of BIM in Turkey have been implemented by public and private organizations. Istanbul Metropolitan Municipality mandated the implementation of BIM in all railway projects, and the government has started to require BIM implementation in a number of projects.

Besides, the universities in Turkey have begun to incorporate BIM programs in their undergraduate and graduate education programs and to offer certificate programs. Construction companies have started to implement BIM in their projects, and private courses providing BIM training have begun to become common. Despite all these efforts, it can be stated that BIM usage is still very limited in the Turkish construction industry, and BIM adoption has not been achieved yet.

# 3. BIM FOR TRANSPORTATION INFRASTRUCTURE INDUSTRY

Transportation infrastructure, which is an integral part of the socio-economic development of a country due to its capability to provide mobility and accessibility, can be classified into the following categories:

- Highways
- Railways
- Bridges
- Airports
- Tunnels

In recent years, BIM has become favored in the transportation infrastructure projects in the world by cause of its capability to increase productivity in various terms such as time, cost, and quality in planning, design, construction, operation, and maintenance phases. Although there is a general impression that the implementation of BIM is for building projects only, many people claim that the "building" statement in the name of Building Information Modeling is not a noun referring to vertical structures. Instead of this, it is expressing the building process. Accordingly, BIM can be implemented for horizontal construction (transportation infrastructure) projects as well. On the other hand, there are several terms specific to the use of BIM in non-building civil infrastructure projects, such as Heavy BIM, Horizontal BIM (Cheng et al, 2016). Besides, the terms Civil BIM, Civil Information Modeling (CIM), and Virtual Design and Construction (VDC) are also used for using BIM in the transportation infrastructure industry. Although the terms are different from each other, they all have the same aim with the same method. Basically, the main objective of all these is to facilitate more efficient planning, design, construction, operation, and maintenance with increased collaboration by using a multi-dimensional data-rich model (McGraw Hill, 2012a).

BIM has substantial advantages throughout the lifecycles of the transportation infrastructure projects in many aspects, nevertheless, it has not become as common in horizontal construction projects as in vertical construction projects yet (Fanning et al, 2015). However, the SmartMarket Report published by McGraw Hill (2012a) suggests that the implementation of BIM in vertical construction (building) projects increases the likelihood of the implementation of BIM in horizontal construction projects. Consequently, the adaptation of BIM in the horizontal construction projects would be more rapid than when the adaptation of BIM has started in vertical construction projects.

Transportation infrastructure projects are complex, intricate and often major projects, therefore, integration of all data and information in detail is crucial for such projects. Cheng et al. (2016) classify the BIM uses for transportation infrastructure projects as 15 items and summarizes their relationships with 4 facility delivery phases (conceptual design phase, detailed design and documentation phase, construction phase and operation and maintenance (O&M) phase) as shown in Table 3.1.

An extensive literature review has been held by Costin et al. (2018) regarding BIM for transportation infrastructure, and specified common challenges have been categorized into five main factors:

- technical challenges
- process-related challenges
- mindset-related challenges
- legal challenges
- return on investment (ROI) challenges

**Table 3.1 :** BIM uses for transportation infrastructure projects (Cheng et al, 2016).

| BIM uses | Conceptual design | Detailed design and documentation | Construction | O&M |
|---|---|---|---|---|
| Visualization | √ | √ | √ | √ |
| Lifecycle information management | √ | √ | √ | √ |
| Design review | √ | √ | | |
| Computational fluid dynamics | √ | √ | | |
| Structural analysis | | √ | | |
| Sunlight analysis | | √ | | |
| Traffic flow simulation | | √ | | |
| Environmental simulation and analysis | | √ | √ | |
| Clash detection | | √ | √ | |
| Schedule modeling (4D) | | √ | √ | |
| Cost estimation (5D) | | √ | √ | |
| Quantity takeoff | | √ | √ | |
| Constructability analysis | | | √ | √ |
| Crane operation simulation | | | √ | |
| Virtual facility inspection | | | | √ |

### 3.1 Comparison of BIM for Building Projects and Transportation Projects

The main reason why BIM is used mostly in building projects rather than the transportation infrastructure projects is the differences between the lifecycles of a building project and a transportation infrastructure project in terms of components, operations, and techniques. Most of the transportation infrastructure projects are public projects differently from the building projects, which are mostly private. Therefore, transportation infrastructure projects commonly have restrictions in some respects such as legal and finance. Contractual and management considerations also have effects on the differences between vertical and horizontal projects regarding BIM implementation. Moreover, transportation infrastructure projects have a restriction to adopt to BIM due to their coordinate system. While building projects only use a coordinate system with a single reference, the coordinate systems of transportation infrastructure projects use multiple stations and alignment curves for references. In addition to these, transportation infrastructure projects require much more earthworks compared to the building projects, and the fact is an essential factor in the difference between the two types of projects (Costin et al, 2018). In connection with this, for transportation infrastructure projects, the terrain properties and surrounding geometrical environment have a huge impact, however, building projects relatively less affected by these. Lastly, modeling methodologies of these two are also different from each other. Even though building models have floors vertically, the models of transportation infrastructure projects have horizontal axis and horizontally extended cross sections along alignments (Cheng et al, 2016).

Despite all, studies on this matter reveal that transportation infrastructure projects and building projects have many similarities in many respects, such as collaboration procedures, coordination methods, and design review approaches (Bradley et al, 2016). Also, they both have similar data management and exchange procedures (Cheng et al, 2016).

It could be stated that transportation infrastructure projects and building projects have different advantages and disadvantages in different aspects regarding BIM implementation. For example, in the modeling of a highway, visualization and clash detection have a minimal advantage in the process of the project during the design phase. However, modeling a building has more advantages during the design phase from the point of visualization and clash detection due to the component-based nature of buildings. In addition to these, while component data and detailed geometry have much more advantages for the building projects, detailed geometry data have minimal effect on transportation infrastructure projects. However non-graphical data such as component performance information, material specifications, cost data, and their visual integration and coordination are very beneficial for the transportation infrastructure projects, and these kinds of data could be used during the pre-construction phase and construction phase efficiently (Bradley et al, 2016).

Transportation infrastructure projects have complexity and multiple stakeholders by nature. Together with BIM, stakeholders could generate and evaluate multiple design alternatives, make changes more effortlessly, and reduce errors and risks through collaboration using BIM models to specify the most effective solution in many regards (Fanning et al, 2015).

## 3.2 BIM in Different Transportation Infrastructure Project Types

### 3.2.1 Highways

Implementing BIM in highway construction projects has crucial advantages in terms of communication, planning, and scheduling (Platt, 2007). BIM capabilities ensure to automate the repeating tasks of highway design and facilitate to determine the optimum alternative by using an object-oriented visual model and therefore aid to save an appreciable amount of time and cost (Costin et al, 2018).

In the €600M M8/M73/M74 motorway improvements project in Scotland, BIM aided to improve coordination, optimize construction scheduling, detect clashes faster, calculate material quantities easier, keep informed all stakeholders about the current state of the project, identify issues in advance of the construction stage (Kumar et al, 2017).

Sankaran et al. (2016) stated that while BIM can facilitate design, workflow, delivery, and asset management processes, and enhance the quality of information for project management, lack of regulations and contractual arrangements are still crucial barriers for highway projects.

### 3.2.2 Railways

Railway infrastructures are composed of various components such as tunnels, roads, bridges, terminal facilities, and electrical, plumbing and communication systems. Hence, the implementation of BIM for railway infrastructure projects requires more effort (Cheng et al, 2016).

Bensalah et al. (2019) studied on five railway projects, (1) Project Mälarbanan in Sweden, (2) Schuman-Josaphat Tunnel in Belgium, (3) Railway SNCF maintenance in France, (4) Crossrail (Elisabeth Line) in the UK, and (5) ONCF 40 electrical substations in Morocco, in which BIM has been implemented. Considering these five projects, the article stated that the implementation of BIM in railway projects brings advantages in terms of collaboration, communication, decision making, and optimization of facility management. Besides, the study concluded that BIM aids to eliminate risk by enabling clash detection, to avoid extra work caused by design errors, and therefore, to save time and cost.

BIM has been implemented in Ataköy-İkitelli Metro Line Project, Dudullu-Bostancı Metro Line Project and Kabataş-Mecidiyeköy-Mahmutbey Metro Line Project in Turkey (Ozorhon, 2018).

### 3.2.3 Bridges

While implementing BIM takes high cost in the initial stage of a bridge project, findings show that BIM brings remarkable returns during the construction stage. Besides, BIM aids all stakeholders to make better decisions with accurate cost estimation, and therefore, brings financial and technical advantages (Costin et al, 2018).

