Improving Decision-Making System in Infrastructure Projects: A Framework to Propose Infrastructure Building Information Modeling (I-BIM) with Artificial Neural Networks (ANN)

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ABSTRACT

In the construction industry, countries are trying to be more careful with projects that they want to invest in due to the more restricted budget allocation that hit the world after COVID-19. Information and Communications Technology (ICT) brought a new vision to the industry under the light of Building Information Modeling (BIM) to save more time and money on huge projects, but there are many challenges in the path of utilization of this technology for other sectors of the construction industry, such as infrastructure. According to the World Economic Forum (WEF), there is enormous growth in the infrastructure budget, which is going to be needed by 2040. Now the main question is: "Does the BIM philosophy, which has been used for more than two decades, come to any sort of adoption for infrastructure projects?" The foundation of this dissertation has been built on top of this question, and it has been followed up to support it by implementing this technology for infrastructure projects and reforming a framework precisely for this sector of the construction industry. To do that, a comprehensive ontology and literature review have been done to identify the adoption of BIM for infrastructure projects and find the main categories and variables to define a new category in information modeling terms as Infrastructure Building Information Modeling (I-BIM). Moreover, a tri-axial model as a conventional BIM method regarding the Policy-Technology-Process (PTP) model has been discussed parallel to competency tire establishment in accordance with five main categories and 26 defined variables in total. Therefore, a questionnaire survey has been conducted to distribute among two target countries, the United States of America and Turkey. Afterwards, in Core Competency, detailed data mining has been performed on each variable in each category for each target country to identify those variables as benefits, neutrals, or barriers to adopting I-BIM terminology. Furthermore, the Domain Competency analysis has been completed by defining meta variables and introducing the Total Number of Meta Variables (TNMV) factor at three different levels to distinguish each meta category more precisely and accurately for each target country individually. The third and last tire was Execution Competency, which has been concluded with the assistance of an Artificial Neural Network (ANN) to train, validate, and test collected data from previous tires in order to find the best performance according to the Q-Factor (Quality) for each country and the E-Factor (Experimental) for each variable to significantly upsurge the accuracy and impact of all variables within the proposed I-BIM framework

Keywords: Building Information Modeling, Project Management, I-BIM, Infrastructure Project, Construction Management, Digital Transformation, Meta Variables, Artificial Neural Network, ANN.

ÖZ

İnşaat sektöründe, COVID-19 sonrası dünyayı etkisi altına alan daha kısıtlı bütçe tahsisi nedeniyle ülkeler yatırım yapmak istedikleri projelerde daha dikkatli olmaya çalışıyor. Bilgi ve İletişim Teknolojileri (BİT), büyük projelerde daha fazla zaman ve para tasarrufu sağlamak için Yapı Bilgi Modellemesi (BIM) ışığında sektöre yeni bir vizyon getirdi, ancak bu teknolojinin diğer sektörler için kullanılması yolunda birçok zorluk var. altyapı gibi inşaat sektörü. Dünya Ekonomik Forumu'na (WEF) göre, 2040 yılına kadar ihtiyaç duyulacak olan altyapı bütçesinde muazzam bir büyüme var. Şimdi asıl soru şu: "Yirmi yılı aşkın süredir kullanılan BIM felsefesi, altyapı projeleri için herhangi bir benimseme var mı?" Bu tezin temeli bu soru üzerine inşa edilmiş ve bu teknolojiyi altyapı projeleri için uygulayarak ve inşaat sektörünün tam da bu sektörü için bir çerçeve reformu yaparak bunu desteklemek için takip edilmiştir. Bunu yapmak için, altyapı projeleri için BIM'in benimsenmesini belirlemek ve bilgi modelleme terimlerinde Altyapı Bina Bilgi Modellemesi (I-BIM) olarak yeni bir kategori tanımlamak için ana kategorileri ve değişkenleri bulmak üzere kapsamlı bir ontoloji ve literatür taraması yapılmıştır. Ayrıca Politika-Teknoloji-Süreç (PTP) modeline ilişkin geleneksel bir BIM yöntemi olan üç eksenli bir model, yetkinlik lastiği oluşumuna paralel olarak beş ana kategori ve toplamda 26 tanımlı değişkene göre tartışılmıştır. Bu nedenle, iki hedef ülke olan Amerika Birleşik Devletleri ve Türkiye arasında dağıtılmak üzere bir anket çalışması yapılmıştır. Daha sonra, Temel Yetkinlikte, bu değişkenleri I-BIM terminolojisini benimsemeye yönelik faydalar, nötrler veya engeller olarak tanımlamak için her bir hedef ülke için her bir kategorideki her değişken hakkında ayrıntılı veri madenciliği yapılmıştır. Ayrıca, her meta kategoriyi her hedef ülke için ayrı ayrı daha kesin ve doğru bir şekilde ayırt etmek için meta değişkenler tanımlanarak ve Toplam Meta Değişken Sayısı (TNMV) faktörü üç farklı düzeyde tanıtılarak Alan Yetkinlik analizi tamamlanmıştır. Üçüncü ve son lastik, Q-Factor'a göre en iyi performansı bulmak için önceki lastiklerden toplanan verileri eğitmek, doğrulamak ve test etmek için bir Yapay Sinir Ağı (ANN) yardımıyla sonuçlandırılan Yürütme Yetkinliği idi (Kalite) ve bunların doğruluğunu ve etkisini önemli ölçüde artırmak için her değişken için E-Faktörü (Deneysel).

Anahtar Kelimeler: Yapı Bilgi Modellemesi, Proje Yönetimi, I-BIM, Altyapı Projesi, İnşaat Yönetimi, Dijital Dönüşüm, Meta Değişkenler, Yapay Sinir Ağları, ANN.

DEDICATION

This research is dedicated to my lovely wife for all her sacrifices in our journey

and

to my parents for their continued support and encouragement during my whole life

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My parents were an inseparable part of this journey, and they did whatever they could for me to lead me to this point, and I don't know how to appreciate them for that; I'm in your debt forever, and thanks for being patient with me as always.

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LIST OF SYMBOLS AND ABBREVIATIONS

AAA	Advance Algebraic Analysis
AEC	Architecture-Engineering-Construction
ANN	Artificial Neural Network
BIM	Building Information Modeling
BrIM	Bridge Information Modeling
CAD	Computer-Aided Design
CiM	Civil Information Modeling
CIM	Civil Information Modeling
CIM	Civil Integrated Management
CR	Contractual Relations
E	Education
F	Financial
ENR	Engineering News-Record
GDP	Gross Domestic Product
GIS	Geographical Information Systems
I-BIM	Infrastructure Building Information Modeling
ICT	Information and Communications Technology
M	Managerial
MC	Meta Managerial
ME	Meta Education
MF	Meta Financial
MM	Meta Managerial
MP	Meta Public Authority

MSE	Mean Square Error
PA	Public Authority
PT	Project Type
PTP	Policy-Technology-Process
RMSE	Root Mean Square Error
SPSS	Social Sciences Program's Statistical
TNMV	Total Number of Meta Variables
UAS	Unmanned Systems Technology
WEF	World Economic Forum

Chapter 1

INTRODUCTION

1.1 Introduction

This chapter starts with a brief introduction to the background of the building industry and the relation of construction and information technology. The primary justifications for doing this study are then given. As a result, the objective and achievements are briefly described, and in the conclusion, the thesis guidelines provide a broad vision of the framework for this PhD thesis.

1.2 Background Information

A sizable global industry that promotes social and economic advancement on a local, regional, and international level is the construction sector. The planning, designing, building, and administration of construction projects, however, are challenging, demanding the contribution of experts to improve project integration between various phases. The complexity and poor production of the building industry draw criticism from all around the world. A new paradigm is required to improve productivity, value, quality, and sustainability while reducing costs and delays due to these concerns that are connected to project delivery and its unique characteristics. Among the solutions put up are new contractual arrangements, integrated project delivery, and technological developments. The growth in population is undeniable fact which lead any nation to difficulties in different sectors including construction industry due to higher demands in multiple related sectors of it including infrastructure domain. Civil infrastructure facilities can be categorized in different domains such as transportation, energy, utility, recreational facility and water management infrastructure. Nowadays, needs for a greater infrastructure is greatly increasing since this domain can consider as the backbone of any country or nation for more proficient, well organized, safe, cost effective and reliable for their citizens and if it manages properly, it can lead to have a greater impact on social development and economic (Costin et al., 2018).

The answer to the aforementioned issue has been identified as building information modeling (BIM), one of the most advanced techniques that improves the construction industry by promoting stronger cooperation between various departments and ensuring efficient project delivery (Lu et al. 2015). By replicating construction processes in a virtual environment, BIM enables building owners to produce a detailed virtual model of the structure with all the necessary information. This model, which also covers design, logistics, construction, and physical activities, may be used to understand the structure of the building as well as facilities management and maintenance after construction (Lu et al. 2014). Buildings are growing more complex, thus collaborating and communicating among project participants, particularly designers and builders, is crucial for their understanding of modern building methods.

To fully comprehend the application of BIM in the building and infrastructure sectors, it is crucial to understand its meaning. According to Eastman et al., (2011) BIM is not only a tool but a process that involves modeling technology and related processes to produce, communicate, and analyze building models (Raja Mohd et al. 2021; Banerjee et al. 2022; do Carmo et al. 2022). BIM is a verb that encompasses tools, processes, and technologies enabled by digital, machine-readable documentation on a building's performance, planning, construction, and operation. Thus, BIM is an activity and not an object. BIM is a digital representation of a facility that is data-rich, object-oriented, intelligent, and parametric. A building information model incorporates the building elements' geometry, spatial relationships, geographic information, quantities, properties, cost estimates, material inventories, and project schedule (Ozturk. 2020; Tan et al. 2021; do Liao et al. 2022). Therefore, BIM is an entire construction lifecycle demonstration that allows for redefining work scope, generating high-quality 3D design schemes, supporting 4D scheduling and 5D cost estimation, and optimizing facility management and maintenance (Kim et al. 2016; Ehrbar. 2016; Abbondati et al. 2020).

The main aim of conducting this research is to identify and prove the existing lack of BIM utilization for infrastructure projects. In order to justify this issue, the United States of America and Turkey has been selected as target construction industry in order to cover a broad range of countries in similar construction and development level; one represents a good case of being an advance country (United States of America) while the other can consider as a developing country (Turkey). This research will try to prove the existing gap with multiple approaches which is going to be discuss in following section of this chapter and more comprehensively with respected chapters.

1.3 Purposes and Objectives

The main aim of conducting this research is to identify and prove the lack of using BIM for infrastructure projects and propose a new framework for industry to utilize this technology under the name of Infrastructure building information modeling (I-BIM) framework. To achieve this, the primary goals of this research have been determined to be:

- To prove the correlation of building information modeling (BIM) utilization between building construction and infrastructure.
- To find and select the most critical factor that influences on BIM utilization in target countries in order to adopt it for the infrastructure building information modeling (I-BIM) framework.
- To choose and select each category as a benefit, neutral, or barrier according to the target respondents in both the United States of America and Turkey.
- To apply the Total Number of Meta Variables (TNMV) in order to create a better platform for proposing a framework based on a more accurate level of collected data.
- Utilize networking system in order to purpose a proper framework resolution for I-BIM.

To achieve the aforementioned objectives, the research questions have been amended and adjusted to support the research:

i. Is there any relation between building construction and infrastructure construction in order to address information technology?

ii. Why is it essential to present different frameworks and BIM adoption strategies based on different construction project categories?

iii. Does BIM utilization and its philosophy, which has been used for more than two decades, come to any sort of adoption for infrastructure projects?

iv. How can we justify the need to propose a generic conceptual BIM adoption framework for infrastructure projects?

v. What are the privileges and obstacles in the way of I-BIM utilization?

vi. How can the barriers be mitigated, and how can the benefits of I-BIM be spread to be more accessible in target countries?

1.4 Research Methodology

In general, there are two main types of reviews - systematic reviews and descriptive reviews. Both of these reviews have their own research questions and objectives, which must be clearly stated. A systematic review is primarily used to answer a research question based on an unbiased assessment of all the research studies related to that question. Such reviews were first introduced in the 1970s in the social sciences and then widely adopted in the medical sciences and epidemiology. The main objective of a systematic review is to evaluate the existing literature and weigh the evidence to improve decision-making (Strech & Sofaer, 2012).

To demonstrate the industry professionals how they can efficiently adopt BIM for infrastructure projects, comprehensive review of existing body of knowledge from many different sources (academic journals, dissertation and conference databases, web, e-books, etc.) is performed and will be described comprehensively in Chapter 2 and also Chapter 6 will go into more detail about the questionnaire design and development. The developed sample of the questionnaire can be found in Appendix A.

1.5 Research Novelty and Contribution

The first question that needs to be answered to justify the needs of this dissertation is, "Why is it essential to present different frameworks and BIM adoption strategies based on different construction project categories?" There are many reasons to do that because, first of all, each project is going to have specific requirements; therefore, they will have unique characteristics and objectives, which have direct effects on project complexity and scale. Moreover, each category needs different considerations and tailored approaches to effectively leverage the advantages of BIM. The next reason can be the involvement of stakeholders and their varying levels of BIM knowledge, expertise, and requirements, which create a need to present different frameworks and strategies. The last reason can be regulatory compliance and standards, which in infrastructure projects often differ from those applicable to building construction or industrial projects. A dedicated framework can address the unique regulatory aspects related to infrastructure projects, ensuring compliance with relevant standards, safety regulations, and sustainability guidelines specific to the infrastructure sector.

Consequently, it can be stated that the main aim of conducting this research is to identify and prove the existing lack of BIM utilization for infrastructure projects. Therefore, in order to accurately represent the process in which this study is conducted from design through conclusion, a series of procedures that reflect the beliefs, assumptions, and nature of reality and truth regarding the topic under study are progressively organized, as shown in Figure 1. As depicted, this research is composed of five sequential processes. The research process starts by selecting two different countries that are in different leagues in terms of adoption of the latest trends, technologies, and processes in construction. Therefore, the United States of America is chosen as an advanced country in terms of existing construction practices, and Turkey is selected as a developing country for the same purpose. Determination and evaluation of the difficulties for very little or no use of BIM adoption in infrastructure projects in these two countries, observing similarities and dissimilarities, and analyzing the reasons that lay under the difficulties will pave the way for proposing an action plan to mitigate those difficulties if they cannot be eliminated. In this way, the author strongly believes that theoretical proof and findings will create the necessary motive for industry professionals to adopt BIM for infrastructure projects.

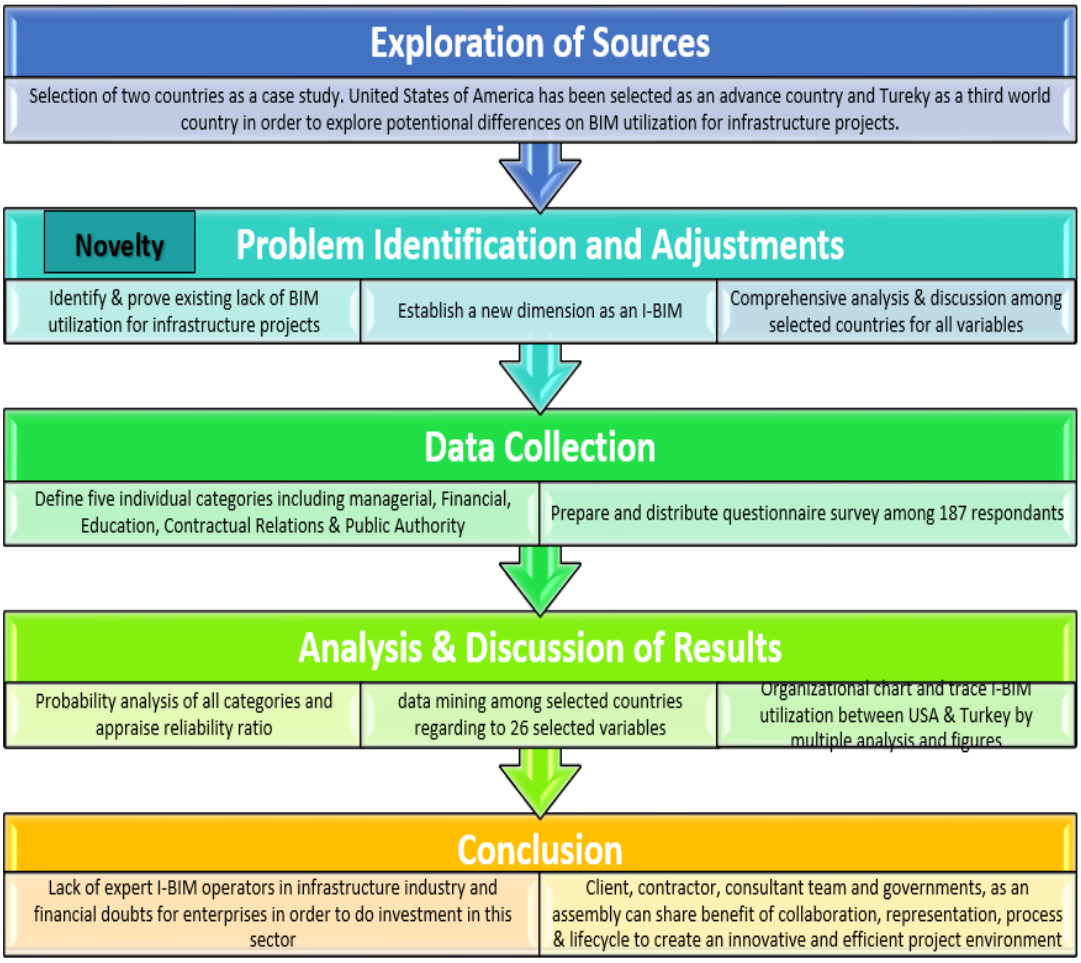


Figure 1: Proposed approach flow chart to define BIM for infrastructure projects

1.6 Thesis Guideline

The research's aims and purpose are specified at the beginning, along with some prior knowledge on construction management. Then, a brief description of the types of information modeling and building projects, including various levels of infrastructure, carried out in the target studies and countries is provided by the literature review. A description of the approach used to analyze the data has been included in the following section. As a result, the data mining and analysis from the questionnaire survey are reported in the subsequent section of the study. The findings of the surveys are then examined, and suggested actions such as meta variables analysis and applying Total Number of Meta Variables (TNMV) value at various levels to improve data accuracy in order to mitigate issues and establish a stable framework are presented. Conclusions, questions and recommendations for future work are presented in the end. All mentioned progressions are divided into nine chapters, which are separately described below:

In Chapter 2, an in-depth literature review is given regarding the various types of information modeling systems used in research as well as the various kinds of construction projects, such as infrastructure projects, which ultimately led to the selection of different I-BIM utilization variables later in Chapter 5.