Crusell cable-stayed bridge (total length of 173.5 m) in Finland is a considerable example of BIM implementation in bridge projects. BIM has been implemented both in the design and construction phases of the Crusell cable-stayed bridge project. The BIM model, which involves all structures of the bridge, the laser scanning data, and the 4D animation, has been produced to use for construction planning, fabrication, quality control, and maintaining the supply chain. According to all the project stakeholders, the implementation of BIM in the Crusell cable-stayed bridge project enabled better organization and management and allowed to save money and time (Eastman et al, 2011).

### 3.2.4 Airports

Airports are among the most challenging transportation infrastructure projects due to their complexity and different types of structures such as runways, terminals, taxiways, aprons, and car parks.

Taking into account the complexity and various components of airports, BIM implementation with BIM model and detailed simulations can facilitate to detect conflicts, to enhance the quality of design and operation, and to reduce the waiting time of passengers (Costin et al, 2018).

BIM has been implemented in İzmir Adnan Menderes Airport terminal project, Sabiha Gökçen Airport HABOM project, and İstanbul Airport project in Turkey (Ozorhon, 2018). Keskin et al. (2019) stated that BIM implementation in the İstanbul Airport project has improved quality, reduced waste, facilitated management, enabled fast resolutions, and increased collaboration.

### 3.2.5 Tunnels

Although BIM implementation enables critical benefits for tunnel projects, there have not been many industrial efforts for BIM implementation in tunnel projects in the world.

For tunnel projects, geological features data, terrain information, and safety monitoring data should be integrated with the BIM model, since tunnels are mostly constructed in mountains or underground. BIM uses such as traffic flow simulations, and environmental simulations and analysis could be used especially for the documentation, detailed design, operation, and maintenance phases of tunnel projects (Cheng et al, 2016).

# 4. RESEARCH METHODOLOGY

This chapter discusses the research methodology which was chosen to satisfy the research objectives. A quantitative research approach was adopted by applying a survey questionnaire amongst BIM professionals who have experience in transportation infrastructure projects in Turkey to investigate their perceptions regarding the challenges to BIM implementation and required preventative actions to the challenges for the Turkish transportation infrastructure industry.

Firstly, a literature review was conducted in order to obtain available information related to BIM and identify the common challenges and preventative actions to the challenges regarding BIM implementation. Later on, in light of this information, a questionnaire was designed with 13 challenge items and 11 preventative action items to collect data and conduct quantitative data analysis. The questionnaire survey mainly provides a statistical basis to identify the challenges of BIM implementation in the Turkish transportation infrastructure industry and to reveal the required preventative actions to these challenges. The results of this survey were digitized and analyzed with descriptive statistics and exploratory factor analysis (EFA) methods by using a statistical analysis program named SPSS.

## 4.1 Data Collection

### 4.1.1 Target population

This research was carried out in Turkey and the targeted respondent group was professionals (engineers, architects, and any other professional with related specialization) with working experience in the Turkish transportation infrastructure industry, who have used BIM on any project they were involved in.

### 4.1.2 Questionnaire design and development

The questionnaire comprises four main sections as follows: (1) general information about the respondent, (2) professional details of the respondent, (3) company details of the respondent, and (4) challenges encountered in BIM implementation and required preventative actions to these challenges considering the Turkish transportation infrastructure industry. A sample of the questionnaire can be found in the Appendix section.

The questionnaire was delivered to 71 target respondents. A total of 64 questionnaires were returned from the respondents, and thus the total response rate is 90.1%. Personal delivery aided to increase the rate of response. However, among the questions in the questionnaire, there are two eliminating questions that evaluate whether the respondent has working experience in the Turkish transportation infrastructure industry and working experience with BIM. Respondents who responded negatively to one of these two eliminating questions could not proceed to the remaining phases of the questionnaire. In this way, potential responses from non-targeted respondents were eliminated from further statistical analysis, and correctness and quality of data were increased. Hence, 8 of the returned questionnaires were not completed due to these eliminating questions. As a result, a total of 56 questionnaires were satisfactorily completed and recognized as valid in accordance with quantitative analysis.

In the main section (4) of the questionnaire, there are 13 challenge and 11 preventative action variables to measure the challenges of BIM implementation in the Turkish transportation infrastructure industry and the preventative actions to these challenges, respectively. In this section, the respondents were asked to rate their agreement on each statement using a 5-point Likert scale, ranging from strongly disagree to strongly agree. The responses of satisfactorily completed 56 questionnaires were assigned numerical codes (1= strongly disagree, 2=disagree, 3=neutral, 4=agree, and 5=strongly agree) and analyzed using descriptive statistics and EFA. Details of these statistical analyses are given in the following section.

# 5. RESEARCH FINDINGS

In this section, the data and findings obtained as a result of the research, the details of the statistical analyses, and the evaluations of the analyses results are presented.

## 5.1 General Information and Professional Details

General information about the 56 respondents and their professional details are given in this section based on the results of the questionnaire survey. In terms of the professions, 43% of the respondents are civil engineers, 32% are architects, 7% are mechanical engineers, and there are electrical, geomatic and geophysics engineers, interior architects, mechanical and survey technicians, and a BIM information technologies (IT) supervisor among the respondents as seen in Figure 5.1.

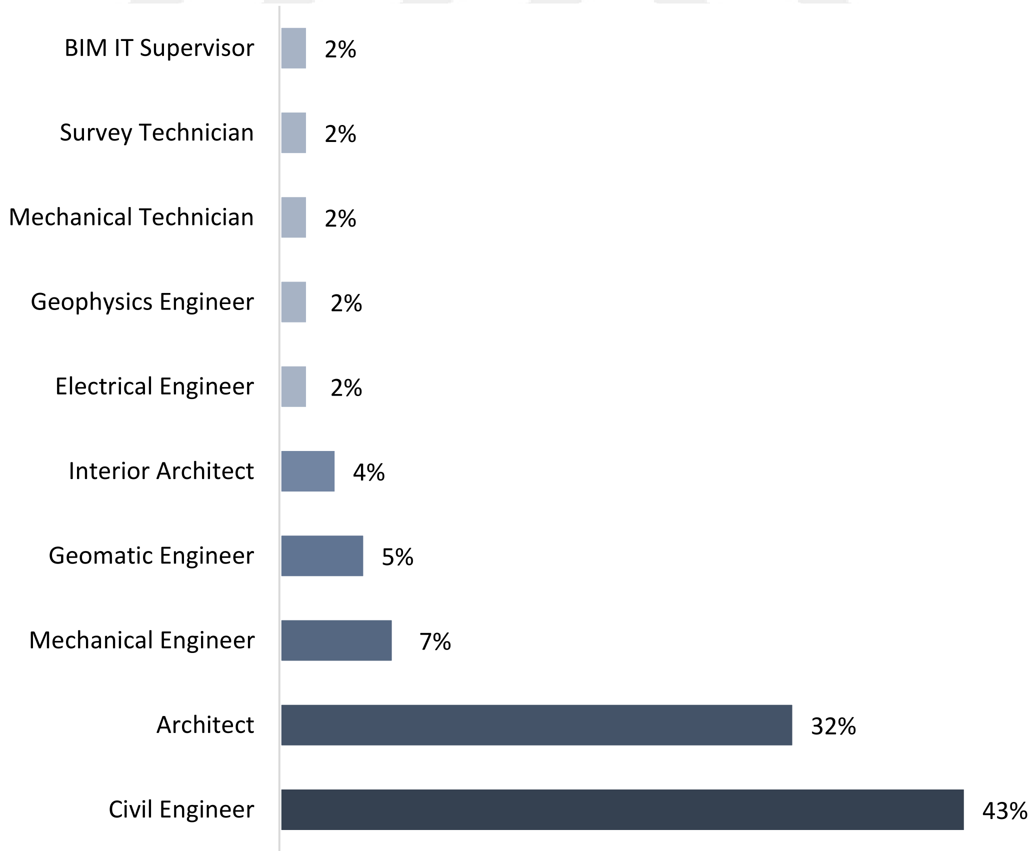


**Figure 5.1 :** Professions of the respondents.

Figure 5.3 shows the education level of the respondents.

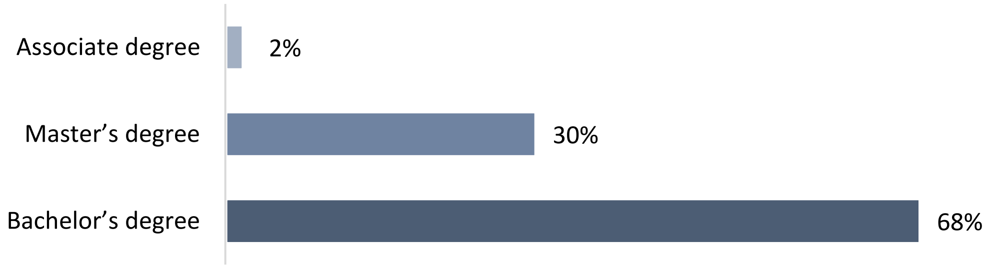


**Figure 5.2 :** Education levels of the respondents.

Considering the positions, the majority (52%) of the respondents are design engineers and architects, 21% are at the managerial level and 16% are at the chief level as seen in Figure 5.2.