Chapter 3 discusses the Turkish and American construction sectors as well as the contemporary infrastructure in each of these regions and their economic stability. As much as COVID-19 has put a focus on digital innovation, both countries are also finding themselves with deeper needs with their projects and needs for long-term design packages, including lower carbon emissions, saving financial resources, better scheduling, and more organized legislation.

In Chapter 4 the research strategy for the thesis is presented. This chapter discusses extensively the data collecting and analyzing techniques conducted, as well as the research philosophies and methodologies that were used.

Chapter 5 starts with defining the I-BIM utilization variables that have been divided into five categories. In this section, each category and all 26 variables have been comprehensively explored and addressed with multiple references. Moreover, the conceptualized proposed framework is going to be discussed at three levels: the Tri-Axial model, the ontology of I-BIM, and the competency tiers of it, which will conclude with the ultimate framework.

In Chapter 6, the completed questionnaire that was used in this research for implementing BIM for infrastructure projects is presented. The chapter additionally proceeds through the process used to construct the questionnaire, how participants are chosen, and how the confidentially of the participants is achieved and a new weighting model is represented in order to be used in succeeding chapters. This chapter also covered the goals that each question that is directed at responders aims to achieve.

The Chapter 7 is comprised of the data mining of the questionnaire results. Additionally, interpretations of the findings are discussed thoroughly with the gathered data from each part of the questionnaire. The chapter concludes by discussing analogies among target countries based on respondents' points of view about each of the I-BIM utilization categories.

Chapter 8 addresses the use of meta variables in this research study and introduces the Total Number of Meta Variables (TNMV) at three distinct levels to improve analysis accuracy. It is noteworthy that each of these levels has been extensively deliberated and instigated for both the United States of America and Turkey.

Chapter 9 is going to present the execution competency of the I-BIM framework by utilizing the Artificial Neural Network (ANN) systems to predict the relation of all I-BIM variables implementation in order to achieve an appropriate model for this dissertation.

Chapter 10 discusses the research's findings and makes recommendations for additional research.

Chapter 2

BUILDING INFORMATION MODELING

2.1 Introduction

The Architecture, Engineering, and Construction (AEC) are one of the largest industries in the world (Murie 2007). To deliver a construction project there should be a financial benefit ahead of doing it but nothing can do to guarantee a profit is going to be made out of a project. It has been stated by Westhuizen that there are three main objectives to complete a project successfully which is time, budget and doing it according to requirements but the main barriers to overcome these objectives is project environment. Project management is an effective approach to anticipate the probability of project success and effective time and cost control can be an important key to any construction projects. To achieve aforementioned parameter and in order to resolve related lack of management information issue, stablish a strong link among different related parties and accomplish progressive practices, Information and communication technologies has been developed and get use by construction industry. (Ahuja et al. 2009; Lu et al. 2014). Amongst different sort of ICTs, Building Information Modeling (BIM) provide a model-based cooperative approach which let the teams manage projects in better condition (Bryde et al. 2013; Froese 2010; Succar 2009). BIM has been addressed as a digital representation for both practical and theoretical features of any establishment during the life cycle of that facility by the National Institute of Building Science (NIBS 2007).

By the previous decade, Building Information Modeling (BIM) has been considered as one of the most important technological improvements in the structure design and construction industry. AEC industry have been attracted by this significant technology. The road map of this technology can be map out back to the 1960s by computing applications and also appearance of need to have solid modeling programs in order to achieve more proper design (Smith, 2014). The establishment of BIM has been started by the development of the ArchiCAD and furthermore Revit software played an important role for implementation of BIM in construction industry. (Bergin, 2012). This technology was introduced to figure out the potential problem of construction project in order to analyze and simulate any effected influences. To achieve this goal BIM presents the building process of a construction project virtually in preliminary stage and before even construction tasks get started. Generally, BIM is more than just a simple application of 2D and 3D techniques. It is more descriptive as a system to help companies in order to organize the right people with accurate information together, efficiently and effectively. So as a highlight, BIM is the combination of information, technology, people, and processes (RICS, 2014).

By the mid-1990s and decreasing of construction projects demand and other obstacles which construction industry has been faced, BIM is being introduced as a solution to overcome these obstacles (Teicholz, 2004). The variety of direct and indirect of BIM's benefits were undeniable and construction phases got more simplified and transparent in many aspects (Lee et al., 2012). In the past two decades, the AEC industry owes its reinvention to BIM. As mentioned, the main concept of BIM was 3D modeling but by the time it's expanded and improved to 4D programming connected with the construction process. Later on, it got even more developed by 5D modeling integrated with cost data. According to Jung & Joo (2011), According to Azhar (2011), BIM technology can be considering as a tool to decrease the delivery time of projects by 7% or eliminate unbudgeted change of projects by 40% and make the process of cost estimation faster up to 80%. Furthermore, it can merge different phase of any construction projects such as demolition, maintenance, design, and construction information into a solid and single higher level phase, and assist all participants with improvements in costs reduction, monitoring risks, and waste management, as well as carbon emissions and generally by efficient performance.

BIM contains rich structured data which is represented by an easily visualized 3D-object database. Moreover, it can be functional in order to analyze building costs, schedules, sustainability, and performance (Uddin, 2013). This technology initially has been applied only for construction phase of building projects, but nowadays, it known as a tool can be contribute at operation or maintenance phase for most of the construction projects such as airports, stadiums or even bridges. Building information modeling is well-known as a representative of any infrastructure and building over their lifecycles and it addressed a set of maturing technologies (Demian & Walters, 2014).

2.2 Information Modeling Classification

This technology originally has been applied only for construction phase of building projects, but currently, it known as a tool can be contribute for life cycle of any construction projects such as stadiums, airports or even bridges and more generally for most of well-known infrastructure domains to advance and expand it (Cheng et al., 2016). Development of a micro computing system for bridge management was one of the earliest discoveries which fit the definition of BIM for transportation infrastructure in this thesis (Hudson, 1993). Shifting from conventional workflow to computer aided workflow means the elimination of paper-based programing and replacing it with electronic and advance programing. This was the point that Bridge Information Modeling (BrIM) has been introduced to industry and this information modeling is an extension of BIM that focuses on bridges and more generally for most of well-known infrastructure domains to advance and expand it and it sometimes referred to as civil information modeling (CiM) (Costin, 2016). CIM terminology refer it to the application of BIM for civil infrastructure like tunnels and bridges but there are other terms like construction information modeling, civil information management or civil integrated management which is use by various institutions to define CIM (Yabuki, 2016). This variety on definition of CIM can led any users to errors while working on a project with other members who work for different companies and make collaboration more challenging. Figure 2 summarizes most popular information modeling terms and meaning.

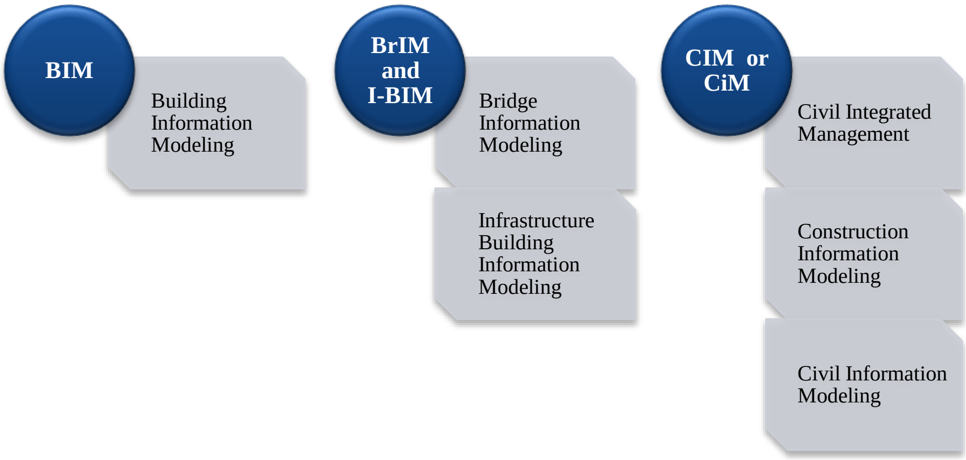


Figure 2: Information modeling terms charts

2.3 Specification of BIM

BIM models are typically divided into different dimensions that reflect the level of detail and the type of information they contain. In this section all these dimensions and level of access to all type of close and open BIM is going to be discussed.

2.3.1 Geometrical Shape in 2D

The second dimension, also known as 2D, is the most basic form of BIM. It involves the use of two-dimensional CAD (Computer-Aided Design) drawings that represent the building's design in plan, elevation, and section views and it is essential because it provides a visual representation of the building's design. 2D CAD drawings are used to develop the initial design concept, including the building's floor plan, elevations, and sections. These drawings are essential for communicating the design intent to stakeholders, including clients, contractors, and engineers. The use of 2D CAD drawings in BIM allows for accurate and efficient communication of design changes. Designers and engineers can quickly and easily modify the drawings, making it easier to respond to client feedback and make design adjustments. The use of 2D CAD drawings also allows for easy coordination with other disciplines, such as structural and mechanical engineers, to ensure that the design is accurate and constructible.

2.3.2 Solid Modeling

The third dimension in BIM is the most common and essential aspect of BIM modeling. It involves the creation of a 3D digital model of the building, including all the necessary details such as walls, floors, roofs, and building systems like electrical, plumbing, and mechanical. The 3D BIM model provides a more detailed and accurate representation of the building compared to traditional two-dimensional (2D) drawings. The use of 3D BIM models allows for improved visualization and coordination of the building design. The model can be used to identify potential clashes between different building systems, which can be corrected before construction begins. This leads to fewer construction errors and delays, and ultimately, a reduction in project costs.

The 3D BIM model can also be used to create accurate and detailed construction documentation, including plans, elevations, sections, and details. This documentation is essential for the communication of the design intent to stakeholders, including clients, contractors, and engineers.

2.3.3 Schedule and Time Management

The fourth dimension in BIM is commonly referred to as 4D BIM. It involves the addition of time-related information to the 3D BIM model. This information can be used to create a construction schedule that incorporates the sequence and duration of construction activities. The 4D BIM model can also be used to evaluate the feasibility of the construction schedule, identify potential delays, and optimize construction sequencing. The use of 4D BIM allows for improved project planning and scheduling, which can lead to reduced project duration and cost savings. The model can be used to evaluate different construction scenarios and identify potential risks before construction begins.

2.3.4 Cost Management

The term "5D BIM" refers to the fifth dimension in BIM. It entails the 4D BIM model being updated with cost-related data. Throughout the duration of a project, the 5D BIM model may be used to compute and manage project expenses, including labor and material expenditures. The model may be used to monitor project expenditures and assess how well they match the original budget. Improved cost control made possible by the use of 5D BIM can save project costs and increase profitability. The model enables cost optimization and value engineering by enabling the evaluation of various design and construction choices.

2.3.5 Facility Management

The term 6D BIM is frequently used to refer to the sixth dimension in BIM. It entails the 3D BIM model being updated with details on facility management and operations. The building's lifetime, including maintenance and repair schedules, equipment inventories, and energy use, can be tracked and managed using the 6D BIM model. Improved facility management and sustainability made possible by the use of 6D BIM can result in lower operating costs and better building performance. The model can be used to pinpoint areas for energy-saving potential and enhance building efficiency.

2.3.6 BIM Level of Maturity

Level 0 (2D CAD) is the most basic level of dimension in BIM. It involves the use of 2D CAD drawings to represent the building's design. This level of dimension is often used in early stages of a project and does not contain any 3D information. Level 0 BIM models typically contain floor plans, elevations, and sections.

Level 1 BIM (3D BIM) involves the creation of 3D models that contain information about a building's geometry, including walls, floors, and roofs. Level 1 BIM models also include information about the building's systems, such as electrical, mechanical, and plumbing. Level 1 BIM models are often used during the design phase of a project and can be used for clash detection and visualization.

Level 2 BIM (Managed 3D BIM) is the most widely used level of dimension in BIM. It involves the creation of managed 3D models that contain information about a building's geometry, systems, and materials. Level 2 BIM models also include information about the building's cost, schedule, and sustainability. Level 2 BIM models are used throughout the construction process and can be used for design coordination, quantity takeoffs, and construction sequencing.

Level 3 BIM (Integrated BIM) is the highest level of dimension in BIM. It involves the integration of BIM models with other software and systems, such as facility management software and building automation systems. Level 3 BIM models are used throughout the building's lifecycle, from design and construction to operation and maintenance. Level 3 BIM models can be used for predictive maintenance, energy analysis, and space utilization. The relation among all aforementioned level has been illustrated in Figure 3.

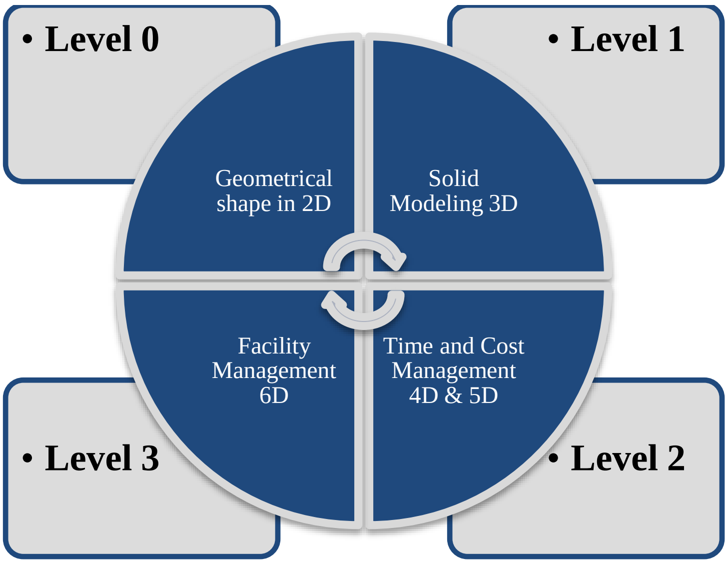


Figure 3: General overview of BIM's specifications

2.4 BIM Implementation Benefits

The way that any building is designed, constructed and maintained has been changed by the introduction of BIM technologies to the construction industry (Elmualim and Gilder, 2013). According to Eastman et al. (2011), owners have better visualization over the sequence of construction activities of the base of their project on anticipated duration. An innovative framework has been proposed by Schade et al. (2011) based on decision-making system which is used based on the design performance in design phase stage. This method has been developed in order to inform decision-maker by making a best choice regarding to life cycle performance of building. This BIM-based model includes a variety of information such as building geometry, materials, structure, functional and installation which lead the project to reduce time and cost for the analysis of energy performance (Park et al., 2012).

BIM is also using by contractors to support several construction managements tasks (Nepal et al., 2012; Ahmad et al., 2012). Farnsworth et al. (2014) investigated that BIM is part of commercial construction processes in recent years. Scholar on this era are found that the advantages of using BIM include better communication systems among different involved parties, provide more accurate scheduling, improving coordination of project teams, improving visualization and accurate clash detection, providing cost estimation in short time and increasing on quantity takeoffs performance accuracy. Eastman et al. (2008, 2011), Nassar (2010), Succar (2009), Hardin (2009) and Weygant (2011) agreed that both clients and contractors have the benefit of 4D and 5D modeling of BIM by increasing the awareness of coordinating, estimating and scheduling of any project aspects.

Managing existing facilities of any project can be categorized as another advantage of BIM which would be achieved by fully linking and modeling of any structure to the computer-generated model. In this manner, all operational error and energy consumption can be monitor by selected team members as a management purpose (Ahmad et al., 2012). Likewise, other potential benefits of BIM implementation such as: Increase productivity through cost and time saving, improve information sharing, improved quality management, support decision making and increase sustainability have been highlighted by Allen Consulting Group (2010). Similarly, researchers through a quantity survey in Australia has been found that the time saving factor is the most significant perceived benefit of using BIM (Aibinu et al., 2014). Also, Newton and Chileshe (2012) gather benefits associated with BIM implementation data through questionnaire survey and the highest-ranking benefits went to reduced clashes, improved visualization and productivity.

McGraw-Hill Construction (2014) report more than %60 of BIM users had a positive point of view about companies turn over through the investments in BIM. By increase of BIM software interoperability among team members, more than %65 of the overall annual cost paid by clients, operators and building users has been saved (Furneaux and Kivvits 2008). According to Khanzode et al., (2008) contractors who used BIM save 1-2% of mechanical, plumbing and electrical systems cost in large health care projects. Also, different parties like software vendors had large benefit on their investment for BIM (Becerik-Gerber and Rice 2010 and Cheung et al., 2012). Furthermore, BIM is capable of making multiple parties, and other benefits could be bringing to the project by team member such as: 3D visualization, full understanding of project requirements, time saving, reduction of construction activities period and reduction of design problems (Yan and Damian 2008; Both et al., 2012; Crotty 2012; Migilinskas et al., 2013 and Ahn et al., 2015). Even So, to gain these benefits on any projects, there are various factors which play a significant role in the success of BIM implementation of any projects. These factors are collaboration among different teams' member (He et al., 2012; Eadie et al., 2013 and SZEDA, 2013), experts team members (Ku and Taiebat, 2011; Kashiwagi et al., 2012; Eadie et al., 2013; SZEDA 2013 and Cao et al., 2016), legal contractual related issues of projects which involving BIM usage

(Olatunji, 2011), project budget (bazjanac, 2006) and project type and geographical location (Cao et al., 2016). It is noteworthy that if any of these components doesn't handle properly in a BIM project, they certainly turn as barriers to BIM adoption of the project.

2.5 BIM Implementation Barriers

BIM implementation requires the development of national strategy and standardize the BIM process. In order to obtain this goal, related organizations need to provide guidance and set out national priorities for the whole industry (Thomson & Miner, 2006; Azhar, 2011). Moreover, there is a need to classify all types of work in construction industry accordingly (Bernstein & Pittman, 2004). However, there is no clear general agreement regarding BIM implementation and use but during the previous decade some guidelines have been developed, but then again still there is no formal standard to organize industry practice. However according to Björk and Laakso, (2010), there are some standards which are applying throughout AEC industry but development of new standards for implementation of BIM is a must to industry.

The inconsistency of data and the data compatibility for exchange and sharing are the most noticeable data related problems (Alreshidi et al., 2014). Also, the inclination of information sharing among project parties is considered as a critical factor and this shows the fact of BIM needs include the capability of transmitting the embedded information in the graphical model and consequently a lack of information sharing could be considered as BIM implementation barrier (Aibinu & Venkatesh, 2014).

BIM as a new technology with the all provided significant benefits to the AEC industry, requires costs for its implementation. The main common costs to BIM adoption are education and training costs as well as initial costs and development costs of this innovative technology. Generally, the implementation cost is recognized as an obstacle to BIM. According to Ganah & John (2014), mainly the large companies which have the most resources are in charge of BIM implementation in the industry. One of the critical requirements of BIM implementation is data storage and specific software which these two factors could make a significant cost to any firms. Depends on the company's IT facility, the costs of purchasing new software could be considered as a barrier to smaller companies and this could easily force investors to reconsider the BIM options more carefully due to nature of the project and its requirements.

According to Allen Consulting Group (2010), education and training cost have a broad influence. For instance, education is ensuring a firm has either the right personnel by retraining existing one or hiring new staff in order to integrate BIM into its operational phase. Also, retraining the majority of existing staff to support the behavioral and organizational changes required to fully adopt BIM technology within a business model. In today's job market, BIM education can considerably increase the competitiveness among students (Wu & Issa, 2014). The fundamental of BIM evolution is training and education (Sharag-Eldin & Nawari, 2010), which could be considered as the best solution that can improve the BIM learning procedure. The lack of adequately trained BIM professionals has hindered BIM implementation and use in the AEC industry (Becerik-Gerber et al., 2010). Similarly, lack of skills is another barrier to implementation of BIM in the future. This condition is going to be worse by the persistent shortage of capable BIM professional over the following decade (Smith & Tardif, 2009).

The issues such as process problems, liability, and trust are categorized as an organizational problem on the way of BIM implementation (Won et al., 2013). The reluctivity of senior managers of any firm about new technology and processes of it is too low while the management system needs more support in order to adopt BIM implementation quicker (Ruikar et al., 2005). A bottom-up approach is considered more efficient in dealing with resistance to change (Arayici et al., 2011). Moreover, the lack of knowledge about the differences between conventional construction methods and using BIM by some managers are identified as one of the other obstacles on the way of BIM implementation (Aibinu & Venkatesh, 2014).

Legislation aspect of BIM development is one of the concerns by scholars and governments. The primary risk about legal aspects of BIM is for data ownership because if clients pay for the design phase of construction projects, they have the right to claim ownership of the documentation. Likewise, there would be a high chance of conflict among other stakeholders than owners and architects in case that they involved in a project (Azhar, 2011). Additionally, it is extremely important to determine who will access data and be responsible for any inaccuracies during the project and this point of view could bring a considerable risk (Thomson & Miner, 2006). Also, stakeholder prefers to have the confidentiality of data and documents in BIM model but there is a range of legal issues which have been identified in connection with administration aspect of projects (Chynoweth et al., 2007; Udom, 2012).

To summarize the benefits and barriers of BIM, there can be three main fields of collaboration regarding all the pros and cons. The first field is “policy” which still needs improvement in all three sub-sectors, as illustrated in Figure 4. On the other hand, the two subsequent fields, which are commonly named "technology" and "process," have already proven their profit to the industry. It is noteworthy to mention

that the Policy-Technology-Process (PTP) procedure has interrelationships with each other; if one fails, it would damage the whole organization.

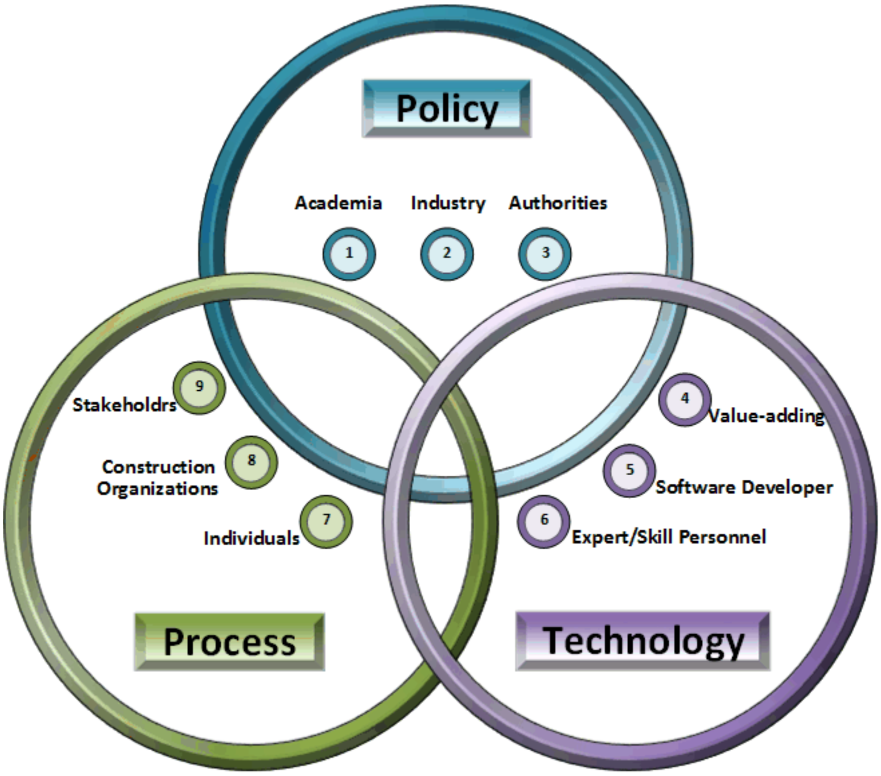


Figure 4: Policy-Technology-Process (PTP) procedure responsibilities

2.6 BIM Computer Aided Programs

BIM is supported by a range of computer-aided programs that help to automate the design and construction process and provide stakeholders with the information they need to make informed decisions. The most important BIM programs are going to be presented as follows.

2.6.1 Autodesk Revit

Autodesk Revit is a BIM software that was first released in the 2000s. It is a powerful tool that is widely used in the AEC industry for its advanced 3D modeling, documentation, and collaboration capabilities. Revit also has a comprehensive library of objects and supports a wide range of building materials, including steel, concrete, masonry, and glass. Revit's collaboration capabilities make it easy for teams of architects, engineers, and contractors to work together on projects, and its advanced visualization tools allow users to create high-quality, photo-realistic 3D renderings.

2.6.2 ArchiCAD

ArchiCAD is a BIM software that was first developed in the 1980s. It is known for its intuitive interface and user-friendly design tools. This software is widely used in the architecture and design industry and is known for its advanced 3D modeling capabilities, including 3D walk-throughs and fly-throughs, as well as its powerful visualization tools. ArchiCAD also includes a comprehensive library of objects, including architectural elements, electrical and plumbing systems, and building materials.

2.6.3 Tekla Structures

Tekla is a BIM software used for steel and concrete structure modeling, detailing and information management. It allows engineers and contractors to create precise and accurate 3D models of buildings, with all the necessary information for fabrication and assembly. Tekla provides a highly detailed and accurate model, which helps in optimizing the construction process, minimizing errors and ensuring that the final product meets the exact requirements.

2.6.4 Naviswork

Navisworks is a BIM software used for project review and coordination. It helps the stakeholders to visualize, analyze and simulate the construction project, ensuring that all the design and construction elements work together seamlessly. Navisworks enables the users to identify potential problems early in the project and make necessary changes, saving time and money in the long run. The program also provides advanced tools for cost estimating and construction scheduling.

2.6.5 BIM360

BIM 360 is a cloud-based platform developed by Autodesk that provides a comprehensive suite of tools for construction project management. It enables teams to collaborate and manage the project lifecycle from design to construction to operation. BIM 360 offers a range of tools including project management, document management, quality control, safety management, and field management. It helps contractors, engineers, and project managers to work together in real-time, reducing the risk of miscommunication and errors and it is highly flexible and customizable to meet the specific needs of individual projects.

2.6.6 VICO

VICO is a construction software that is known for its advanced 4D construction modeling and project planning capabilities. It enables users to integrate cost and time information into their BIM models, creating a highly accurate and detailed construction timeline. VICO also includes a powerful cost management system that helps teams to track and monitor project expenses, ensuring that the project stays within budget. Additionally, it offers robust collaboration and communication tools that allow teams to share information, track progress, and make data-driven decisions.

Furthermore, this software program provides real-time data updates, allowing teams to make informed decisions and take action quickly.

2.7 Construction Projects Categories

AEC are one of the largest industries in the world. Construction projects are specially made by a municipal agency as public property or privately by a property owner. There are multiple types of construction projects and it can be divided into four main categories and as it stated in problem state of this dissertation, the main target of author is to investigate the BIM utilization for infrastructure. Therefore, out of the following four categories, only infrastructure is going to be discussed further in detail.

- Residential Building: A simple form of construction that aims to fulfill the basic needs of mankind to live in a place in order to satisfy the living requirements
- Commercial and Organizational Building: This type of building is targeted at any type of business that sells goods or provides services to make a profit.
- *Specialized Construction:* This is not a common type of construction, and the nature of each project is reflected in its needs, such as the construction of power plants, industrial processes, petroleum facilities, or hazardous waste facilities
- Heavy Construction and Infrastructure: consists of comprehensive engineering projects that focus on public infrastructure improvements. In most cases, the maintenance and design work that goes into them must account for existing structures and natural environments.

Infrastructure is defined by the oxford dictionary as the basic physical and organizational structures and facilities needed for the operation of a society or enterprise. Therefore, as the main focus of this thesis is on infrastructures assets, these assets can be broken down in to 5 main domains as it illustrated in Figure 5.

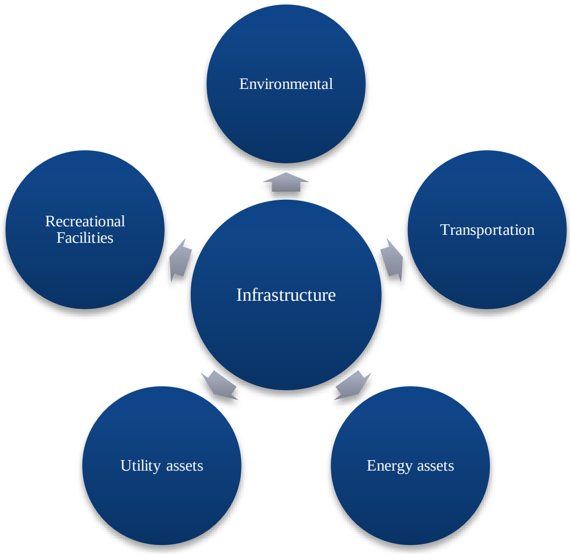


Figure 5: Infrastructure assets domains

2.7.1 Transportation

There has not been a universal classification of civil infrastructure facilities because distinguishing between any categorizations can be difficult since some can overlap with other. Generally, civil infrastructure is a structure, utility or in greater scale a facility which needed to support human activities and civilization. Each country is involved with different organizations and each one of these organization have diverse classification methods based on multiple approach and terminologies in civil infrastructure facilities. McGraw-Hill (2012), Bentley (2014), and others are categorized all major types of transportation infrastructure facilities into 6 types as it illustrated in Figure 6. It is noteworthy to mention that different transportation modes can dictate the necessary category change among multiple type of transportation infrastructure.

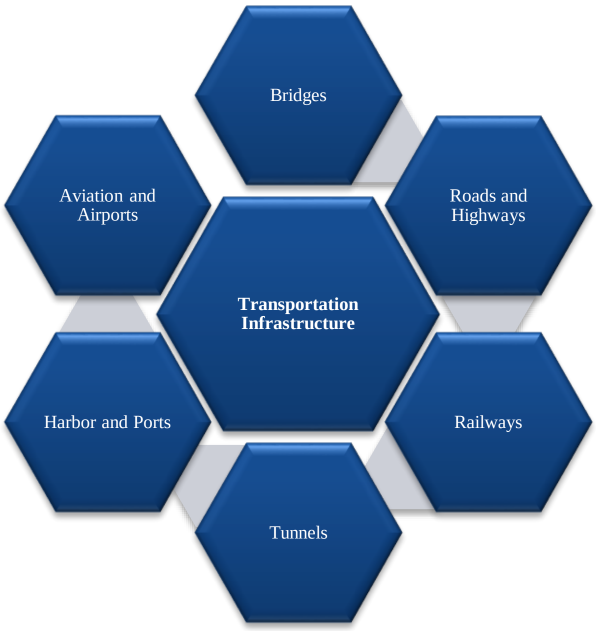


Figure 6: Categories of transportation infrastructure

2.7.2 Energy Assets

Utility infrastructure assets and energy infrastructure assets are related but distinct concepts. As it explained the utility infrastructure consist of different facility to operate and run a country, organization or even a society properly. Energy infrastructure assets, on the other hand, are a subset of utility infrastructure assets that specifically pertain to the generation, transmission, and distribution of energy, such as electricity, water, natural gas and etc. Energy infrastructure assets can include power plants, transmission lines, substations, transformers, natural gas and water pipelines, and even storage facilities.

2.7.3 Utility Assets

Utility infrastructure assets are critical to the functioning of modern societies and are often heavily regulated by government agencies to ensure their safety, reliability, and affordability. Utility assets are physical structures, equipment, and systems that provide essential services to communities and businesses. These assets are owned and operated by utility companies, which may be public or private entities. They also require significant capital investment and ongoing maintenance to keep them operating efficiently and effectively. Utility infrastructure assets can be categorized as follow:

1. Energy infrastructure assets: Power plants, transmission and distribution lines, substations, transformers, and other equipment used to generate, transmit, and distribute electricity.
2. Water infrastructure assets: Water treatment plants, reservoirs, pipelines, and other equipment used to collect, store, treat, and distribute drinking water and wastewater.
3. Communication infrastructure assets: Telecommunications networks, fiber-optic cables, satellites, and other equipment used to facilitate communication and information exchange.
4. Public works infrastructure assets: Government buildings, schools, hospitals, parks, and other facilities that provide basic public services.

2.7.4 Recreational Facilities & Environmental

The Recreation Infrastructure program aids local initiatives to develop and maintain facilities that boost resident demand, such as parks, sports grounds, or cycling trails. It also increases retention while expanding prospects for sports tourists.

According to European Commission (2019) Environmental or green infrastructure defined as strategically planned network of natural and semi-natural areas with other environmental features, designed and managed to deliver a wide range of ecosystem services such as water purification, improving air quality, providing space for recreation, as well as helping with climate mitigation and adaptation.

Chapter 3

CONSTRUCTION INDUSTRY IN UNITED STATES OF AMERICA AND TURKEY

3.1 Introduction

Construction projects help to build civilizations. The construction sector is frequently regarded as one of the most demanding in many nations. It is crucial for the growth of regions, homes, businesses, and eventually the nation. The success and expansion of the economy are dependent on the building industry.

The construction industry in the United States of America is a vital sector that contributes to economic growth and development, employing millions of workers across the country. The industry has faced several challenges, including labor shortages, rising costs, and regulatory constraints, but has continued to adapt and innovate to meet the demands of a rapidly changing market. On the other hand, Turkey's construction industry has been a significant driver of economic growth and development in recent years, contributing to the country's modernization and urbanization. However, the industry has faced multiple barriers, including economic volatility and safety issues.

This chapter presents a brief analysis and evaluation of the United States of America and Turkish construction sectors in terms of the BIM utilization in different sectors including the infrastructure.

3.2 United States of America Construction Industry

The US construction industry is a diverse and dynamic sector that encompasses various sub-industries, including residential and commercial construction, infrastructure, and industrial construction. The industry has been a significant driver of economic growth and development in the country, accounting for nearly 3.8% of the country's Gross Domestic Product (GDP) in 2022, according to the Engineering News-Record (ENR). It’s illustrated in Figure 7 that the top two profitable construction project is building and transportation in United States of America. One of the most significant challenges facing the United States of America construction industry is a shortage of skilled labor. The industry has struggled to attract and retain workers, particularly in high-skilled trades, such as electricians and plumbers. This shortage has led to increased labor costs and project delays, which have put pressure on profit margins.