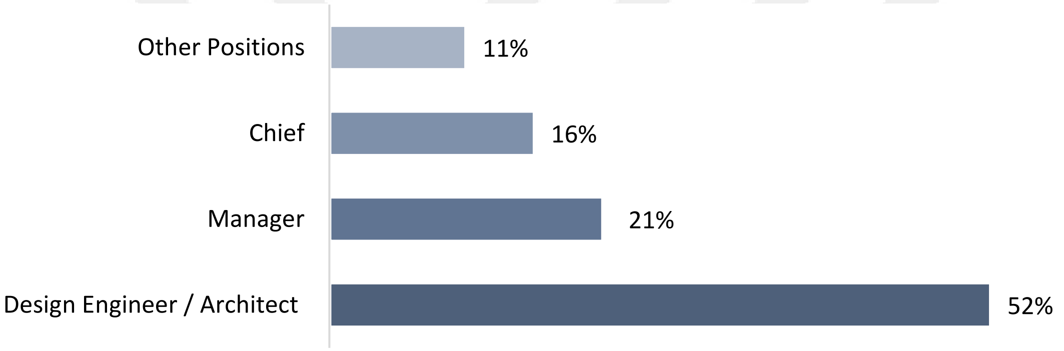


**Figure 5.3 :** Positions of the respondents.

The respondents' experience in their professions is 1-5 years for 46%, 5-8 years for 34%, 8-15 for 13%, and 15-30 for 7% as seen in Figure 5.4.

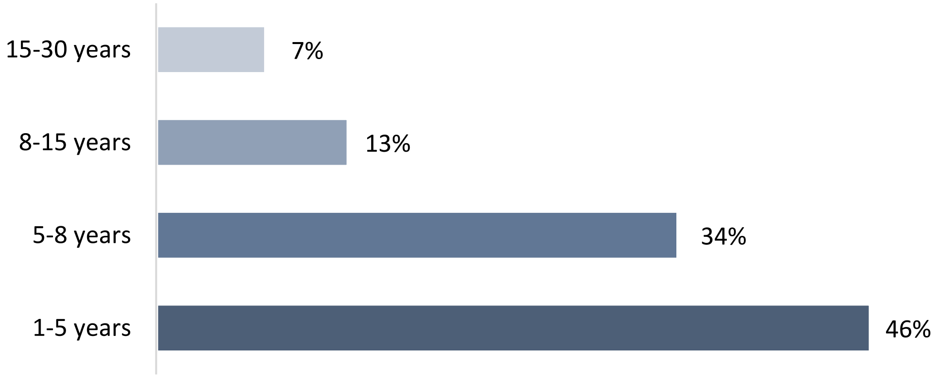


**Figure 5.4 :** Experience in professions of the respondents.

Among the respondents, 73% are currently working on a transportation infrastructure related project/study in Turkey, and the rest of the respondents worked on a transportation infrastructure related project/study in Turkey in the past. Besides, all the respondents have BIM experience. These show that the respondents surveyed are suitable for the target group and have the competence to answer questions in light of experience and knowledge.

While all respondents expressed that they have experience in using Autodesk products, the majority (75%) of the respondents stated that they are highly experienced in using Autodesk products. Besides, 25% of the respondents expressed that they have experience in using Bentley products. The rate is 23% for Graphisoft products and 20% for Nemestschek products. It reveals that while Autodesk products are well-known and used by the majority of BIM users who have experience in the Turkish transportation infrastructure industry, the usage and knowledge of the other software packages are very limited.

Figure 5.5 shows how respondents learned to utilize BIM and related software. According to the figure, 36% of the respondents stated that their BIM training type was industry-led training. While it is self-taught for 25%, 20% of them stated that they learned it in private courses. 13% of them learned BIM during the bachelor's degree program, and the rest of them learned it during the master and/or PhD degree program.

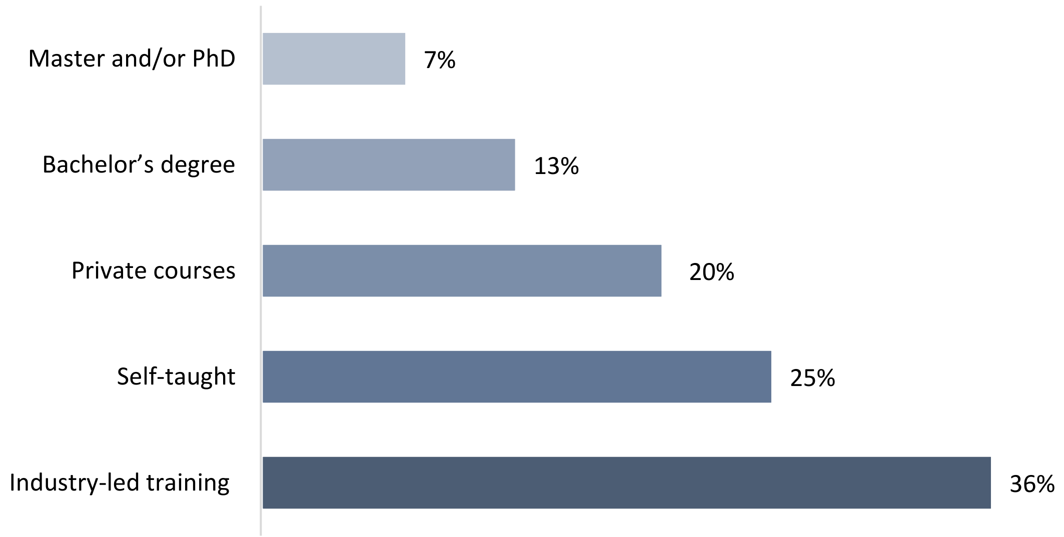


**Figure 5.5 :** BIM training types of the respondents.

## 5.2 BIM Implementation in Transportation Infrastructure Companies in Turkey

In this chapter, it is aimed to identify the current situation of the transportation infrastructure companies in Turkey considering BIM implementation. Accordingly, an evaluation was made based on the responses of respondents currently using BIM on transportation infrastructure projects. A total of 36 respondents are the target respondents defined for this chapter.

Firstly, eliminated respondents who do not utilize BIM in the company they are currently working in were asked to estimate and grade how likely it is that their company would use BIM in the future. 40% of the respondents subjected to this question stated that their companies are extremely likely to use BIM in the future, and there were no respondents rated this question as “not likely”. This situation reveals the need for digital transformation in the Turkish transportation infrastructure industry and its inevitability.

Considering the 36 respondents targeted for this chapter, around 86% are currently working in the private sector, and the rest of the respondents are currently working in the public sector. The number of the respondents from the public sector is relatively few, however, this survey does not aim to identify differences of BIM implementation between the public sector and private sector, therefore this situation is considered irrelevant. Besides, all the respondents who do not currently work in the private sector have had previous experiences in the private sector except only one respondent.

Among the respondents who are currently working in the private sector, 65% are working in the companies which operate in the design field. While the rate is 19% for the companies that operate in consultancy, the rest of the companies that are surveyed operate in construction.

In the case of software packages, Autodesk products are the most widely preferred system in all the companies, and other products, such as Bentley, Nemetschek and Graphisoft products, Bexel Manager and M-Files, are used by the very minority of the companies. 19% of companies use BIM for less than 3 years. 40% stated that their companies started to use BIM 3-5 years ago, 27% stated that it was 6-10 years ago and it was 11-15 years ago for 6% as seen in Figure 5.6.

When the Figure 5.6 is interpreted, it can be seen that BIM implementation is in its early stages in the Turkish transportation infrastructure industry.

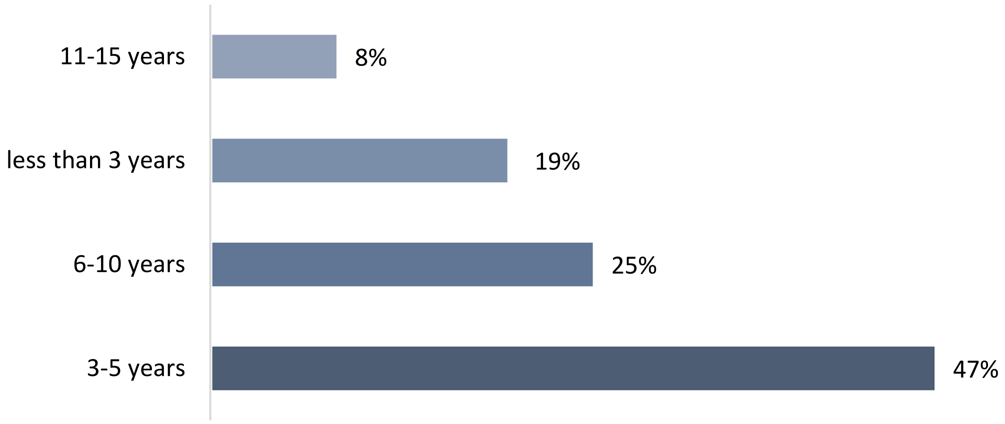


**Figure 5.6 :** BIM implementation periods of the companies.

Figure 5.7 shows how many employees are directly utilizing BIM and related software in these companies.