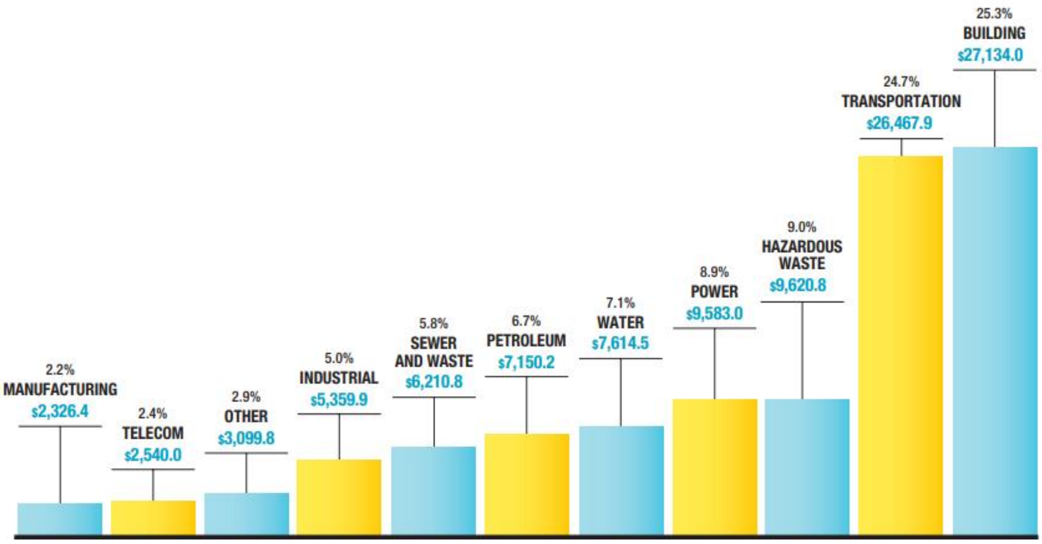


Figure 7: Markets’ share of total revenue (ENR, 2022)

Another challenge facing the United States of America construction industry is rising costs. The cost of construction materials, such as lumber and steel, has increased significantly in recent years due to supply chain disruptions and tariffs. Additionally, regulatory constraints, such as zoning and building codes, have added to the cost of construction projects, making it challenging for firms to operate efficiently and profitably. The United States of America construction industry has also faced safety challenges, with construction accidents and fatalities remaining a significant concern. Despite efforts to improve safety standards and regulations, accidents and fatalities continue to occur, highlighting the need for continued efforts to promote safety in the industry.

Despite these challenges, the United States of America construction industry has continued to adapt and innovate to meet the demands of a rapidly changing market. Technology has played a significant role in this process, with firms adopting digital tools and processes to streamline operations, improve efficiency, and reduce costs. For example, building information modeling (BIM) and virtual reality technologies have allowed firms to visualize and plan projects more effectively, reducing the risk of errors and delays.

As summery, the United States of America construction industry is a vital sector that contributes to economic growth and development, employing millions of workers across the country. While the industry has faced several challenges, including labor shortages, rising costs, and safety concerns, firms have continued to adapt and innovate to meet the demands of a rapidly changing market. The future success of the industry will depend on continued investment in technology and innovation, efforts to address labor shortages and rising costs, and continued efforts to promote safety and sustainability in the industry.

3.3 Turkey Construction Industry

The construction industry in Turkey has been characterized by rapid growth and development over the past few decades, driven by rising demand for commercial and residential buildings, infrastructure projects, and tourism-related developments. According to Figure 8, Middle East has only 7% of total international markets' share but yet due to the potential of region, it attracted significant foreign investment, particularly from Persian Gulf countries and Russia, and has been a key employer, creating jobs for millions of workers across the country. However, the industry has faced several challenges, particularly in recent years. One of the most significant challenges has been economic volatility, as the country has experienced political instability, high inflation, and a weakening currency. These factors have led to a decline in investment and reduced demand for construction projects.

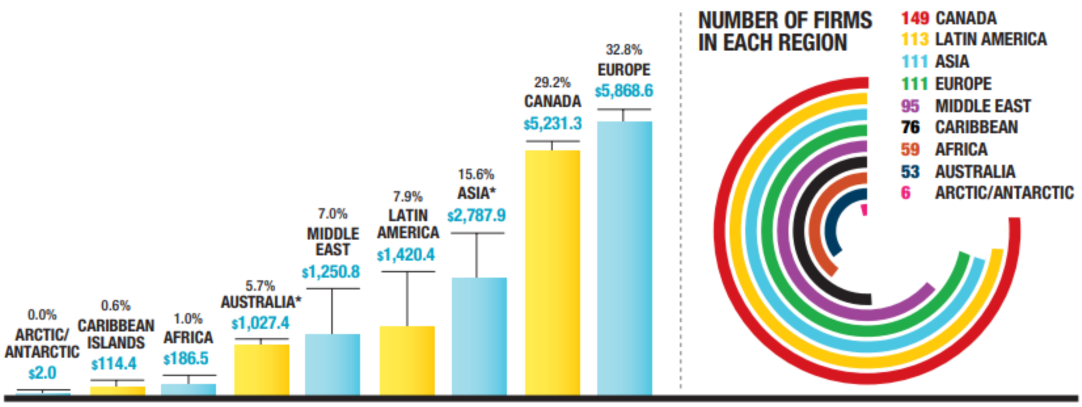


Figure 8: International market analysis excluding United States of America (ENR, 2022)

Another challenge facing the Turkish construction industry is regulatory constraints. The industry has been subject to complex and cumbersome regulations that have made it difficult for firms to operate efficiently and competitively. For example, obtaining construction permits can be a lengthy and bureaucratic process, and there have been concerns about corruption and lack of transparency in the industry. Safety issues have also been a significant challenge for the Turkish construction industry. There have been several high-profile accidents, including collapses of buildings and other structures, which have led to injuries and fatalities. These incidents have highlighted the need for improved safety standards and regulations to protect workers and the public.

Despite these challenges, the Turkish government has made efforts to support the construction industry and boost economic growth. The government has invested heavily in infrastructure projects, including transportation, energy, and telecommunications, to modernize the country's infrastructure and promote development. Additionally, the government has launched several initiatives to promote affordable housing and support small and medium-sized construction firms.

In conclusion, the construction industry in Turkey has been a critical driver of economic growth and development in recent years. While the sector has faced several challenges, including economic volatility, regulatory constraints, and safety issues, the government's efforts to support the industry and invest in infrastructure projects could help to mitigate some of the negative impacts. The industry's future success will depend on continued investment, improved safety standards, and efforts to streamline regulations and promote competition.

3.4 Infrastructure in United States of America and Turkey

In recent years, the condition of the country's infrastructure has become a growing concern. According to the American Society of Civil Engineers, the overall infrastructure in the United States received a grade of "C-" in their 2021 report card.

This grade indicates that much of the country's infrastructure is in poor to fair condition and in need of repair or replacement. One of the biggest concerns is the condition of the country's bridges. Over 4,000 bridges in the United States are considered "structurally deficient," meaning that they are in poor condition and in need of repair or replacement. This poses a significant risk to the safety of motorists and the economy as bridge closures can disrupt transportation and commerce.

Another area of concern is the country's water and sewage systems. Many of these systems are outdated and in need of upgrades to ensure the continued supply of safe and clean water. The lack of investment in these systems can result in water contamination and health hazards. Transportation infrastructure, such as roads and highways, is also in need of improvement. The increasing congestion on these roads and highways not only slows down transportation but also contributes to air pollution and climate change.

In addition to the physical infrastructure, the country's digital infrastructure, including broadband networks and communication systems, is also in need of improvement. Access to high-speed internet and modern communication systems is crucial for the economy, education, and healthcare. The cost of improving the country's infrastructure is substantial, and the lack of investment has become a major challenge.

Currently, Turkey has made significant investments in its infrastructure, resulting in significant improvements in many areas. One of the key achievements has been the expansion of the country's transportation network, including the construction of new highways and high-speed railway lines. This has improved transportation options for commuters and goods, stimulating economic growth and improving access to markets.

Another area of improvement has been the country's energy infrastructure, including the expansion of renewable energy sources such as wind and solar power. This has not only reduced greenhouse gas emissions but also increased the country's energy security. However, despite the significant investments and improvements, the condition of infrastructure in Turkey continues to face several challenges. One of the biggest challenges is the maintenance of existing infrastructure, as many structures have reached the end of their useful life and are in need of repair or replacement. This is especially true for the country's water and sewage systems, which are in need of upgrades to ensure the continued supply of safe and clean water.

3.5 Necessity of BIM Utilization for Infrastructure Projects

Massive infrastructure expenditures are currently being made as a result of growing development, growth in population, and industry in developing nations. Most high-income nations have a huge stock of aging infrastructure assets that need to be replaced, repaired, or removed, implying that significant expenditures are required even in countries with reasonably well-developed and mature infrastructure networks. In many cases, these investments are not driven primarily by sustainability. They are designed to improve a certain set of results, most typically economic growth. Whether or whether that development is sustainable is determined by how the massive amount of infrastructure development that will occur in the next years is planned, executed, and managed. Unsustainable infrastructure investment can leave a legacy for next generation.

Worldwide financial investment in infrastructure has reached an all-time high of roughly US$2.3 trillion each year. Bhattacharya et al., 2016 estimated that the new and replacement infrastructure would require $94 trillion in capital investment by 2040 as it has been illustrated in Figure 9 and this prediction is greater than the value of the world's existing infrastructure which is about $50 trillion. Therefore, BIM can be used as a powerful tool for infrastructure projects for several reasons, including improved collaboration to avoid potential conflicts, enhanced visualization to decrease project delays, increased efficiency to save more time and money, and maintenance and operation of a project to increase the life of the infrastructure.

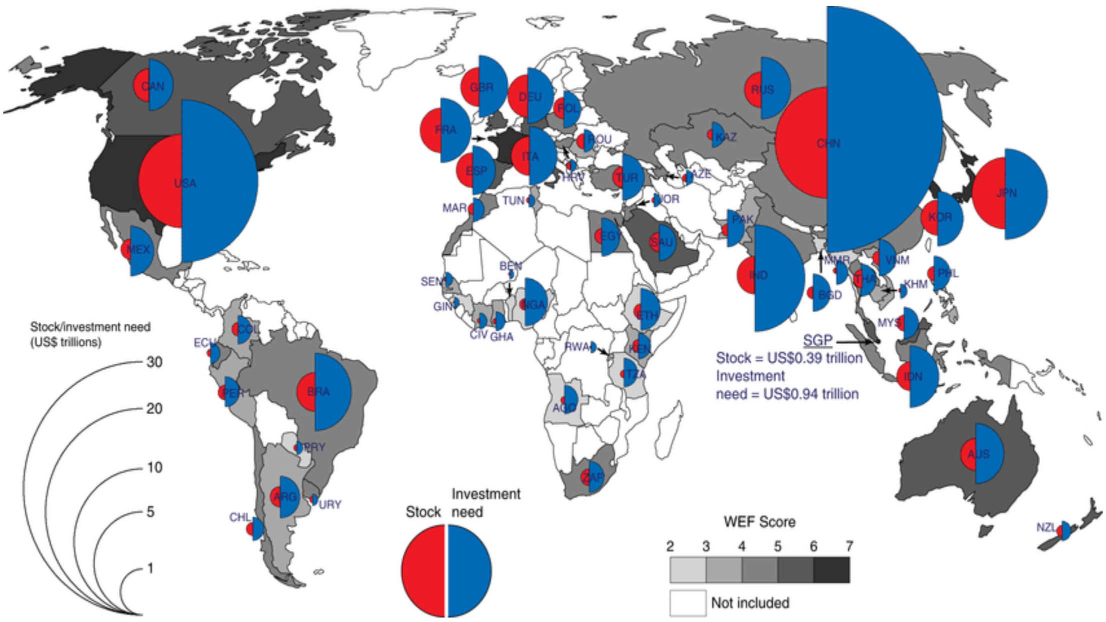


Figure 9: Infrastructure investment requirements in the present and the future according to world economic forum (WEF, 2022)

All these financial data prove the need and importance of utilizing a generic conceptual BIM adoption framework for infrastructure projects to increase the adoptability of information technology in infrastructure construction industry. A well-designed I-BIM framework can transform the construction industry by improving collaboration, efficiency, cost-effectiveness, and overall project quality. It can also drive innovation, support sustainability goals, and help the industry adapt to evolving regulatory requirements. The adoption of a I-BIM framework is a strategic move that can benefit individual organizations, the industry as a whole, and society at large. I-BIM propose framework can have profound impact on the industry in several ways:

1. **Enhanced Collaboration**: I-BIM frameworks encourage multidisciplinary collaboration among architects, engineers, contractors, and other stakeholders. By standardizing processes and data sharing, teams can work more efficiently and effectively, reducing conflicts and errors.
2. **Improved Project Visualization**: I-BIM allows stakeholders to create 3D and 4D models, enhancing project visualization. This aids in design validation, early clash detection, and better communication of design intent to clients and construction teams.
3. **Cost and Time Savings**: I-BIM frameworks promote better project planning and scheduling. By identifying clashes and design issues early, costly rework is minimized. Projects are more likely to stay on schedule and within budget.
4. **Quality Control**: I-BIM enables rigorous quality control throughout the project lifecycle. Detailed models and data allow for more accurate inspections, reducing defects and ensuring that construction meets design specifications.
5. **Data-Driven Decision-Making**: I-BIM frameworks emphasize data collection and analysis. This data-driven approach allows for better decision-making throughout a project's lifecycle, from design optimization to maintenance planning.
6. **Sustainability**: I-BIM can support sustainable design and construction practices by providing tools to analyse energy efficiency, materials usage, and environmental impact. This contributes to more environmentally friendly and resource-efficient buildings.

7. **Risk Mitigation**: I-BIM frameworks can help identify and mitigate project risks more effectively. Through simulations and analysis, potential problems can be identified and addressed early in the project, reducing overall risk.
8. **Asset Management**: Beyond construction, I-BIM models can serve as a foundation for effective facility management. Accurate and up-to-date information about building components and systems simplifies maintenance, repairs, and renovations.
9. **Standardization**: the propose I-BIM framework can promote standardization in data formats, terminology, and processes within the industry. This helps reduce confusion and ensures that I-BIM models and data are interoperable across projects and organizations.
10. **Global Competitiveness**: Firms that adopt and excel in I-BIM practices gain a competitive advantage in the global construction industry. They can offer clients more efficient, cost-effective, and sustainable solutions, making them more attractive in the marketplace.
11. **Educational and Training Opportunities**: I-BIM frameworks can lead to the development of educational programs and training resources that help professionals acquire the skills needed to work with I-BIM effectively. This can create career opportunities and foster a more skilled workforce.
12. **Regulatory Compliance**: In many regions, governments are mandating I-BIM adoption for public projects. The propose I-BIM framework can assist the industry in complying with these regulations and standards, preventing legal or contractual issues.
13. **Innovation and Research**: I-BIM frameworks encourage innovation in technology and processes. Researchers and developers are continuously

working on improving I-BIM tools and methods, leading to advancements in the industry.

Chapter 4

RESEARCH METHODOLOGY

4.1 Introduction

It is concluded that a suitable research technique is a process where significant data for the study is carefully gathered, examined, and validated. There have been a lot of completed studies and a lot more that are currently being worked on, but for either circumstance, there isn't yet a formula that can be used to direct the researchers and assist them choose the "best fit" study approach. However, it is important to emphasize the distinction between methodology and method. Research method, as defined by Castro et al. (2010), are categorized with data collecting tools including surveys, interviews, questionnaires, and other techniques for gathering information. The phrase "research methodology," according to Collis and Hussey (2009), is refer to describe the whole strategy for doing research, including the theoretical foundation and data collecting and analysis.

In accordance with the aforementioned facts, this chapter of the thesis describes in detail how the research method that was chosen and the research methodologies used impacted the data collecting, analysis, and the process of developing the theory that this particular study benefited from. The research's primary emphasis will be the questionnaire survey that was sent to prominent construction enterprises located in the United States of America and Turkey. Additionally, the gathered data would be examined using the social sciences program's statistical (SPSS) software. Moreover, to conduct enhanced research, all the described parameters are expounded as a research design by the end of this chapter.

4.2 Research Approaches

Neville (2005) identified three categories of research methodologies: applied/basic, deductive/inductive, and quantitative/qualitative. Diverse methodologies can be combined by researchers. To briefly clarify, statistical and mathematical data are commonly searched for in quantitative research. Researchers that employ this approach believe that qualitative approaches are poorly organized and that quantitative research strategies are highly structured. Comparative to quantitative research, qualitative research is more subjective. Qualitative data requires more analysis and interpretation than quantitative data does.

In contrast to fundamental of research, where the researcher individually seeks to broaden his or her knowledge, applied research is designed from the outset to apply its results to an existing situation. Deductive reasoning often starts with accepted theory and proceeds from there. This strategy aims to create a theory based on knowledge already in existence (Hyde, 2000; Neville, 2005; Wilson, 2010).

According to Monette et al. (2005), the deductive technique involves formulating a hypothesis based on the tenets of an existing theory. Inductive research, on the other hand, starts from a specific viewpoint and works its way out to broader theories (Neville, 2005). In other words, when study progresses and observations are made, researchers tend to make generalizations based on empirical data. Both deductive and inductive research methodologies can be merged and applied to the same study, according to Cavaye (1996) and Perry (2001), who indicated that locating a midpoint

point between the two ways can lead to confirming or disconfirming the proposed theory, has also proved the practicality of this.

According to aforementioned explanation, it can be claimed that the inductive and deductive procedures were used equally in this particular study. For instance, in the existing literature, growth of infrastructure activities in construction industry and lack of BIM usage in these projects is a known as an issue. Difficulties in adopting the BIM due to all challenges for infrastructure projects is another issue yet to be resolved.

In consideration of abovementioned, the author of this study in the context of conforming or disconfirming the proposition of expanding the disposition of BIM from building construction industry and considering it as a tool and expansion for infrastructure projects that are incurred to the all involved construction parties have benefitted from deductive approach. In addition to these, in this research it is proposed that I-BIM utilization for infrastructure cannot be standardized for all parts of the world and in this case, the author, due to the lack of existing literature concerning the utilization of BIM for infrastructure project in the United States of America and Turkey construction industries, by considering these countries as an advance and developing country, intends to develop a new framework.

4.3 Research Methods

The term "research methods" refers to any approach that a researcher uses when doing research to try to solve the recognized problem. In order to identify a potential solution, the researcher must consider the obtained data and undiscovered aspects of the problem to be related to one another in some manner. Accordingly, research methodologies may be classified into three main groups, which are as follows:

1. Data Collection as a method to collect relevant data from the target respondent;
2. Data Analysis as a statistical method to generate the relationships among unknowns and data collection;
3. Data Evaluation as a method to evaluate the accuracy of the obtained results to benefit the researcher.

4.3.1 Data Collection Tools

To gather the required empirical data for this study, the author primarily conducted a questionnaire and interviews. Like most of the studies, the questionnaire of this research has been designed in accordance to the research objectives. The main aim of this research is to find and select the most critical factor that influences BIM utilization in target countries in order to adopt it for I-BIM and prove the correlation of BIM utilization between building construction and infrastructure. The two target countries as respondents to this questionnaire have been chosen as the United States of America and Turkey in order to create a better set of data to make a deep comparison among two different countries to help the author generalize the framework. The questionnaires were prepared at four different levels, which are going to be explained comprehensively in Chapter 6, Section 2.

1. Segment A: Respondents Information
2. Segment B: I-BIM Category(s)
3. Segment C: I-BIM Components Utilization
4. Segment D: Effectiveness Weight of Each Factor.

4.3.2 Data Analysis Tools

After obtaining the required information for this study with the use of the aforementioned data collecting tools, the information is analyzed to provide an answer to the research question expressed in chapter 1. Therefore, one of the most popular tools for statistical analysis in the social sciences named, Statistical Package for the Social Sciences (SPSS), has been chosen as a main analysis tool of this research. Market researchers, health researchers, survey firms, the government, researchers in the field of education, marketing organizations, and others utilize it (Argyrous, 2009). The base program includes tools for statistical analysis, data administration (case selection, file restructuring, producing derived data), and data documentation (Levesque, 2007) therefore it is the best choice to fulfill the requirements of this study. It is noteworthy to mention that the MATLAB program has also been used to finalize the determination for execution competency in the proposed framework, which is going to be discussed comprehensively in the following chapters.

The mean, median, and mode are the three primary measures of central tendency used by SPSS to determine how data has been assembled together around a central point. Additionally, according to Equation 1 and 2 measurements of dispersion regarding the range, variation ratio, and standard deviation of the acquired findings were made in order to provide a platform for observing whether or not the participants' opinions in particular circumstances complied or contrasted.

$$S^2 = \frac{\sum(X-\bar{X})^2}{n-1} \tag{1}$$

$$S = \sqrt{\frac{\sum(X-\bar{X})^2}{n-1}} \tag{2}$$

Where:

- X = Respondent opinion in each case;
- $\bar{X}$ = Arithmetic means of selected I-BIM variable;
- n = Number of respondents that answered the questionnaire;
- S^2 = Sample variance

- S = Standard deviation

The internal consistency of the test is examined in a reliability study that requires providing a single test form to a group of candidates. When data from a research like this are analyzed, a coefficient is produced that estimates how consistently candidates perform on different test items within a single test session (Crocker and Algina, 1986). Cronbach's alpha is one of these assessments that is frequently used to evaluate the consistency of research. The reliability of a test is assessed using Rulon's approach, and the coefficient alpha is the average of all the split-half coefficients that would be achieved if the test were divided into all conceivable half test combinations. The formula in Equation 3 is used to get the coefficient of alpha:

$$\hat{\alpha} = \frac{k}{k-1}\left(1 - \frac{\sum \hat{\sigma}_i^2}{\hat{\sigma}_x^2}\right) \quad (3)$$

Where:

- k = Number of selected I-BIM variables in questionnaire
- $\hat{\sigma}_i^2$ = Variance of each I-BIM variables
- $\hat{\sigma}_x^2$ = Total questionnaire variance
- $\hat{\alpha}$ = Cronbach’s alpha coefficient

There will be a total of two Cronbach’s alphas according to the two target countries for this research, which has been discussed comprehensively in Chapter 6.

4.3.3 Data Evaluation

All of the data are analyzed by consulting professionals after the relevant information has been gathered by distributing questionnaire surveys to all 187 respondents for the proposed I-BIM framework for the construction industries in the United States of

America and Turkey. The suggested system and the outcomes achieved as a result of its implementation have been shared with experts.

4.4 Research Design

The author of this research established a research design that is shown in Figure 10 in accordance with the research methodology already mentioned in this chapter. In addition to the methodologies and tools used at each stage of the process, the figure itself illustrates how the embedded processes used in this study cross over with the major issues of the research. Additionally, the author's selected research philosophy, technique, and method were decided following a thorough study of the relevant literature. In terms of research design, this particular study has been divided into a total of 7 major parts. These phases are dispersed over the whole research project, which is illustrated in Figure 10 and includes the 7 stages of the research process. It is noteworthy to mention that the red arrow represents the research theme, and following that, the orange arrow describes the process of this research in 7 steps, and the yellow arrow is the tool or method of each major theme for this study.

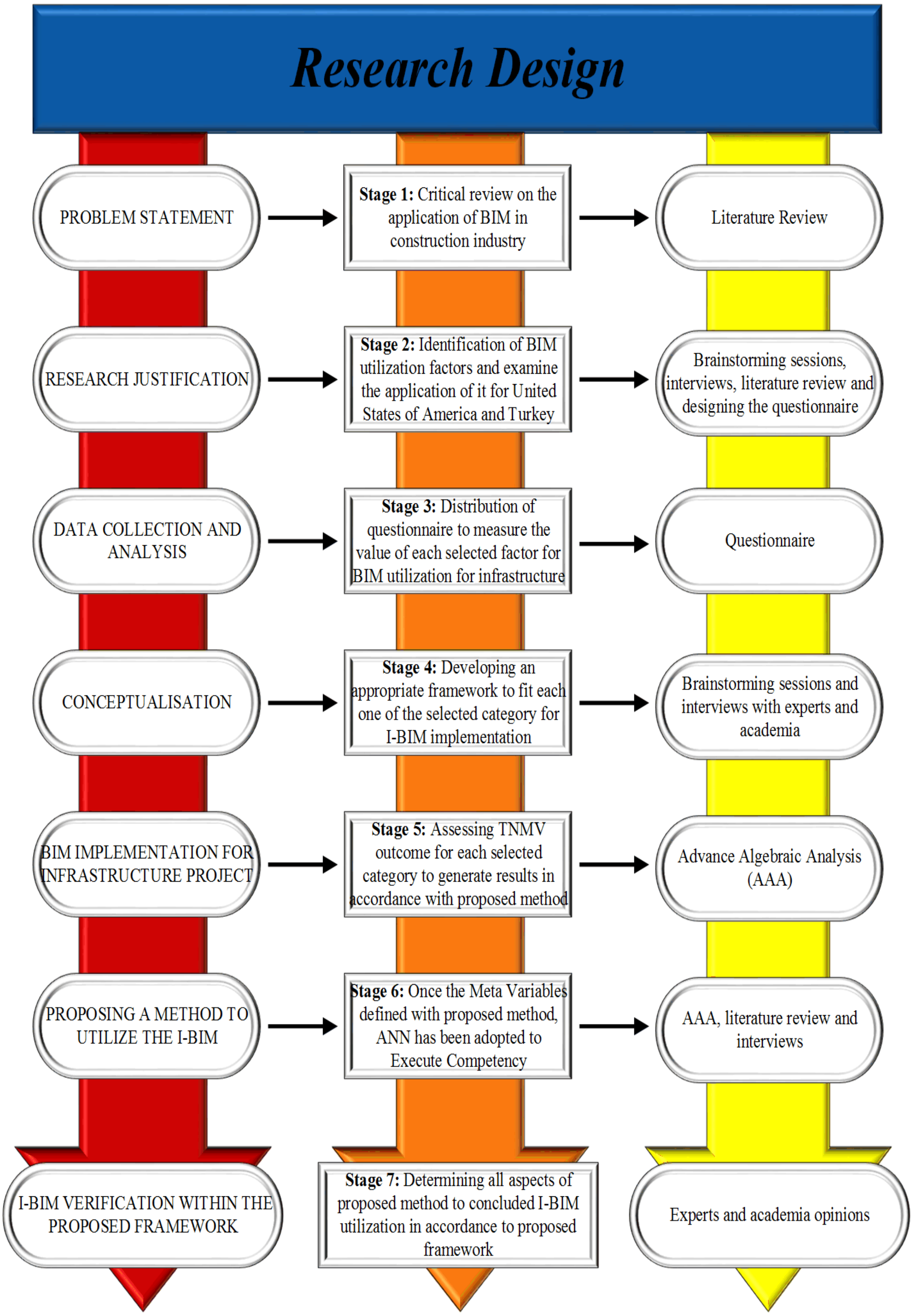


Figure 10: Research design

Chapter 5

CONCEPTUALIZE A FRAMEWORK FOR INFRASTRUCTURE BUILDING INFORMATION MODELING (I-BIM)

5.1 I-BIM Definition

The main objective of this dissertation is to shape the new terminology of “I-BIM," which represents the utilization of BIM for infrastructure projects. To be able to achieve this purpose, a new framework is going to be proposed in this chapter and will expanded in Chapter 7, 8 and 9 to shape a whole new dimension of BIM technology. But to do that, there are some setups and schemes that need to be explained alongside enormous data collection and analysis to shape the conceptualize Framework for infrastructure building information modeling (I-BIM)

5.2 Components of I-BIM Implementation

By inspiration from modality of BIM, there can be an adoption to other sub-branch of construction industry such as infrastructure domain. Since BIM has proven benefits in buildings, infrastructure projects can gain similar advantages through proper implementation. Therefore, the author proposes a new framework in order to suggest a new relationship for the purpose of BIM adoption for infrastructure projects, namely, Infrastructure Building Information Modeling (I-BIM), as illustrated in Figure 14 by the end of this chapter.

Table 1 provides a comprehensive assessment on critical variables of I-BIM implementation, in five prime categories including; Contractual Relations (CR), Education (E), Financial (F), Managerial (M) and Public Authority (PA). The detailed assessment of each variable is added to explain the reason and philosophy of their selection, including references for each prime category and their variables, like availability of expert personnel (E1) for the educational category or responsibility for inaccuracies (CR3) for contractual relations. Correspondingly, these variables are not uncorrelated from each other and by presenting data mining, these relations will be shown with more details in Chapter 7.

5.2.1 Contractual Relations

BIM has numerous benefits, including improved project coordination, reduced errors and omissions, and responsibility for inaccuracies. However, the use of BIM can also create contractual issues that need to be addressed to ensure a successful project outcome and BIM utilization in a construction project requires a clear understanding of the responsibilities, obligations, and risks of each party involved. The following are some of the contractual issues that may arise when using BIM.

The ownership of the BIM model is a significant contractual issue that needs to be addressed. The ownership of the BIM model is often a contentious issue because it involves multiple parties, including the designer, contractor, owner, and subcontractors. It is essential to determine who owns the BIM model, who has the right to use it, and who is responsible for its accuracy and completeness.

This issue can be addressed in the construction contract by specifying the ownership of the BIM model and the rights and responsibilities of each party involved. On the other hand, the level of detail required in the BIM model is another contractual issue that needs to be addressed. The level of detail required in the BIM model can vary depending on the project's complexity and the owner's requirements. It is essential to specify the level of detail required in the BIM model in the construction contract to avoid any misunderstandings or disputes during the project.

BIM also has an impact on the negotiation of contracts and project delivery method. BIM provides stakeholders with a greater understanding of the project, enabling them to negotiate contracts that are fair and equitable for all parties. BIM also enables the use of alternative project delivery methods, such as integrated project delivery and public-private partnerships, which can improve the overall efficiency and effectiveness of the project.

5.2.2 Education

The impact of BIM has also been felt in the field of education, where BIM has the potential to influence various educational variables and shape the future of the construction industry. One of the key educational variables that BIM affects is curriculum development and awareness of academia. BIM requires a new set of skills and knowledge, and as a result, universities and other educational institutions have had to adapt their curriculums to meet the changing needs of the industry. This has involved introducing new courses and programs in BIM, as well as incorporating BIM into existing courses in architecture, engineering, and construction management. By doing so, educational institutions are helping to ensure that the next generation of construction professionals is equipped with the skills and knowledge they need to succeed in a rapidly changing industry.

Another educational variable that BIM affects is student learning. BIM provides students with a hands-on and interactive learning experience, allowing them to explore and understand complex building systems and structures in a virtual environment. This enhances their understanding of construction processes and enables them to make informed decisions about design, materials, and systems.

BIM also provides students with the opportunity to collaborate and work with other students, improving their communication and teamwork skills. BIM also has an impact on the professional development of construction professionals. By providing access to advanced technologies and information management systems, BIM enables professionals to enhance their skills and knowledge throughout their careers. This helps to ensure that they remain competitive in a rapidly changing industry, and that they are able to continue delivering high-quality construction projects.

5.2.3 Financial

The relationship between BIM and financial variables is complex and multifaceted, with BIM affecting and being affected by various aspects of project finance. One of the key financial variables that BIM affects is project cost management. By providing detailed and accurate information about the building design, structure, and systems, BIM enables stakeholders to better understand the costs associated with different options and make informed decisions about how to allocate resources.

This leads to improved cost predictability and greater control over project budgets, reducing the risk of cost overruns and improving profitability. Additionally, BIM can also help to reduce the amount of waste generated during construction, which has a direct impact on project costs. Another financial variable that BIM influences is project financing. BIM provides lenders and investors with increased visibility into the project, enabling them to assess the risk associated with the project and make informed decisions about funding. BIM also provides valuable information about the energy performance of the building, which can be used to secure favorable financing terms and reduce the overall cost of financing.

5.2.4 Managerial

Building Information Modeling (BIM) has revolutionized the construction industry by providing a digital platform for collaboration, design, and construction management. It has also brought new opportunities to enhance the efficiency and productivity of construction projects by leveraging advanced technologies and information management with affecting and being affected by various aspects of project management.

One of the key managerial variables that BIM affects is communication and collaboration. BIM provides a common platform for all stakeholders to access and share information, reducing the risk of misunderstandings and ensuring that all parties have the same understanding of the project. This improved collaboration leads to faster decision-making and more efficient use of resources, reducing the overall duration of the project and improving its quality.

Another managerial variable that BIM influences is project quality management. By providing a comprehensive digital model of the building and its systems, BIM enables stakeholders to identify and assess potential risks early in the design stage, reducing the likelihood of costly errors and delays. BIM also helps to reduce the risk of disputes by providing a centralized repository of project information that is easily accessible to all parties.

Cost control and predictability are two important managerial variables that are positively impacted by BIM. By providing detailed and accurate information about the building design, structure, and systems, BIM enables stakeholders to better understand the costs associated with different options and make informed decisions about how to allocate resources. This leads to improved cost predictability and greater control over project budgets, reducing the risk of cost overruns and improving profitability.

Last but not least, BIM also has an impact on sustainability and environmental performance. BIM provides a platform for stakeholders to assess the environmental impact of different design options, enabling them to make more informed decisions about how to reduce the environmental footprint of the building. BIM also provides valuable information about the energy performance of the building, allowing stakeholders to optimize the design to minimize energy use and reduce carbon emissions.

5.2.5 Public Authority

BIM has also had a significant impact on the relationship between public authorities and construction professionals, affecting various public authority relation variables and shaping the way that building projects are delivered. One of the key public authority relation variables that BIM affects is the regulatory process. BIM provides public authorities with a wealth of information about the building, enabling them to make informed decisions about building regulations and codes. This leads to a more efficient and effective regulatory process, with improved compliance and reduced risks of disputes and legal battles. BIM also helps to improve transparency and accountability in the regulatory process, by providing a clear and auditable record of the building and its compliance with regulations.

Another public authority relation variable that BIM affects is the procurement process. BIM enables public authorities to more effectively manage the procurement of construction services, by providing detailed information about the building and its requirements. This leads to improved competition and cost savings, as well as better quality control and a reduced risk of disputes. BIM also helps to reduce the risk of fraud and corruption in the procurement process, by providing a clear and transparent record of the project.

Also, in many countries, there are no specific laws or regulations governing the use of BIM in construction projects. This lack of regulation has resulted in a fragmented and inconsistent approach to BIM, with different stakeholders using different methods and standards. This lack of standardization has led to difficulties in exchanging information between stakeholders and a higher risk of errors and misunderstandings.