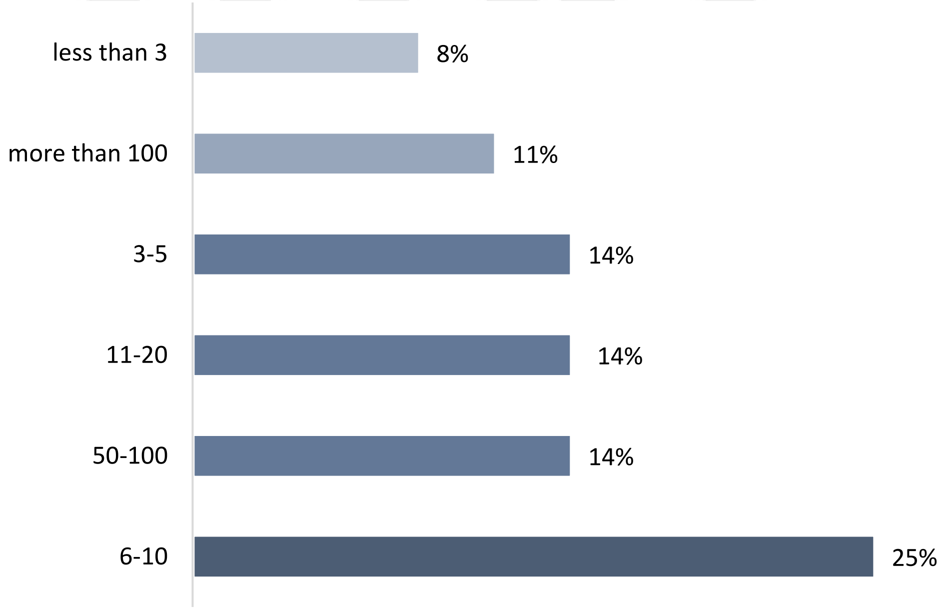


**Figure 5.7 :** Number of BIM professionals in the companies.

Figure 5.8 shows the model production levels of these companies. 11% of the respondents stated that their companies use BIM tools to analyze BIM models but do not create their own models.

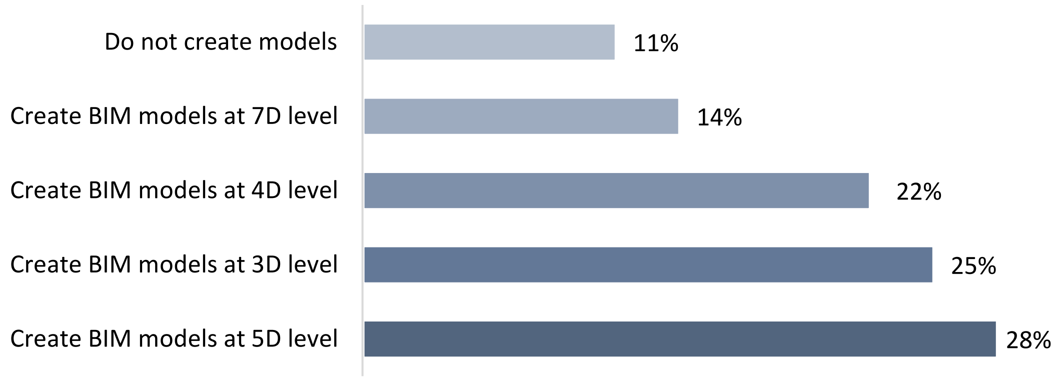


**Figure 5.8 :** Model production levels of the companies.

Figure 5.9 shows the percentage of the companies' projects which have utilized BIM within the past 5 years. This figure shows that the majority of companies (53%) utilize BIM in almost all their projects within the past 5 years.

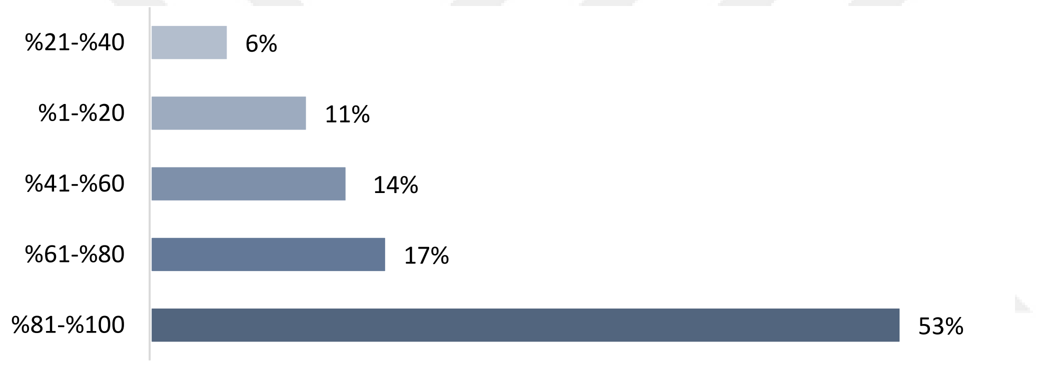


**Figure 5.9 :** Percentage of the companies' projects utilizing BIM (past 5 years).

In this stage, respondents were asked to indicate which type of efficiency of BIM contributes more to the different phases of a transportation infrastructure project. Respondents carried out the evaluation based on their BIM experience in their companies. The views of the respondents who worked in a transportation infrastructure project in the past were also included in this evaluation, and the results are given in Figure 5.10. When the figure is interpreted, it can be seen that while the most important contribution of BIM to the documentation stage is time efficiency (73%), it provides the most significant advantage to the design phase in regards to quality efficiency (68%). According to the results, BIM is very beneficial from the point of cost efficiency (63%) during the construction and logistics phases of a transportation infrastructure project. Besides, BIM significantly contributes to a transportation infrastructure project in terms of cost (43%) and quality (45%) efficiencies during operation and maintenance phases.