Table 1: Definition of I-BIM variables in existing body of knowledge

Prime Category	Variables	Expounding	References
Contractual Relations (CR)	CR1: Collaboration of different companies' staff for same project	The relationship between national and international infrastructure projects is critically important, and coordination is necessary due to the number of personnel involved	Azhar, S. **(2011)**, Costin, A., et al **(2018)**, Ayinla, K.O. **(2018)**, Zhao, X., et al. **(2018)**, Ali Enshassi, A., et al **(2018)**, Costin, A., et al **(2018)**, Zhou, Y., et al **(2019)**, Qin, X., et al **(2020)**, Ma, G., et al **(2020)** and Tan et al., **(2022)**
	CR2: Supportive contract form for I-BIM	Different types of project delivery methods raise the need for specific types of contracts to support any sort of BIM adoption for infrastructure projects	
	CR3: Responsibility for inaccuracies	It is easier for all related construction parties to find and investigate the inaccuracies in projects as technology involvement in the construction sector increases	
	CR4: Appropriate insurance policy for project	One of the new approaches that need to take place in infrastructure projects is to apply a specific type of insurance, which is adopted I-BIM as a construction tool	
Education (E)	E1: Availability of expert personnel	Parallel to the utilization of this technology in industry, students and experts need to be educated and taught to make the transition phase more comfortable	Becerik-Gerber, B., **(2010)**, Costin, A., et al **(2018)**, Olowa, T., et al **(2020)**, Xing, W., et al **(2020)**, Qin, X., et al **(2020)**, Ma, G., et al **(2020)** and Tan et al., **(2022)**
	E2: Education awareness of academia	People have to be educated, and this requires changes in the curriculum of universities and an increase in the number of workshops to maximize the I-BIM implementation	
	E3: Information sharing in I-BIM	All related parties can easily share information due to the BIM philosophy, but it needs a proper education system to fulfill all aspects of any project	

Financial (F)	F1: Initial cost of software	The cost of any sort of technology including BIM is unavoidable, but with proper funding through government and private firms, it can be a game-changing variable	Azhar, S. **(2011)**, Ganah, A., et al **(2014)**, Costin, A., et al **(2018)**, Gerbov, A., et al **(2018)**, Koseoglu, O. **(2018)**, Raposo, C., et al **(2019)**, Alvanchi, A., et al **(2019)**, Rodrigues, F., et al **(2020)**, Matos, R., et al **(2021)** and Tan et al., **(2022)**
	F2: Cost of implementation process	The technology proved itself to be one of the most developing sectors in the world; therefore, its implementation can take several years, especially for small firms	
	F3: Cost of training and education	The change in education systems and training the industry through workshops needs investment, and people have to feel that need to start the process	
	F4: Company's turn over	The implementation of this technology should be beneficial to both small firms as subcontractors and big companies as general contractors in order to collaborate	
	F5: Cost of development	The development of each country is tied to technology, and to be able to manage infrastructure projects properly, there will be a need for critical changes in their structure	
	F6: Stakeholder involvement	There is a huge difference in the structure of big firms compared to small ones, and as shareholder involvement increases, decision-making becomes more complicated	
Managerial (M)	M1: Client requirements	To maximize the design, construction, or maintenance procedures of any current or future infrastructure in accordance with public or private requirements	Azhar, S. **(2011)**, Ganah, A., et al **(2014)**, Cao, D., et al **(2016)**, Celik, T., et al **(2017)**, Costin, A., et al **(2018)**, Gerbov, A., et al **(2018)**, Ali Enshassi, A., et al **(2018)**,
	M2: Coordination among parties	The philosophy of this technology can provide a well-organized system to increase performance and make coordination accessible among top-ranking managers	
	M3: Project size and complexity	Infrastructure projects are commonly huge in size and very complex and detailed in design; therefore, I-BIM can mitigate and reduce this complexity	
	M4: Project life cycle cost	Cost management is one of the strongest suits of I-BIM, and with proper implementation, there could be a huge savings in the total life cycle cost of infrastructure projects	
	M5: Project social cost	The most well-known social cost is carbon emissions, but in infrastructure projects, there are many more that can be mitigated and quantified in the future with this technology	

	M6: Project scheduling and time management	Time management is another dimension of this philosophy that proves itself to be one of the most valuable variables due to its direct relation to the total budget of projects	Raposo, C., et al **(2019)**, Alvanchi, A., et al **(2019)**, Albert van Eldik, M., et al **(2020)**, Rodrigues, F., et al **(2020)**, Qin, X., et al **(2020)**, Rodrigues, F., et al **(2020)**, Ma, G., et al **(2020)**, Xing, W., et al **(2020)** and Matos, R., et al **(2021)**
	M7: Project quality	Quality management can have a direct impact on all aspects of a project, such as standards and guidelines, data accuracy and integrity, or even risk management	
	M8: Environmental Impact Assessment (EIA) of project	The EIA is an extremely crucial process that can help with sustainability analysis, conflict resolution, compliance, and permitting of any infrastructure project	
	M9: Project geographic location	Infrastructure Interoperability is subject to many parameters, such as climate and environmental factors, project logistics, regulations, and construction methodologies	
	M10: Leadership and management support	Controlling infrastructure projects and proper leadership management are significant factors for successful projects and more challenging than building construction	
Public Authority (PA)	PA1: Incomplete national standard	The national standards are growing more than ever for BIM in current years, but there will be a need for clear standards for infrastructure projects due to other prime categories	Azhar, S. **(2011)**, Aibinu, A. **(2014)**, Costin, A., et al **(2018)**, Zhou, Y., et al **(2019)**, Raposo, C., et al **(2019)**, Zhou, Y., et al **(2019)** and Rodrigues, F., et al **(2020)**
	PA2: Awareness level of the industry	This variable needs more perception and insight from the government in order to be implemented as a mandatory choice for infrastructure projects	
	PA3: Lack of government regulation	The government has to adopt the I-BIM framework and compile a compulsory regulation in accordance with their own rule for the short- and long-term projects	

5.3 Conceptualizing of I-BIM Framework

A framework "may well substitute for a theory in many ways," according to Meredith, and is essentially a pre-theory. Accordingly, it may, like theory, "identify essential variables, classify them, describe their interactions, and allow a mapping of items (such as the existing literature or research studies) onto the framework" (Dubin, 1978). As defined by Reisman (1994), a framework "displays the gestalt, the structure, the anatomy, or the morphology of a field of knowledge or the connections between apparently unrelated fields or sub-disciplines." Thus, structuring domain knowledge, eliciting tacit expertise, and promoting the generation of new knowledge may all be helped by a well-structured theoretical framework. As noted by Minsky (1975), these frameworks are useful because A frame is a structure that is chosen from memory whenever a new circumstance (or a significant change in how one sees the current issue) is encountered. This is a memorized structure that may be modified as needed to meet reality. A frame is a data structure that illustrates a predetermined scenario. There are several types of data attached to each frame. Using the frame is covered in some of this information, some of it is about anticipating what will happen next, some of it concerns what to do in the event that these predictions are not realized and a frame is a collection of nodes and relationships.

In this dissertation, in order to shape up the I-BIM framework, there will be three crucial paths that need to be taken. The first one is the Tri-axial framework, including BIM policy, BIM technology, and BIM process, which has been mentioned before in Chapter 2 as PTP procedure, but it will be the first piece of the I-BIM framework. The second phase is going to be the I-BIM Ontology framework, and it is trying to explain and describe the knowledge sets and information uses that need to be developed for the framework. The last phase will be the Competency framework, which needs data mining, the formation of meta variables, and artificial Neural Networks (ANN) analysis to fulfill the concepts of the framework and be utilized as a model uses. All three phases of the framework are going to be explained individually in the following section.

5.3.1 Tri-axial Segment

Succar (2013) claims the BIM framework is continuously expanding by adding new or refining existing interrelated nodes such as models, terms, taxonomies and ontologies. Additionally, the BIM framework largely consists of a three axial structure that supports any additional conceptual constructions including infrastructure as it is illustrated in Figure 11.

The X-Axis shows the BIM Policy, which represents the involvement of Industry, governments, private and public firms, or even academia to define a project(s) and conduct the feasibility study.

The second one, the Y-Axis, tries to conceptualize the definition of BIM Technology. Therefore, to achieve this purpose, the determination of concepts such as utilization, relations, standards, and development of resources is needed to finalize the transition to the next phase.

The Z-Axis is the last phase, and basically it can be defined as the construction business function including planning, design, financing by shareholders or individuals, contracting, time and cost management, resource management, quality management, and facility management.

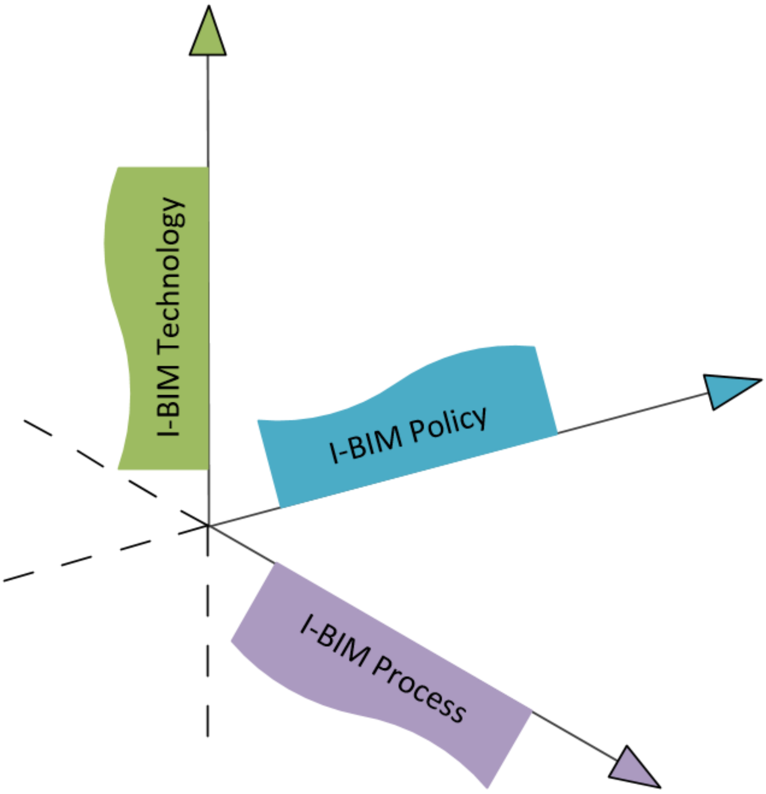


Figure 11: Tri-axial model of I-BIM

5.3.2 Ontology Segment

Ontologies are "content theories concerning the categories of things, characteristics of objects, and relationships between objects that are feasible in any particular domain of knowledge. They offer prospective vocabulary for expressing our understanding of the field (Chandrasekaran et al., 1999). Ontologies can be categorized as application, domain, generic, or representational, according to Van Heijst et al. (1997). By making implicit assumptions clear and promoting inter-person communication, domain ontologies play a significant part in the acquisition, analysis, and application of domain knowledge (Milton, 2007). As a result of information acquisition, reflection, and representation using ontologies, domain ideas and their interactions may be interdependently codified. This can serve as a foundation for further knowledge acquisitions (Holsapple & Joshi, 2006).

The I-BIM ontology is intended as a domain vocabulary (Chandrasekaran et al., 1999) for representing the similar BIM concepts and their relationships; facilitating knowledge acquisition from subject matter experts; and sharing domain knowledge. According to Succar (2013) "The BIM ontology is an informal, semi-structured, domain ontology intended for knowledge acquisition and communication between people". The I-BIM ontology includes specific concepts, their relations and attributes, domain knowledge of applying BIM concepts in infrastructure projects. Figure 12 is representing visual ontological relationships among concepts of Tri-axial framework and I-BIM implementation.

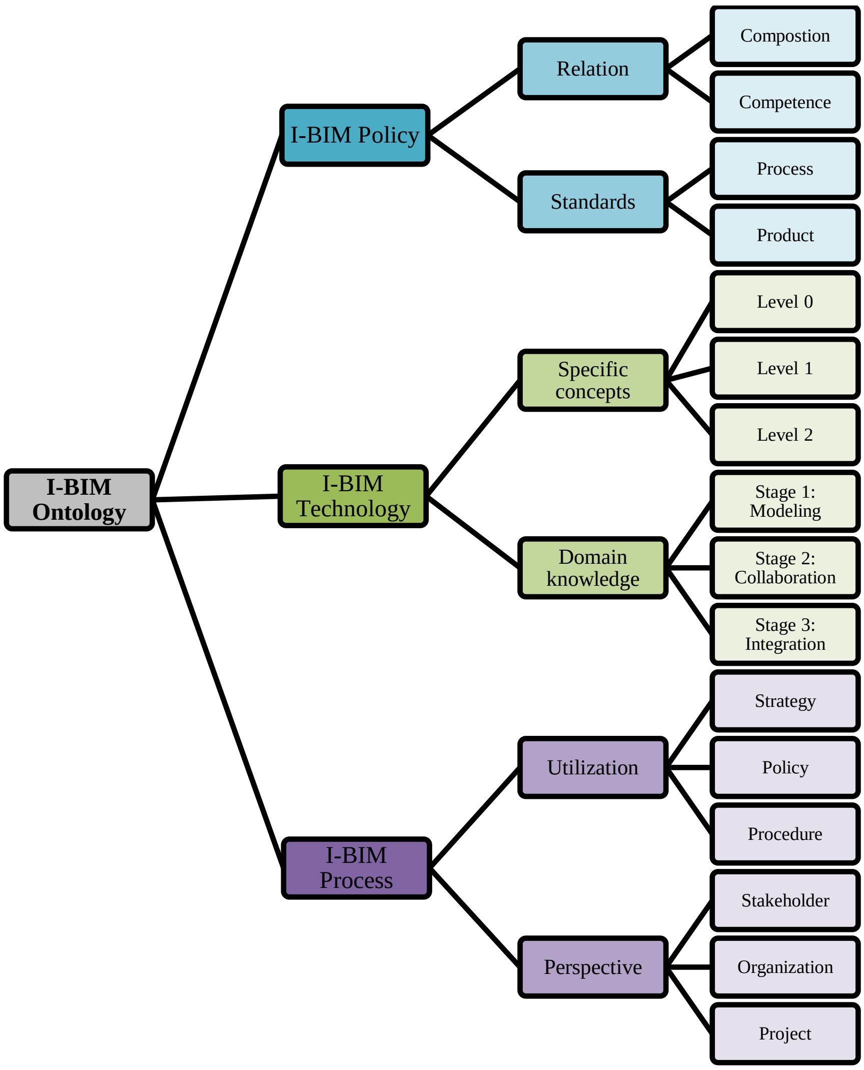


Figure 12: Ontology of I-BIM framework in correlation with the Tri-axial model

5.3.3 Competency Segment

The competency segment of the I-BIM framework is divided into three different competency tiers. The first tier is going to be deep data mining, which is going to be explained comprehensively in Chapter 7. The second tire will be defining meta variables in accordance with the collected data from the data mining in order to determine the most accurate set of data in terms of different analyses based on the total number of meta variables (TNMV) that is discussed in detail in Chapter 8. The third and last tire will be ANN analysis with MATLAB that has been explicated comprehensively in Chapter 9. The relationship between these three tiers has been illustrated in Figure 13.

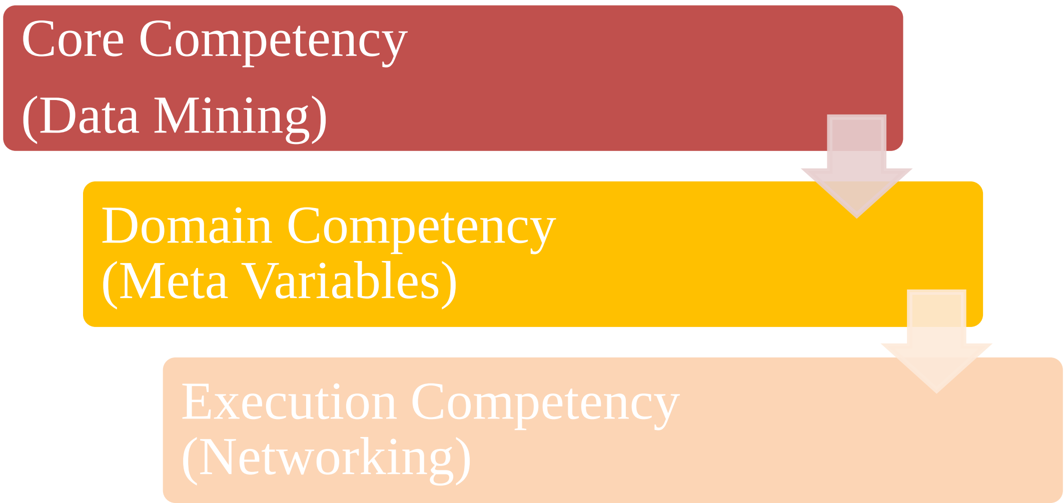


Figure 13: I-BIM competency tiers relationship

5.3.4 Ultimate Framework

Figure 14 has been demonstrated in order to summarize the relation of all three paths of the I-BIM framework with one another and, moreover, to shape up and finalize the proposed concept to be able to implement and utilize it for infrastructure projects in both target countries.