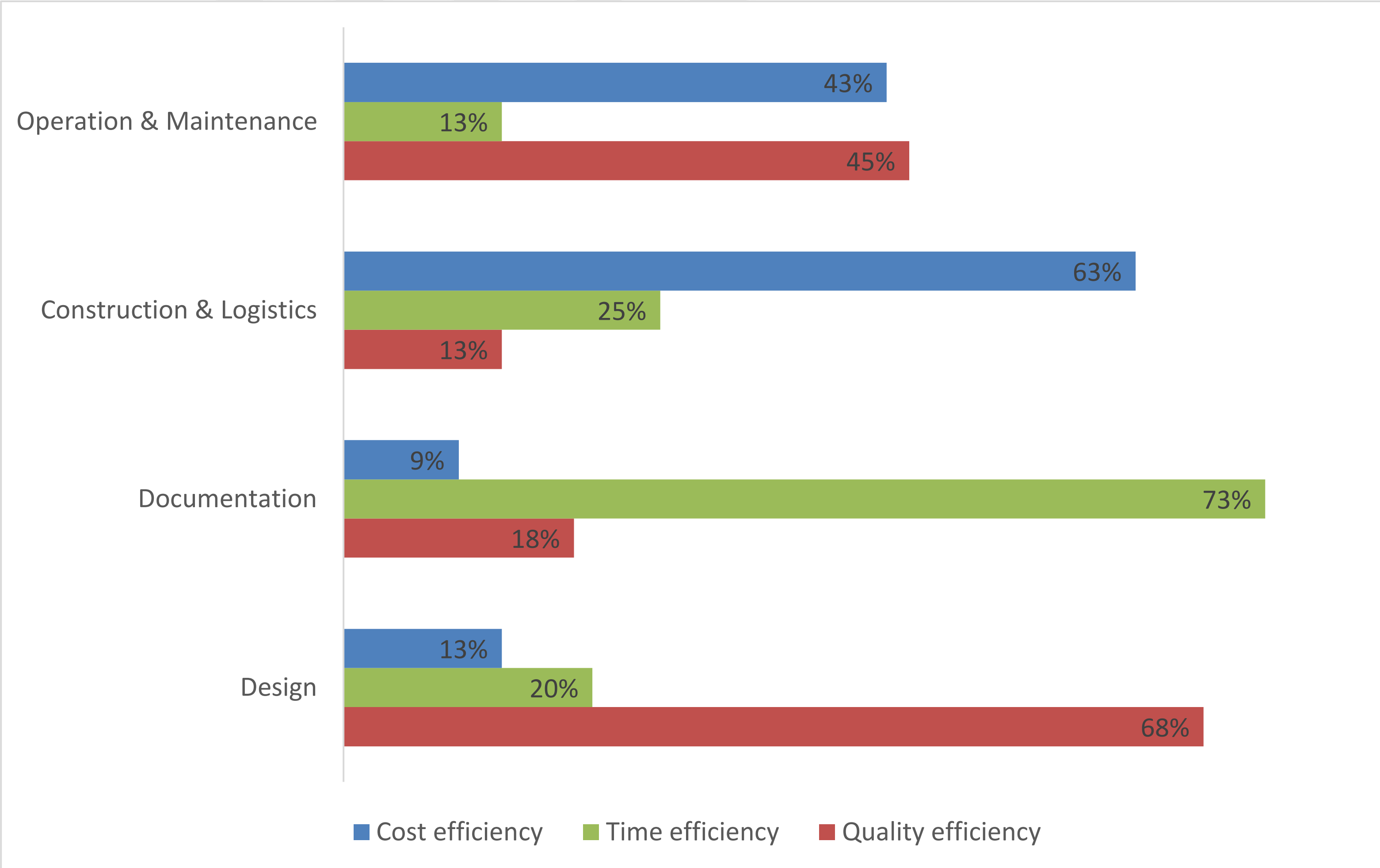


**Figure 5.10 :** Evaluation of BIM efficiency at different project phases.

## 5.3 The Turkish Transportation Infrastructure Industry Analysis Regarding BIM Implementation

In this section, challenges of BIM implementation for the Turkish transportation infrastructure industry and preventative actions to the challenges are investigated using data obtained from the survey. The data were analyzed using a statistical analysis software package named SPSS. The following outputs were obtained using this software: descriptive statistic tables; values to be used for the Kaiser–Meyer–Olkin (KMO) adequacy test, the Barlett's test of sphericity, and multicollinearity test; and rotated component matrices as outputs of exploratory factor analysis.

The analyses consist of 2 stages: analyzing (1) the challenges of BIM implementation for the Turkish transportation infrastructure industry and (2) the preventive actions to these challenges. Descriptive statistics and exploratory factor analysis methods were implemented for the analyses. Before proceeding to the analyses, a reliability test was performed to ensure the reliability of the data set.

### 5.3.1 Test of reliability

Cronbach's alpha was used to analyze the reliability of the data and ensure that the questionnaire is appropriate for data collection. Cronbach's alpha coefficient value is between 0 and 1. Reliability and internal consistency increase as this coefficient value increases. Cronbach's alpha coefficient was calculated as 0.814 for the challenges and 0.907 for the preventative actions, as shown in Table 5.1. Since these values are greater than 0.80, it is considered as "good scale" (Garson, 2013). Thus, the coefficient values demonstrate that the questionnaire is highly reliable.

**Table 5.1 :** Reliability statistics.

| Analyse | Cronbach's Alpha Value | N of Items |
|---|---|---|
| Challenges | 0.814 | 13 |
| Preventative Actions | 0.907 | 11 |

### 5.3.2 Descriptive statistics

Descriptive statistics were used to detect the most significant and critical challenges and preventative actions to these challenges regarding BIM implementation for the Turkish transportation infrastructure industry. 13 challenges and 11 preventative actions to these challenges were specified for using as variables in the analysis. Table 5.2 and Table 5.3 show the descriptive statistics of variables of the challenges and the preventative actions created using the responses collected from the targeted respondents, respectively. The tables show the rankings of the 13 and 11 variables according to the mean values of the responses.

Considering the results, it is concluded that (1) lack of regulations and contractual arrangements specified for BIM, and (2) the resistance to the adversity of changing working culture and adapting to a new and unfamiliar system, are the most significant challenges. The least significant challenges, on the other hand, are (1) increased risk-sharing between stakeholders because of the collaborative approach of BIM, and (2) the belief that BIM and related software is hard to learn. As for the preventative actions, it could be seen that (1) BIM implementation in governmental agencies in order to lead the industry, and (2) development of BIM-specific contracts and regulations by governmental authorities are the most significant preventative actions. Whereas, (1) collaboration with the government to drive BIM implementation in private companies, and (2) company strategies specific to BIM training and employing are the least significant preventative actions among the 11 variables.

**Table 5.2 :** Descriptive statistics of the challenges.

| Mark | Variables | Mean | SD | Variance |
| --- | --- | --- | --- | --- |
| V1 | Lack of regulations and contractual arrangements specified for BIM | 3.89 | 0.91 | 0.82 |
| V11 | The resistance to the adversity of changing working culture and adapting to a new and unfamiliar system | 3.86 | 1.12 | 1.25 |
| V4 | Lack of demand and enforcement of BIM utilization from public authorities | 3.75 | 1.10 | 1.21 |
| V10 | The fragmented working culture (lack of high-level collaboration) | 3.68 | 1.05 | 1.09 |
| V12 | Lack of BIM experience of the project team | 3.68 | 0.96 | 0.91 |
| V3 | Lack of BIM implementation standards | 3.64 | 0.88 | 0.78 |
| V5 | Lack of demand and enforcement of BIM utilization from private companies | 3.59 | 1.09 | 1.19 |
| V8 | The need for numerous new software licenses | 3.39 | 1.02 | 1.04 |
| V9 | Not being able to find sufficiently equipped BIM consultants for the implementation period | 3.36 | 1.21 | 1.47 |
| V13 | The unwillingness of the project team to communicate and collaborate actively | 3.30 | 1.19 | 1.42 |
| V6 | The difficulty of BIM implementation by reason of its high initial investment cost | 3.18 | 1.21 | 1.46 |
| V7 | The belief that BIM and related software is hard to learn | 3.05 | 1.29 | 1.65 |
| V2 | Increased risk-sharing between stakeholders because of the collaborative approach of BIM | 2.79 | 1.06 | 1.12 |

**Table 5.3 :** Descriptive statistics of the preventative actions.

| Mark | Variables | Mean | SD | Variance |
|---|---|---|---|---|
| V2 | BIM implementation in governmental agencies in order to lead the industry | 4.41 | 0.71 | 0.50 |
| V3 | Development of BIM-specific contracts and regulations by governmental authorities | 4.39 | 0.73 | 0.53 |
| V9 | Company incentives for employees to learn to work with BIM and its sofware | 4.36 | 0.82 | 0.67 |
| V10 | In-company trainings for increasing awareness of employees about the benefits of BIM in terms of time/cost | 4.30 | 0.83 | 0.69 |
| V5 | Promoting BIM training of new recruits in the private sector by governmental incentives and training programs | 4.21 | 1.04 | 1.08 |
| V4 | Development of BIM-specific standards by governmental authorities | 4.21 | 0.95 | 0.90 |
| V7 | Comprehensive cost analysis of the project lifecycle to persuade the stakeholders regarding the financial advantages of BIM | 4.20 | 0.90 | 0.82 |
| V1 | Development of governmental BIM policies to make it mandatory | 4.18 | 0.81 | 0.66 |
| V11 | Compulsory BIM lessons in higher education | 4.14 | 1.05 | 1.11 |
| V8 | Company strategies specific to BIM training and employing | 4.13 | 0.83 | 0.69 |
| V6 | Collaboration with the government to drive BIM implementation in private companies | 4.04 | 1.01 | 1.02 |

### 5.3.3 Exploratory factor analysis

The variables that are included in the last part of the survey regarding the challenges of BIM implementation for the Turkish transportation infrastructure industry and the preventative actions to these challenges were used to conduct exploratory factor analysis. Exploratory factor analysis is a statistical data reduction method that is used to determine the correlations among the variables and reduce the number of them to a relatively narrow set of variables that represent these correlations as underlying factors. In this study, 13 and 11 variables were used to specify the underlying challenge factors of BIM implementation in the Turkish transportation infrastructure industry and the underlying preventative action factors to the challenges, respectively.

To perform the exploratory factor analysis, principal component analysis (PCA) was used as an extraction method. Zaiontz (2014) stated that PCA is a statistical analysis method that explains a large number of variables into a smaller number of principal components with a minimum loss of information by evaluating the interrelationships among the variables. As the rotation method, varimax was chosen. Varimax rotation method aims to distribute a smaller number of variables into each factor and to maximize the distribution of loadings within factors, and thus to create more interpretable factors (Field, 2018).

In advance of the exploratory factor analysis, three tests named (1) Kaiser–Meyer–Olkin (KMO) adequacy test, (2) Barlett's test of sphericity, and (3) multicollinearity test were carried out to ensure the exploratory factor analysis could be used to analyse these data set. Afterward, exploratory factor analysis was performed, and rotated component matrices with the other outputs were generated within the scope of the analysis.

#### 5.3.3.1 Kaiser–Meyer–Olkin (KMO) adequacy test

KMO measure of sampling adequacy was carried out to confirm that exploratory factor analysis is suitable for the survey.

KMO value is 0.706 for challenges and 0.775 for preventative actions which are above the value of 0.5 (KMO>0.5 (Kaiser, 1974)). The results indicate that the data set is valid for the exploratory factor analysis.

#### 5.3.3.2 Bartlett's test of sphericity

The Bartlett's test of sphericity was used to determine if the correlations between variables are strong enough.

Bartlett's test of sphericity has resulted in a significant value = 0.000 (less than 0.05 (Field, 2018)) for both data set. The results show that the correlations between variables are significantly different from zero. Hence, the implementation of exploratory factor analysis is appropriate for the data obtained from the survey.

The results of KMO and Bartlett's test of sphericity measures are reported in Table 5.4.

**Table 5.4 :** KMO and Bartlett's test of sphericity measures.

| Analyse | KMO Measure of Sampling Adequacy | Bartlett's Test of Sphericity |
|---|---|---|
| Challenges | 0.706 | 0.000 |
| Preventative Actions | 0.775 | 0.000 |

#### 5.3.3.3 Multicollinearity test

The multicollinearity of the data was checked by using the determinant value. If the determinant value is less than 0.00001, there is a multicollinearity problem. This means some of the variables are very highly correlated with each other, and one of them needs to be eliminated (Field, 2018).

The determinant values were calculated as $7.45 \times 10^{-5}$ for challenges and $5 \times 10^{-3}$ for preventative actions, which are greater than 0.00001. The values show that there is no multicollinearity problem, and the data set could be used for exploratory factor analysis without any elimination.

#### 5.3.3.4 The results of the exploratory factor analyses

The results of the exploratory factor analyses for the challenges and the preventative actions are examined under two separate sections, respectively. As a result of the exploratory factor analyses, rotated component matrices with the other outputs were generated. A rotated component matrix shows the loadings of variables on the factors, and thus variables can be grouped by evaluating this matrix.

**Challenges**

In order to generate exploratory factor analysis outputs of 13 variables related to the challenges, the PCA method and varimax rotation method were used. The PCA produced a three-factor solution with eigenvalues greater than 1, thus 13 variables were classified into 3 groups. As seen in Table 5.5, the three factors explained 58.94% of total variance with component 1 contributing 32.51%, component 2 contributing 15.41%, and component 3 contributing 11.02%. The rotated component matrix is shown in Table 5.6. For clarity, factor loading values less than 0.45 were eliminated from the table. As can be seen from the matrix, each variable weighs heavily on only one of the factors. Considering the common features of the variables, the 3 factors were named as organization, initial stage and leadership.

Figure 5.11 shows the graphical representation of the analysis results of the challenges.

**Preventative actions to the challenges**

In order to categorize 11 variables of preventative actions to the challenges, PCA method and varimax rotation method were used. The analysis categorized the 11 variables as three underlying factors by considering eigenvalues greater than 1. The three factors explain 79.07% of total variance with component 1 contributing 54.14%, component 2 contributing 15.83%, and component 3 contributing 9.10% as seen in Table 5.7. As a result of the analysis, a rotated component matrix which is shown in Table 5.8 was generated. For clarity, factor loading values less than 0.40 were eliminated from the table. As seen from the rotated component matrix, each variable weighs heavily on only one of the factors. Considering the common features of the variables, the 3 factors were named as private sector, government and education.

Graphical representation of the analysis results of the preventative actions is shown in Figure 5.12.

**Table 5.5 :** Total variance explained for the challenges.

| Component | Initial Eigenvalues | | | Extraction Sums of Squared Loadings | | | Rotation Sums of Squared Loadings | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 1 | 4.226 | 32.510 | 32.510 | 4.226 | 32.510 | 32.510 | 2.857 | 21.975 | 21.975 |
| 2 | 2.003 | 15.411 | 47.921 | 2.003 | 15.411 | 47.921 | 2.490 | 19.156 | 41.131 |
| 3 | 1.432 | 11.016 | 58.937 | 1.432 | 11.016 | 58.937 | 2.315 | 17.806 | 58.937 |
| 4 | 0.996 | 7.663 | 66.600 | | | | | | |
| 5 | 0.852 | 6.551 | 73.151 | | | | | | |
| 6 | 0.811 | 6.237 | 79.388 | | | | | | |
| 7 | 0.670 | 5.151 | 84.539 | | | | | | |
| 8 | 0.525 | 4.039 | 88.578 | | | | | | |
| 9 | 0.479 | 3.684 | 92.262 | | | | | | |
| 10 | 0.353 | 2.718 | 94.980 | | | | | | |
| 11 | 0.244 | 1.879 | 96.860 | | | | | | |
| 12 | 0.207 | 1.595 | 98.455 | | | | | | |
| 13 | 0.201 | 1.545 | 100.000 | | | | | | |

**Table 5.6 :** Rotated component matrix of the challenges.

| Comon Factors | Variables | 1 | 2 | 3 |
|---|---|---|---|---|
| Organization | Lack of BIM experience of the project team | 0.810 | | |
| | The unwillingness of the project team to communicate and collaborate actively | 0.809 | | |
| | The fragmented working culture (lack of high-level collaboration) | 0.686 | | |
| | Increased risk-sharing between stakeholders because of the collaborative approach of BIM | 0.661 | | |
| | Not being able to find sufficiently equipped BIM consultants for the implementation period | 0.603 | | |
| Initial Stage | The difficulty of BIM implementation by reason of its high initial investment cost | | 0.828 | |
| | The need for numerous new software licenses | | 0.795 | |
| | The resistance to the adversity of changing working culture and adapting to a new and unfamiliar system | | 0.697 | |
| | The belief that BIM and related software is hard to learn | | 0.610 | |
| Leadership | Lack of regulations and contractual arrangements specified for BIM | | | 0.727 |
| | Lack of BIM implementation standards | | | 0.714 |
| | Lack of demand and enforcement of BIM utilization from private companies | | | 0.669 |
| | Lack of demand and enforcement of BIM utilization from public authorities | | | 0.663 |


**Figure 5.11 :** Analysis results of the challenges.

**Table 5.7 :** Total variance explained for the preventative actions.

| Component | Initial Eigenvalues | | | Extraction Sums of Squared Loadings | | | Rotation Sums of Squared Loadings | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 1 | 5.956 | 54.143 | 54.143 | 5.956 | 54.143 | 54.143 | 3.191 | 29.006 | 29.006 |
| 2 | 1.741 | 15.831 | 69.975 | 1.741 | 15.831 | 69.975 | 3.057 | 27.788 | 56.794 |
| 3 | 1.001 | 9.097 | 79.071 | 1.001 | 9.097 | 79.071 | 2.450 | 22.277 | 79.071 |
| 4 | 0.628 | 5.713 | 84.784 | | | | | | |
| 5 | 0.434 | 3.948 | 88.732 | | | | | | |
| 6 | 0.363 | 3.302 | 92.034 | | | | | | |
| 7 | 0.322 | 2.925 | 94.960 | | | | | | |
| 8 | 0.255 | 2.318 | 97.278 | | | | | | |
| 9 | 0.141 | 1.286 | 98.563 | | | | | | |
| 10 | 0.081 | 0.740 | 99.304 | | | | | | |
| 11 | 0.077 | 0.696 | 100.000 | | | | | | |

**Table 5.8 :** Rotated component matrix of the preventative actions.

| Common Factors | Variables | 1 | 2 | 3 |
|---|---|---|---|---|
| Private Sector | Promoting BIM training of new recruits in private sector by governmental incentives and training programs | 0.902 | | |
| | Collaboration with the government to drive BIM implementation in private companies | 0.862 | | |
| | Company strategies specific to BIM training and employing | 0.791 | | |
| | Comprehensive cost analysis of the project lifecycle to persuade the stakeholders regarding the financial advantages of BIM | 0.714 | | |
| Government | Development of BIM-specific contracts and regulations by governmental authorities | | 0.901 | |
| | Development of BIM-specific standards by governmental authorities | | 0.874 | |
| | BIM implementation in governmental agencies in order to lead the industry | | 0.750 | |
| | Development of governmental BIM policies to make it mandatory | | 0.749 | |
| Education | Compulsory BIM lessons in higher education | | | 0.877 |
| | Company incentives for employees to learn to work with BIM and its software | | | 0.778 |
| | In-company trainings for increasing awareness of employees about the benefits of BIM in terms of time/cost | | | 0.776 |


**Figure 5.12 :** Analysis results of the preventative actions.

### 5.4 Evaluations of Analysis Results

This section discusses and interprets each of the factors obtained for the challenges of BIM implementation and preventative actions to these challenges as follows.

#### 5.4.1 Challenges

According to the results of the factor analysis, three factors, named organization, initial stage and leadership, were identified for 13 challenge items of BIM implementation in the Turkish transportation infrastructure industry.