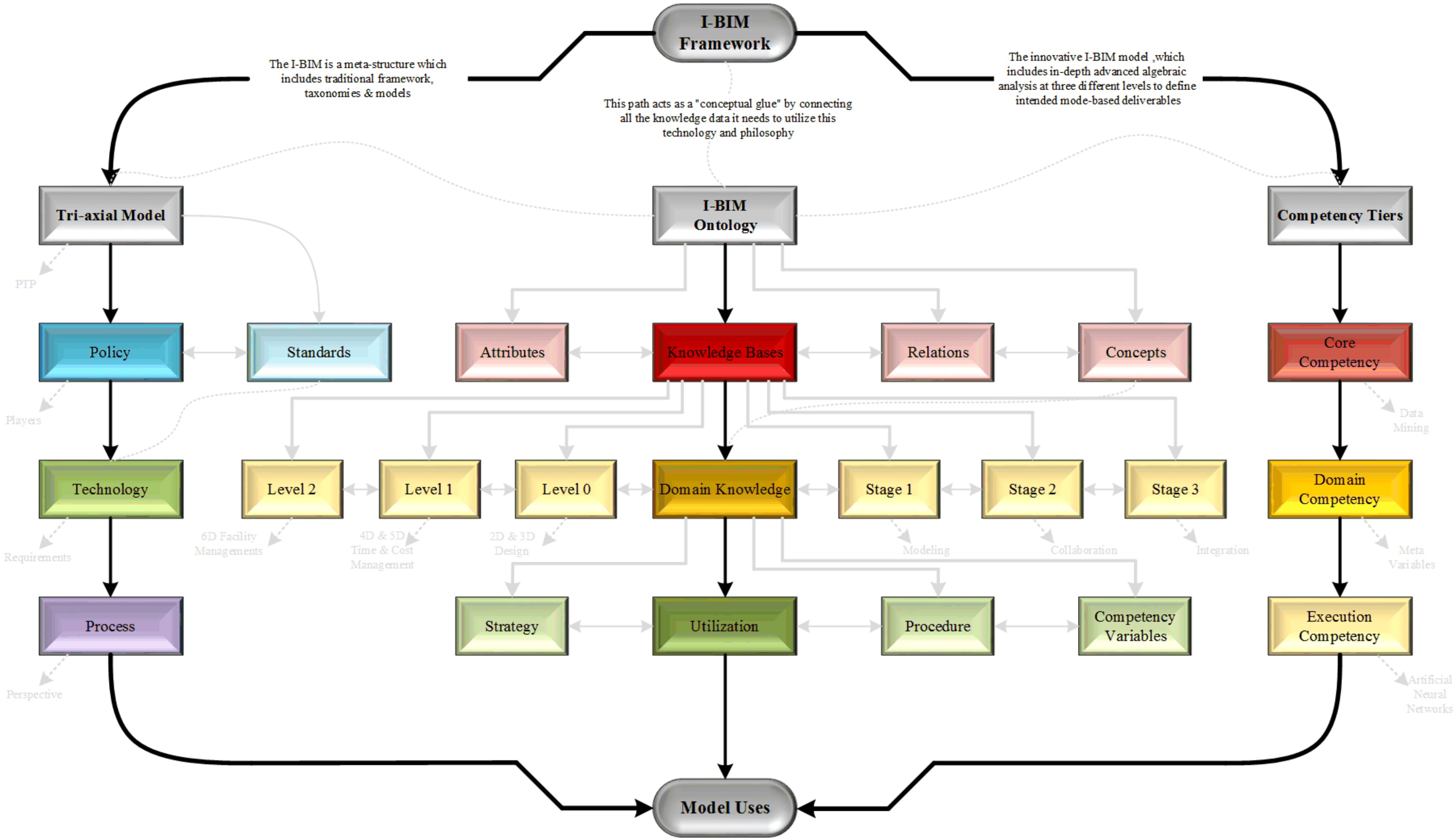


Figure 14: Ultimate framework of I-BIM implementation

Chapter 6

EXECUTED QUESTIONNAIRE TO UTILIZE BIM FOR INFRASTRUCTURE PROJECTS

6.1 Introduction

To demonstrate the industry professionals how they can efficiently adopt BIM for infrastructure projects, comprehensive review of existing body of knowledge from many different sources (academic journals, dissertation and conference databases, web, e-books, etc.) is performed. During this critical review, the benefits and barriers of I-BIM implementation are identified in terms of 26 variables, where these variables are later assessed and rated by the professionals through their involvement of the conducted questionnaire. As illustrated in Figure 15, these variables are correlated and clustered under 5 different headings as suggested.

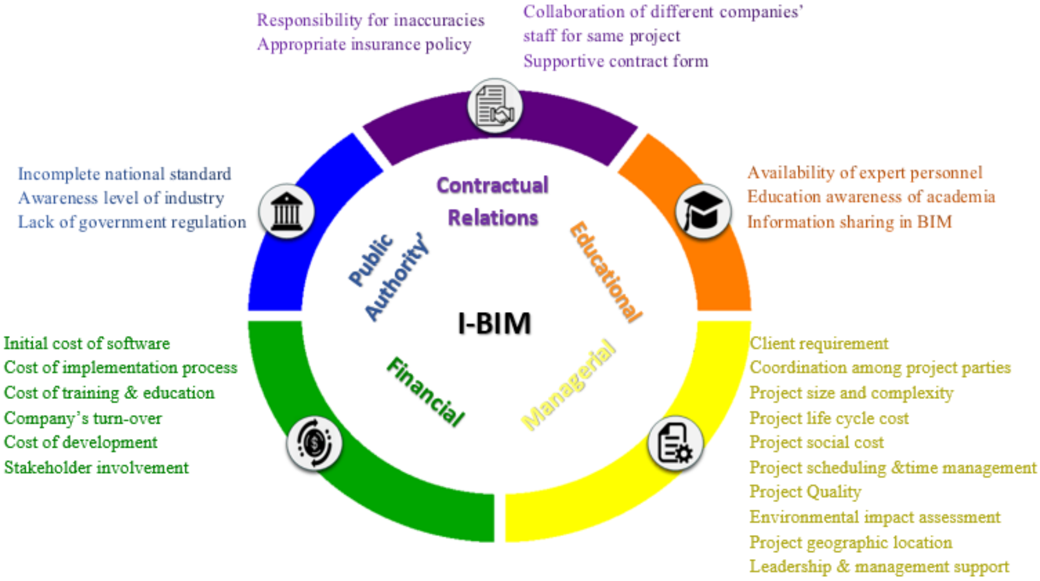


Figure 15: Infrastructure Building Information Modeling (I-BIM) variables

6.2 Data Collection

Subsequent to the identification and classification of the 26 variables, it was vitally important to obtain the opinions and feedback of the professionals and benefit from their experiences of BIM adoption. This is why questionnaire surveys are selected as an instrument for collecting data in this respect. After about 4 months of efforts, 187 experts working in the United States of America and Turkey were reached in different cities, such as: Ruston, Louisiana; Arlington and Dallas, Texas; Los Angeles and Irvine, California; Chicago, Illinois; Istanbul, Turkey; and Ankara, Turkey. The institute and people who helped collect data have not been named here due to ethical and regulatory concerns, but it is noteworthy to mention that according to ENR 2022, three out of ten top design firms in the United States of America helped authors tailor the questionnaire more carefully. For the participants with whom the author had personal communication, questionnaires were conducted face-to-face in an interview-based environment. The rest of the respondents were reached through newsletters, professional organizations, and academic networks and participated through online tools. Also, the participant has been selected carefully by consulting related parties to increase the accuracy of responses and keep the response rate in an acceptable range, which is going to be discussed in more detail in this chapter.

The questionnaire is comprised of four main parts. In the first part, general information about the participants concerning the type of firm they work for, their affiliation, their level of proficiency in BIM, work experience, and knowhow in using a BIM software is investigated though 14 questions. In the second part, 26 variables are identified from the literature review and the foundation of the questionnaire itself is constructed to be ready to distribute among the target respondents. Afterward, in the third part, all participants under 5 different categories that have been classified by the authors rank each single variable either as a barrier or a benefit, and participants have prioritized these variables so that a relative importance index of the variables can be obtained from 1 to 9. In the last part author try to collect data through interview and consultation with expert in order to find an effective weight of each factor under the tab of category. All these four parts, which have been explained, are going to be discussed more comprehensively in the following section.

6.2.1 Segment A: Respondents Information

The Segment A of this questionnaire has been designed to Gather demographic information about the selected respondents. It was attempted to gather some fundamental and general information about the chosen firms along with specific question to determine the proficiency level of each firm about BIM. This section included fourteen questions, each of which was shortened as follows:

1. Question 1: Educational qualification
2. Question 2: Experience in academia and industry
3. Question 3: Total number of project involvement in a year
4. Question 4: Total number of permanent personnel
5. Question 5: The total annual turnover
6. Question 6: Field of interest in construction industry
7. Question 7: Main role in firm
8. Question 8: Country of residence
9. Question 9: The proficiency level of firm about BIM
10. Question 10: Project(s) involvement using BIM
11. Question 11: Total BIM Project(s) values
12. Question 12: BIM utilization software and tool

13. Question 13: BIM Level of Maturity of firm

14. Question 14: Financial outcome of BIM adoption.

6.2.2 Segment B: I-BIM Category(s)

The I-BIM categories and their similarity to BIM components were discussed comprehensively in Chapter 2 and Chapter 5, and according to the findings of this study, a total of five categories have been selected, as stated in Table 2, along with the reason for each selection for each category and how it can mitigate or improve the effect of each factor in the path of I-BIM implementation and utilization.

Table 2: Selected I-BIM categories

I-BIM Categories	Reason of Selection
Contractual Relations	Most of the conflict and tension in the construction industry arise from a lack of communication and misunderstandings in contractual form among all related parties. But by introducing I-BIM, these issues can be greatly mitigated, and responsibilities are going to be assigned more clearly to each staff member, even if there are multiple firm members involved in a project.
Education	Academia is the apex of any organizational change in the world, and if there is any way to implement I-BIM in the near future, it needs to start by educating millennials to enhance the current software program and train more professional BIM engineers.
Financial	There are two different approaches to the financial aspects of I-BIM implementation that need to be considered. First, it's an investment approach to motivate the firms in order to train skilled staff and acquire necessary tools and software. Second will be the stakeholders' approach and how this enhanced technology can provide better financial flow to the firm in both the short-term and long-term.
Managerial	This can be the main advantage of I-BIM implementation since this category can revolutionize the construction industry by providing a digital platform for collaboration, design, and construction management and bringing new opportunities to enhance efficiency and productivity.
Public Authority	Due to the nature and complexity of infrastructure projects and the lack of national standards, it is crucial to create a platform to provide a clear and transparent record of the project and reduce the risk of fraud and corruption in the procurement process.

6.2.3 Segment C: I-BIM Components Utilization

The primary goal of this part was to examine the I-BIM components and their principal categories in order to utilize them. According to the major I-BIM category in Table 1, a total of 26 variables have been selected with the following identifiers and counts for each category in Table 3 in order to make the questionnaire more organized for the respondents and later on for the author to conduct the results and data analysis in Chapter 7.

Table 3: Selected I-BIM components of each category

I-BIM Categories	Identifier	Number of Component
Contractual Relations	(CR#)	4
Education	(E#)	3
Financial	(F#)	6
Managerial	(M#)	10
Public Authority	(PA#)	3

In the next step, the chosen components need to be ranked from 1 to 9 by a selected respondent from both countries, and in this case, it has been decided to consider each ranking score according to Table 4, including the sub-rankings of I-BIM Effectiveness to make it clearer and more accurate to the respondent. For instance, by considering a variable as 7, the respondent means that that variable contributes a great deal to I-BIM utilization, but it may still need some improvements.

Table 4: Detailed version of ranking method

I-BIM Effectiveness	Ranking score	Rating score
Benefit	9	Major
	8	Moderate
	7	Minor
Neutral	6	Fair

	5	Impartial
	4	Nonaligned
Barrier	3	Impediment
	2	Hindrance
	1	Catastrophic

6.2.4 Segment D: Effectiveness Weight of Each Factor

As it's been stated, this section has been conducted through interviews and consultation with experts in order to find an effective weight for each variable under the tab of all five main categories. The effectiveness weight has been divided into two sub-sections in order to be able to weight each variable individually and more accurately. The first section is called Quality (Q) Weight Factor, and since the essence of both countries, Turkey and the United States of America, regarding construction and infrastructure activities and projects is different from one another, this factor has been defined as stated in Table 5. Scholars such as Rajeev and Tesfamariam (2012) and Jough and Şensoy (2016), declare that the mean value of their main target categories has been decreased by 25% to prove the differentiation in their algorithm for their numerical tests, and the author has adopted the same pattern and logic for this dissertation to support the reason for this selection. Moreover, there are other reasons to set the United States of America as a benchmark compared to Turkey for Q-factor selection, such as the development levels in terms of construction and infrastructure, the welfare of society, economic stability, etc.

Table 5: Q-Factor weight for target countries

Turkey	**United States of America**
75%	100%

The second sub-section of this segment is called the Experimental (E) Weight Factor, which has been calculated individually for each variable according to consulting and interviews with experts. The E factor weight has been defined for each variable of each category in terms of satisfying the following condition in Equation 4, and the formula in this equation represents the procedure of this calculation.

$$\mathrm{E_i} = \mathrm{V_{i1}} + \mathrm{V_{i2}} + \cdots + \mathrm{V_{in}} \quad (4)$$

Condition of Equation 4 has to be: $\mathrm{V_{i1}} + \mathrm{V_{i2}} + \cdots + \mathrm{V_{in}} = 1$

Where:

- E = Total Experimental Weight Factor
- i = Identifier of I-BIM categories according to Table 3
- V = Assigned E-Factor Weight for each variable.

The results of E_i are illustrated in Figure 16 in accordance with Equation 4. It's noteworthy to mention that this result has been concluded based on a total of 40 interviews with experts in the industry. The main aim of this interview was to ask the opinion of each respondent to determine the importance level of each variable in each category in order to define a weight, respectively.

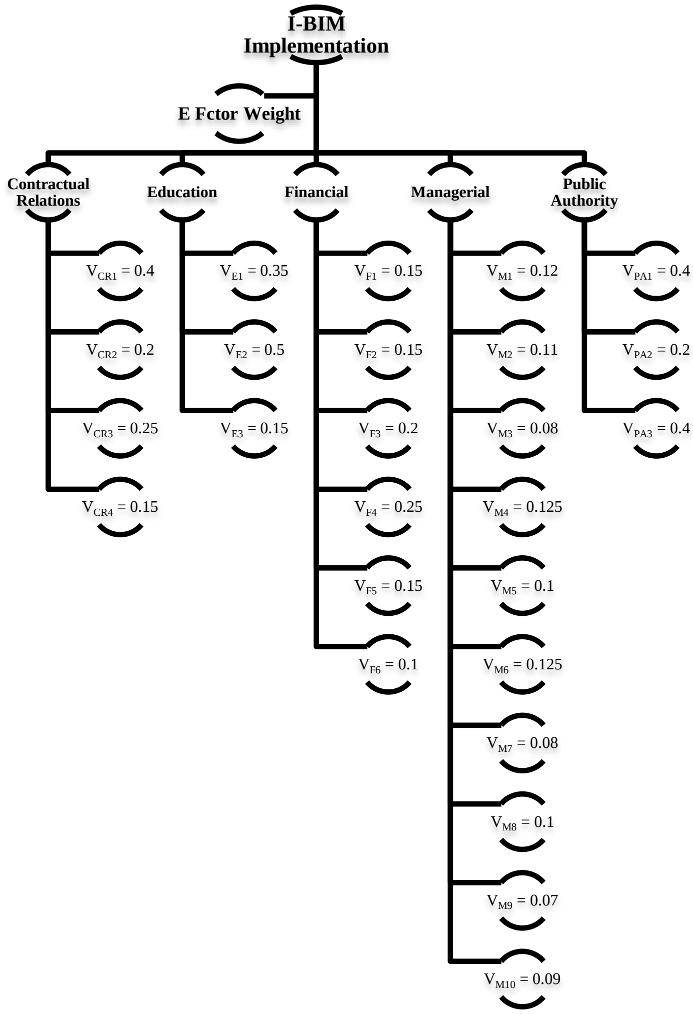


Figure 16: Tree-Diagram of the E-Factor weighting system for I-BIM

6.3 Validation and Reliability of the Questionnaires

The reliability of obtained data is one of the most crucial factors to examine in any research. Because if the evidence is untrustworthy, the primary process of investigation will fail and the ultimate response to the main objective will be undesirable. Researchers devised several solutions to this difficulty, demonstrating the internal consistency of each study. Therefore, author has been decided to use two different approaches in order to support the accuracy of this research and demonstrate that the response rate is acceptable.

6.3.1 Response Rate

This section is representing two different parts. First part is calculating the response rate. The author evaluated two primary concepts in this case to discover and filter an inaccurate questionnaire. First, if any answers are missing; second, if all answers have the same scoring pattern from start to finish. In this regard, 12 faulty questionnaires have been identified and the involvement of 175 respondents is taken into account during the study. On the other hand, it is worth noting at this point that 44% of respondents are from the United States, and the remaining number of participants were from Turkey as it has been stated in Table 6. Moreover, Akintoye (2000) suggested that an acceptable response rate for construction research is between 20% and 30%.

Table 6: Distribution and responses of questionnaire

Selected Country	Distributed	Respondents	Response Rate
United States of America	80	77	96.25%
Turkey	107	98	91.60%
Total	187	175	93.58%

The second part is comparing the target population and response rate of this study with other similar studies to support the accuracy of the questionnaire. As mentioned in Table 2, a total of 187 questionnaires have been distributed, and the total response rate was 93.58%. The main reason for such a high response rate was targeting the right population in Turkey and the United States of America; for instance, in the United States of America, the author tried to gather information from respondents in target workshops located in different cities such as Arlington, Chicago, Ruston, and Los Angeles. Moreover, according to the study titled "Empirical study of BIM implementation-based perceptions among Chinese practitioners" by Jin et al., (2017) at the University of Leeds, the questionnaire has been delivered to a total of 297 respondents, and only 94 answers have been collected from both hardcopies and online distribution. In another study that was conducted in 2018, Özmen, declared that out of 200 respondents, only 108 of them helped him investigate the path to implementing BIM in the Turkish construction industry. Furthermore, Jones (2020) targeted all UK RIBA companies in three different years, followed by 2011, 2014, and 2018, with a total of 3752 companies, but his total number of respondents was only 125. Recently, Tan et al., (2022) tried to model BIM implementation in developing countries with a total sample size of 1028 people for their study. The response rate of their study was only 23.63%, with a total of 243 completed questionnaires.