##### 5.4.1.1 Factor 1: organization

The first factor regarding BIM implementation challenges involves five items related to the organization of implementing BIM.

The fragmented working culture (lack of high-level collaboration) of the Turkish transportation infrastructure industry is one of the most significant two challenges (mean value, 3.68) in the organization factor. One of the most distinctive features of BIM implementation is collaboration, and the BIM approach primarily requires high-level interoperability. To implement and adopt BIM, the Turkish transportation infrastructure industry needs to transform its fragmented working culture and adopt a collaborative organizational approach.

Lack of BIM experience of the project team is another important factor with the same mean value (3.68). The BIM implementation is in early stages in the Turkish transportation infrastructure industry. Lack of BIM experience due to this reason creates a major obstacle to the adoption and utilization of BIM. The process of gaining BIM experience takes time and causes productivity losses, and it is not very easy to organize a new BIM experienced team.

Not being able to find sufficiently equipped BIM consultants for the implementation period (mean value, 3.36) is also critical because of that there is a great need for guidance in order to make correct decisions and to make the organization correctly during the implementation phase.

The unwillingness of the project team to communicate and collaborate actively (mean value, 3.30) is also an important organizational challenge because it is not possible to take advantage of BIM without active communication, and breaking resistance to active communication requires a serious organizational transformation.

Increased risk-sharing between stakeholders because of the collaborative approach of BIM has the lowest mean value (2.79) in this category and also among all items. It shows that the collaborative approach of BIM does not have a major negative impact on projects and stakeholders in the Turkish transportation infrastructure industry.

#### 5.4.1.2 Factor 2: initial stage

Factor 2 contains four challenges that are concerned with the initial stage of BIM implementation.

The resistance to the adversity of changing working culture and adapting to a new and unfamiliar system (mean value, 3.86) is ranked the second most significant challenge among all of the items. In the initial stage, until the system becomes accustomed, more effort is required than usual. The resistance to this difficulty is due to the lack of awareness of the convenience in the later stages.

The need for numerous new software licenses (mean value, 3.39) is another highly important challenge. This challenge is related to both the software cost and the need to create an infrastructure for using the software, hence it requires not only cost but also time and effort.

The difficulty of BIM implementation by reason of its high initial investment cost (mean value, 3.18) is also a crucial challenge to BIM implementation. Although this loss of cost is recovered in the later stages, this is seen as an obstacle in the initial stage.

The belief that BIM and related software is hard to learn (mean value, 3.05) is another item of challenges to implement BIM in the Turkish transportation infrastructure industry. Implementing BIM approach and related software increase time and energy efficiency in the later stages, however they have difficulties in terms of learning and adoption at the initial stage.

#### 5.4.1.3 Factor 3: leadership

Factor 3 involves four challenges, which are mainly related to leadership.

The first challenge variable in leadership factor is the lack of regulations and contractual arrangements specified for BIM (mean value, 3.89), and it is also the most important challenge among all of the challenge variables. The absence of regulations or contractual arrangements is a barrier to intention and decision to implement BIM. Unless the implementation of BIM is specified legally or contractually, it cannot be proceeded to overcome the barriers described in the initial stage and organization sections.

Lack of demand and enforcement of BIM utilization from public authorities (mean value, 3.75) is another significant variable. In most cases, major changes are avoided without an inevitable driving force. Demand and enforcement of BIM utilization from public authorities are crucial for BIM to become widespread in the Turkish transportation infrastructure projects, and also to increase the awareness of its benefits.

Lack of BIM implementation standards (mean value, 3.64) is also a critical challenge for BIM implementation. The lack of a specific standard for BIM can lead to conflicts and disagreements, and therefore it is a challenge for both the BIM implementation stage and the future stages such as project submissions.

Lack of demand and enforcement of BIM utilization from private companies (mean value, 3.59) is the last variable in this category. The transformation of companies is not easy without compulsory demand and enforcement. Thus, demand and enforcement of BIM utilization from private companies necessarily effect the other related companies such as subcontractors.

### 5.4.2 Preventative actions to the challenges

As result of the factor analysis, three factors, named private sector, government and education, were identified for 11 items of preventative actions to challenges of BIM implementation in the Turkish transportation infrastructure industry.

#### 5.4.2.1 Factor 1: private sector

The first factor of preventative actions to the challenges regarding implementation of BIM is related to the private sector and involves four items.

Promoting BIM training of new recruits in the private sector by governmental incentives and training programs (mean value, 4.21) is the most important variable in the private sector category.  A substantial alteration can be achieved in private companies through governmental incentives and leadership. Hence, this action is crucial to prevent organizational and working culture related challenges mentioned in the previous section as it focuses on new employees.

Comprehensive cost analysis of the project lifecycle to persuade the stakeholders regarding the financial advantages of BIM (mean value, 4.20) is also a significant preventative action. Comprehensive cost analysis provides a clear view of the BIM benefits and increases awareness. Awareness of BIM benefits is one of the key triggers to implement and adopt BIM.

Company strategies specific to BIM training and employing (mean value, 4.13) is another item of preventative actions to challenges. Company strategies specific to BIM is significant action not only for BIM implementation but also for the most efficient utilization of BIM.

Collaboration with the government to drive BIM implementation in private companies has the lowest mean value (4.04) in this category and also among all items. The results show that while governmental incentives and training programs are seemed significant factors to drive BIM implementation in private companies, collaboration with the government is seemed less significant preventative action.

#### 5.4.2.2 Factor 2: government

Factor 2 contains four preventative actions that are concerned with governmental strategies.

BIM implementation in governmental agencies in order to lead the Turkish transportation infrastructure industry (mean value, 4.41) is the most significant preventative action among the all of variables. Since the working system of the public institutions affects all other organizations related to transportation infrastructure, this is a crucial driving force for BIM implementation in the Turkish transportation infrastructure industry.

Development of BIM-specific contracts and regulations by governmental authorities (mean value, 4.39) is ranked the second most important preventative action among all of the items. The development of BIM-specific contracts and regulations by governmental authorities is one of the main driving forces for both the public and private sectors to decide to implement BIM, and this strategy is a priority for proceeding to the stage of overcoming the other obstacles.

Development of BIM-specific standards by governmental authorities (mean value, 4.21) is also a significant preventative action. Clarification of information such as how BIM will be implemented, in which format the project deliveries will be submitted, is crucial in terms of overcoming the initial stage and organizational challenges and preventing possible conflicts and disagreements.

Development of governmental BIM policies to make it mandatory (mean value, 4.18) is another important variable in this factor. Governmental BIM mandate policies are effective for the implementation and adoption of BIM in the transportation infrastructure industry since transportation infrastructure projects are public projects.

#### 5.4.2.3 Factor 3: education

The third factor includes three items related to education.

Company incentives for employees to learn to work with BIM and its software (mean value, 4.36) is the most significant educational strategy. Company incentives for employees related to BIM education create a basis for the company's transformation and enable the processes to be more informed.

In-company trainings for increasing awareness of employees about the benefits of BIM in terms of time/cost (mean value, 4.30) is another important variable related to education. Increasing awareness is important in terms of preventing the challenges of unwillingness to collaborate and resistance to change the working culture described in the previous section.

Compulsory BIM lessons in higher education (mean value, 4.14) is also an educational preventative action. With these lessons, it is ensured that higher education students have knowledge about BIM and its benefits and difficulties to use in their professional life.

# 6. CONCLUSIONS

Building Information Modeling (BIM) has a great potential to increase efficiency, in terms of time, cost, and quality in the design, construction, operation, and maintenance phases of transportation infrastructure projects. BIM has been widely adopted in the construction industry worldwide, and implementing BIM in transportation infrastructure projects is increasing rapidly around the world. It is considered that BIM will inevitably become widespread in the transportation infrastructure industry in the coming years. Various strategies have been developed around the world to accelerate the adoption process of BIM and benefit from the advantages of BIM implementation earlier. While the initiatives and investments are increasing in Turkey, the adoption process is slow due to the limitations and challenges.

In this study, the challenges of BIM implementation for the Turkish transportation infrastructure industry were examined. Furthermore, the required strategies were specified to overcome these challenges. To achieve these objectives of the thesis, a literature review and a questionnaire survey were conducted. Afterward, the results of this survey were digitized and analyzed with statistical analysis methods.

In the literature review, (1) definitions of BIM, (2) historical development of BIM, (3) global strategies for BIM implementation, (4) the current situation of BIM implementation in Turkey, (5) BIM implementation for transportation infrastructure industry, and (6) BIM implementation in different transportation infrastructure project types were investigated. In light of this review, a questionnaire survey was designed with 13 challenge items and 11 preventative action items to collect data regarding BIM implementation in the Turkish transportation infrastructure industry. The questionnaire was applied amongst BIM professionals who have experience in transportation infrastructure projects in Turkey to investigate their perceptions regarding the challenges to BIM implementation and preventative actions to these challenges for the Turkish transportation infrastructure industry. The data obtained from the questionnaire were analyzed using statistical analysis methods which are descriptive statistics and exploratory factor analysis (EFA).

In this context, primarily the current status of the BIM implementation in the Turkish transportation industry was examined based on the data obtained from the questionnaire. The results show that the majority of the surveyed companies have started to implement BIM in the last 10 years with producing their own BIM models, and they have benefited from BIM at different project phases. According to the respondents' experience in the Turkish transportation infrastructure industry, the most important contribution of BIM (1) to the documentation stage is time efficiency, (2) to the design stage is quality efficiency, (3) to the construction and logistics stages is cost efficiency, and the most important contributions of BIM (4) to the operation and maintenance stages are cost and quality efficiencies.

To analyze the surveyed challenges and the required preventative actions, descriptive statistics were used to calculate the importance weight of each challenge items and preventative action items. Besides, EFA was used to find out the underlying challenge factors of BIM implementation in the Turkish transportation infrastructure industry and the underlying preventative action factors to the challenges.

As a result of the descriptive statistics, it is concluded that (1) lack of regulations and contractual arrangements specified for BIM, (2) the resistance to the adversity of changing working culture and adapting to a new and unfamiliar system and (3) lack of demand and enforcement of BIM utilization from public authorities are the most significant challenges. As for the preventative actions, it is identified that (1) BIM implementation in governmental agencies in order to lead the Turkish transportation infrastructure industry, (2) development of BIM-specific contracts and regulations by governmental authorities and (3) company incentives for employees to learn to work with BIM and its software are the most critical and required preventative actions.

According to the results of the EFA, three main factors underlying the challenges of BIM implementation in the Turkish transportation infrastructure industry were identified. The three factors were named by considering the common features of the challenge items included in each group, as (1) organization, (2) initial stage, and (3) leadership. As for the preventative actions, three factors were identified, and these factors were named as (1) private sector, (2) government, and (3) education.

Since all of the transportation infrastructure projects in Turkey are public projects, it is considered that leadership of the government and the public institutions is the most effective strategy for the adoption of BIM in the Turkish transportation infrastructure industry. Accordingly, it is anticipated that the adoption of BIM primarily in the public institutions will effectively lead the adoption of BIM in the private sector and prevent the resistance to the adversity of changing working culture, which is determined as one of the most important challenges, for both public and private sectors, and eliminate many other organizational barriers. Besides, it is anticipated that supporting this transition progress with BIM-specific regulations, standards, and contracts will enable a more stable, progressive, and conscious BIM implementation process.

The results of the study show that one of the most important challenges to BIM implementation in the Turkish transportation infrastructure industry is that the transition to BIM requires changing the working culture. Besides, lack of awareness about the advantages of BIM and lack of experience of the project team make this working culture transformation more difficult. Increasing the awareness of employees and stakeholders about the benefits of BIM in terms of cost and time efficiency is one of the key requirements for overcoming many challenges, especially the organizational and initial stage related resistances and barriers. Accordingly, to increase the awareness and knowledge of all parties, training and certification programs should be arranged and promoted by companies and public institutions. The strategies proposed are considered critical for the transition process and more accurate and effective utilization of BIM in the Turkish transportation infrastructure industry.

The findings of the study can facilitate further researches in this domain and contribute to the strategies to be developed for the implementation of BIM in Turkish transportation infrastructure projects.

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**APPENDIX**

**QUESTIONNAIRE**

**1. GENERAL INFORMATION**

1.1 What is your profession?

Civil engineer
Architect
Mechanical engineer
Electrical engineer
Geotechnical engineer
Interior architect
Other (Please specify)

1.2 What is your position in the project you are working on or your last project?

Design engineer / Architect
Design chief
Project manager / Vice manager
Control or Chief engineer / Architect (for public authority employees)
Vice director / Director or superior (for public authority employees)
Academician / Teaching assistant
Other (Please specify)

1.3 What is your education level?

Associate degree
Bachelor's degree
Master's degree
PhD degree
Associate professor or superior

1.4 How many years of experience do you have in your profession?

1-5
5-8
8-15
15-30
30+

## 2. PROFESSIONAL DETAILS

2.1 Have you ever worked on a transportation infrastructure related project/study in Turkey?

Yes
No

2.2 Are you currently working on a transportation infrastructure related project/study in Turkey?

Yes
No

2.3 Have you used BIM on any project you have worked on?

Yes
No

2.4 If Yes, how did you learn to utilize BIM and related software?

Self-taught
Industry-led training
During the bachelor's degree
During higher education (Master and/or PhD)
Private courses

2.5 Which of the following BIM software packages do you have experience working with? (Please rate each option: 0-no experience / 5-highly skilled)

Autodesk products
Bentley products
Nemetschek products
Graphisoft products
Other (Please specify)

## 3. COMPANY DETAILS

3.1 Which sector are you currently working in?

Public
Private
Academy

3.2 If you currently working in the private sector, which field does your company operate in?

Design
Consultancy
Construction

3.3 Does your company have any experience with using BIM?

Yes
No

3.4 If your company does not currently use BIM, how likely it is that your company would use BIM in the future? (0-not likely / 5-extremely likely)

0 1 2 3 4 5

3.5 How many professionals who are directly utilizing BIM and related software are employed by your company?

Less than 3
3-5
6-10
11-20
20-35
35-50
50-100
More than 100

3.6 How many years has it been since your company first implemented BIM?

Less than 3
3-5
6-10
11-15
16-20
More than 20

3.7 How is your company related to BIM utilization?

Using BIM tools to analyze BIM models but not creating BIM models
Creating BIM models at 3D level
Creating BIM models at 4D level
Creating BIM models at 5D level
Creating BIM models at 6D level
Creating BIM models at 7D level
BIM Education
Academic Research
Other (Please specify)

3.8 What percentage of the projects, which your company has executed, have utilized BIM within the past 5 years?

None
%1-%20
%21-%40
%41-%60
%61-%80
%81-%100

3.9 Which of the following BIM software packages does your company utilize? (Multiple options can be selected)

Autodesk products
Bentley products
Nemetschek products
Graphisoft products
Other (Please specify)

3.10 In light of your experience in your company, please indicate which type of efficiency of BIM contributes more to the phases given below.

| Phase | Time efficiency | Cost efficiency | Quality efficiency |
|---|---|---|---|
| Design | | | |
| Documentation | | | |
| Construction & Logistics | | | |
| Operation & Maintenance | | | |

## 4. CHALLENGES AND PREVENTATIVE ACTIONS

4.1 Please rate the following listed challenges encountered in BIM implementation considering the Turkish transportation infrastructure industry.

| Challenge Items | Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree |
|---|---|---|---|---|---|
| 1) Lack of regulations and contractual arrangements specified for BIM | | | | | |
| 2) Increased risk-sharing between stakeholders because of the collaborative approach of BIM | | | | | |
| 3) Lack of BIM implementation standards | | | | | |
| 4) Lack of demand and enforcement of BIM utilization from public authorities | | | | | |
| 5) Lack of demand and enforcement of BIM utilization from private companies | | | | | |
| 6) The difficulty of BIM implementation by reason of its high initial investment cost | | | | | |
| 7) The belief that BIM and related software is hard to learn | | | | | |
| 8) The need for numerous new software licenses | | | | | |
| 9) Not being able to find sufficiently equipped BIM consultants for the implementation period | | | | | |
| 10) The fragmented working culture (lack of high-level collaboration) | | | | | |
| 11) The resistance to the adversity of changing working culture and adapting to a new and unfamiliar system | | | | | |
| 12) Lack of BIM experience of the project team | | | | | |
| 13) The unwillingness of the project team to communicate and collaborate actively | | | | | |

4.2 Please rate the following listed preventative actions required to eliminate the challenges considering the Turkish transportation infrastructure industry.

| Preventative Action Items | Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree |
|---|---|---|---|---|---|
| 1) Development of governmental BIM policies to make it mandatory | | | | | |
| 2) BIM implementation in governmental agencies in order to lead the industry | | | | | |
| 3) Development of BIM-specific contracts and regulations by governmental authorities | | | | | |
| 4) Development of BIM-specific standards by governmental authorities | | | | | |
| 5) Promoting BIM training of new recruits in the private sector by governmental incentives and training programs | | | | | |
| 6) Collaboration with the government to drive BIM implementation in private companies | | | | | |
| 7) Comprehensive cost analysis of the project lifecycle to persuade the stakeholders regarding the financial advantages of BIM | | | | | |
| 8) Company strategies specific to BIM training and employing | | | | | |
| 9) Company incentives for employees to learn to work with BIM and its software | | | | | |
| 10) In-company trainings for increasing awareness of employees about the benefits of BIM in terms of time/cost | | | | | |
| 11) Compulsory BIM lessons in higher education | | | | | |

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