Therefore, according to previous studies that has been conducted from 2017 to 2022 and their response rate and total number of respondents, author of this dissertation, believe that the sample population and total number of respondents in this research were enough and sufficient to start the investigation in the path of implementation of BIM for infrastructure projects.

6.3.2 Cronbach's Alpha Test

In this research total number of 26 variables has been chosen to be consider as barrier, neutral (uncertainty) or benefit of I-BIM utilization. As it has been mentioned, the main target countries are United States of America and Turkey, therefore each of these countries need validity according to the total number of respondents and their opinions. Table 7 is shown the interpret of Cronbach's Alpha coefficient according to George and Mallery, (2003). This statistical technique is going to assess the internal consistency of the questionnaire and help to measure the reliability of all selected variables by measuring how closely they are related to each other.

Table 7: Interpret of Cronbach's Alpha coefficient

Cronbach's Alpha	**Interpret**
$\hat{\alpha} > 0.9$	Excellent
$\hat{\alpha} > 0.8$	Good
$\hat{\alpha} > 0.7$	Acceptable
$\hat{\alpha} > 0.6$	Questionable
$\hat{\alpha} > 0.5$	Poor
$0.5 > \hat{\alpha}$	Unacceptable

As an outcome, all of the respondents' answers were acceptable since the Cronbach's alpha for each parameter was regarded as Excellent. Tables 8-9 also provide the primary coefficient for each selected country. It is worth noting that Cronbach's alpha has been set based on each of the mentioned I-BIM variables in Table 1, Chapter 5, and that analysis has been conducted separately for each of the target countries to differentiate the answers among advanced countries and developing countries.

Table 8: Reliability coefficient of the United States of America questionnaire

I-BIM Category	**Cronbach's Alpha**	**Number of Variables**
Contractual Relations	0.9021	4
Education	0.8581	3
Financial	0.9339	6
Managerial	0.9368	10
Public Authority	0.9038	3
Total	0.9485	26

Table 9: Reliability coefficient of the Turkey questionnaire

I-BIM Category	**Cronbach's Alpha**	**Number of Variables**
Contractual Relations	0.8592	4
Education	0.8510	3
Financial	0.9458	6

Managerial	0.9405	10
Public Authority	0.9216	3
Total	0.9561	26

Chapter 7

RESULTS AND DISCUSSIONS

7.1 Introduction

A dissertation's effective completion depends significantly on data analysis. Data analysis, a crucial component of research, helps researchers to examine, evaluate, and come to relevant conclusions from the information acquired. It offers the methods and tools required to convert unprocessed data into practical information that advances the primary objective of the research. This article seeks to clarify the value of data analysis in dissertations, the relevance of data analysis in various research techniques, and the numerous ways to data analysis. Therefore, Data analysis is extremely important in the setting of a dissertation since it enables researchers to accomplish the goals such testing hypotheses, identifying patterns and drawing inferences.

For instance, in testing hypotheses, researchers can assess the viability of their ideas by systematically analyzing the acquired data. By providing actual evidence to support or refute research conclusions, data analysis techniques like statistical testing, regression analysis, or inferential analysis support the overall reasoning. Also researchers can find patterns, trends, or links in the gathered data by identifying patterns and trends. This aids in revealing hidden information and comprehending the fundamental principles underlying the study issue. Researchers may convey complicated findings in a straightforward and understandable way, allowing comprehension and additional investigation, by using techniques like data visualization. Moreover, researchers can establish solid deductions and conclusions based on the gathered data by drawing inferences. It offers a framework for the analysis and interpretation of the findings, ensuring that they are consistent with the study's objectives. Well-analyzed data provide credibility to the dissertation and increase its overall validity.

7.2 Segment A: Respondents Information

7.2.1 Respondent Profiles

This questionnaire survey had 175 complete responses. Figure 17 categorized all respondents by their occupation and level of expertise in the construction industry. It is noteworthy to mention that the level of expertise refers to the respondents' strengths in the construction industry regardless of their main occupation, and as it can be stated, a quarter of the respondents in this survey were recognized as BIM consultant experts. In this case, it has been tried to distribute survey among the infrastructure expert's firms. Moreover, 77 participants were located in the United States of America which is equivalent to 44% of total survey and remaining number were located at Turkey.

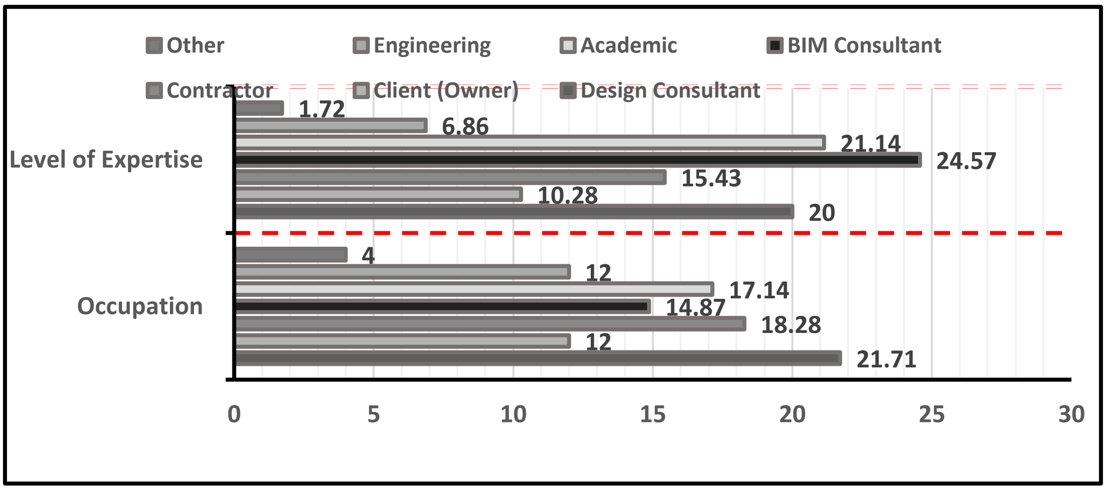


Figure 17: Respondent's profiles charts

7.2.2 BIM Project Profiles

Respondents were asked to select a Project Type (PT) which has been done in their firm by using BIM in order to make construction line of business for following research. As it is shown in Figure 18, all 175 participants of the survey were involved in 683 projects which has been shown by PT1 to PT14 indicators. These indicators are represented as commercial (PT1), Residential (PT2), Educational (PT3), Industrial (PT4), Airport (PT5), Transportation (PT6), Public & Government (PT7), Sports & entertainment (PT8), Water Supply & Resources (PT9), Bridges (PT10), Power Generation & Transmission (PT11), Tunneling (PT12), Pipeline Infrastructure (PT13) and None (PT14). It can be stated from Figure 18 that there are plenty of Residential and Commercial projects which utilize BIM but current usage of heavy construction and more specifically infrastructure, based on BIM is growing fast all around the world but still needs raising concerns of industry.

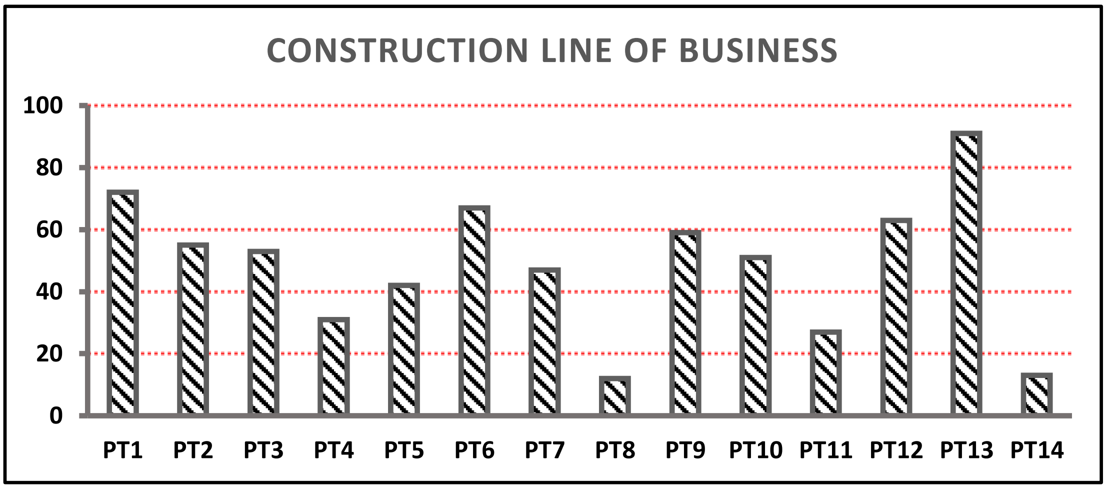


Figure 18: Respondent’s project types

On the other hand, there will be another way to categorize selected respondents which has been done by firms’ projects value and illustrated in Figure 19. According to survey data which has been elicited, most of involved firms are fell into more than $50 million range (42%), followed by $30-$50 million (31%). Therefore, these result shows that I-BIM is also more applicable to large invested projects.

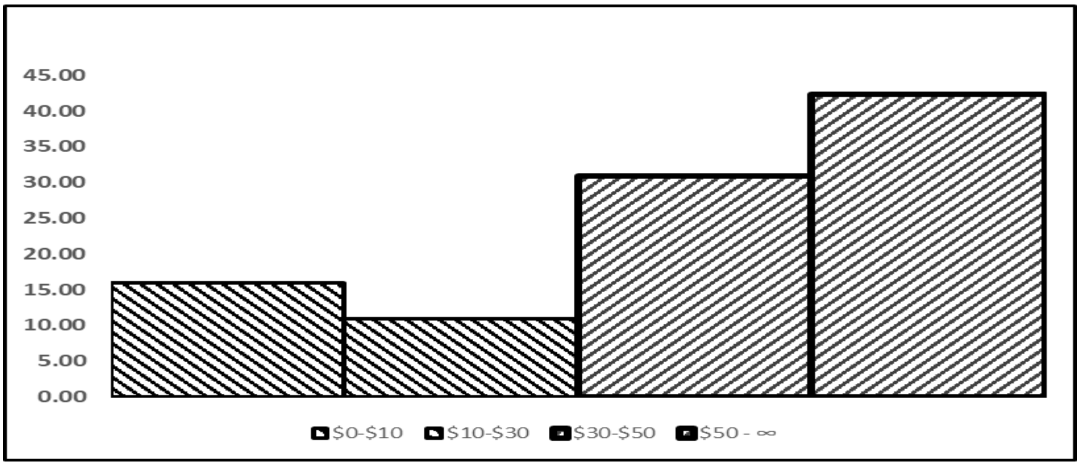


Figure 19: Operated project's value by respondent's

7.2.3 Adoption of BIM for different dimensions

During the previous decade, there were several BIM analysis and authoring tools available to design and monitoring different aspects of the construction industry. Due to survey results, as it illustrated in Figure 20, AutoDesk programs such as Revit and Navisworks are widely used in the selected country. Afterward, Graphisoft ArchiCAD by 14% and Tekla by 7% are the most common BIM tools which are being used by industry. Also, around two-thirds of the architecture firms are using Autodesk, and Tekla is a popular tool among the engineering firms, according to the respondents.

It is noteworthy to mention that the VICO is going to be offline by the end of 2023 according to the developers due to the lack of users. Also, BIM360 is trying to expand its user base through different methods, including a free demo program or trial for firms, companies, institutes, and universities, to help both academia and industry follow the adoption of this philosophy and technology faster.

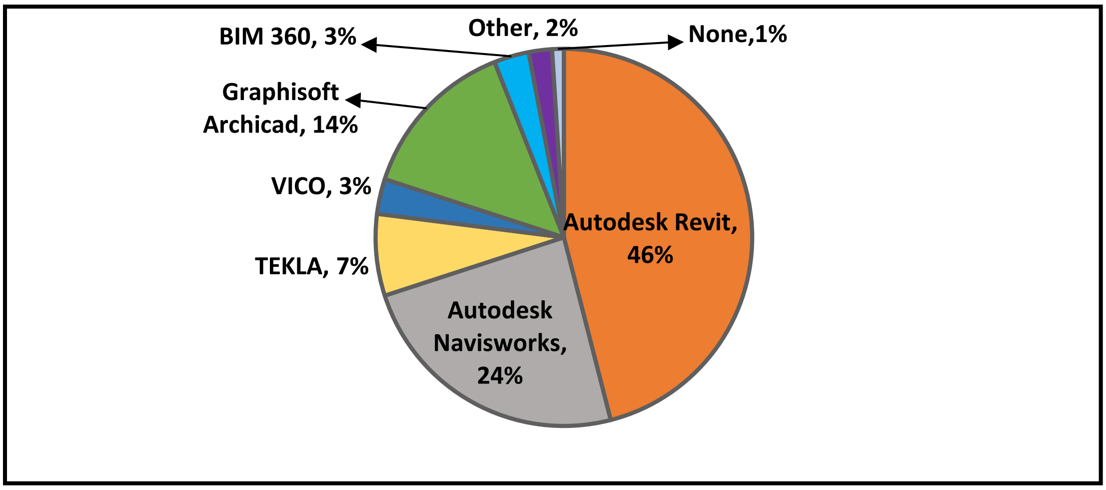


Figure 20: BIM software's used by firms

To investigate more on BIM adoption, respondents were asked about the BIM dimension (task) which they used for their firm's projects. According to Figure 21, Visualization (3D) and scheduling (4D) where the most important BIMs dimension is used in projects. Likewise, Cost Estimating is one of the most critical tasks to finalize any project phases on time and on budget. It is raising a concern that 5th dimension of BIM needs more attention and there is high potential impact which could be investigated by researchers such as social cost effect in today's construction activities by using BIM as a quantification tool.

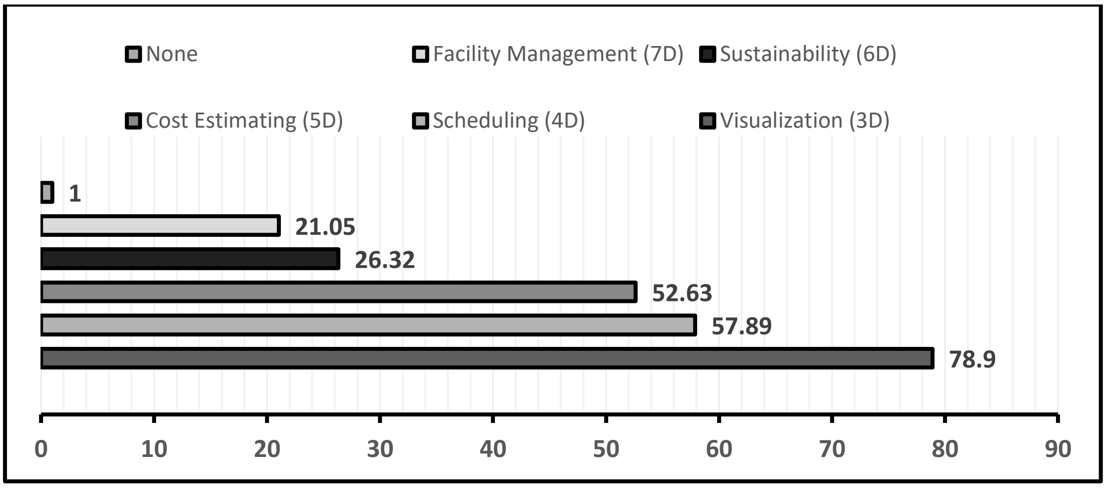


Figure 21: BIM dimensions used by firms

7.3 Contractual Relations

The agreements among all involved firms during the construction of any structure is one of the most important parameters of any successful project. By introducing BIM to construction industry, accuracy level of any construction activities increased. In this section, there have been four parameters selected to be evaluated in the path of I-BIM utilization.

According to respondent opinions, the collaboration of different companies' staff for same project and responsibility for inaccuracies on project tasks are the most important beneficial aspect of I-BIM which is currently contractors and architecture firms are using it on their projects. In these cases, each person who is involved in project has access to online cloud system to create, modify and monitor any tasks, depending on their roles. This system clearly reduces any inaccuracies and make the quality and control management of the project at a higher level.

On the contrary of the first two parameters, Supportive contract forms for I-BIM and Appropriate insurance policy for projects are considered, not as a barrier nor benefit, but as underdeveloped parameters which need more perception by related parties. For instance, in the United States of America, there are some advantageous insurance policies which motivates customers to use those technologies.

In construction industry, there are different types of insurance; but as technology is finding its own way to the industry, lack of beneficial insurance policy for the firms who are using I-BIM in their projects is sensate because as it mentioned, by using I-BIM there can be lots of revenue for everyone, including publics by saving the notable amount of tax payment to the government. Even as a solution, there could be clause in contracts agreements forms among the client (or the consultant firms on behalf of client) and contractors which shows the responsible firm is using I-BIM in the project and by using it, there would be exemptions for contractors and sub-contractors due to advantageous of it.

As a matter of fact, I-BIM easily helped to contractual relations segment of the construction industry by making more proper collaboration among involved companies in the same project. More than that, it aids to investigate any inaccuracies at any stage of any project and simply realize the responsible role who led the task to error so by this manner any aspect of any project could be easily managed.

It’s noteworthy to mention the uncertainty of developinh countries about these matters because as it stated in CR2 and CR4 analogy Figure 22 (b) & (d), around 40% of respondents are not sure how these two variables could help their firms. But hopefully in near future there will be appropriate insurance policy for the projects which are using BIM and I-BIM by the legislation experts all around the world because this can be inhibitory factor to motivate the firms to apply this technology to their infrastructure project.

To conclude this segment, CR1 and CR3 variables are going to be useful to manage the project accordingly, but still, there are no clear project delivery methods adopted by using I-BIM, which is an obstacle in the path of globalization of this philosophy for infrastructure projects because when it happens, industry is going to go through the transition phase more accurately and easily, and all firms are going to utilize it regardless of being large or small.

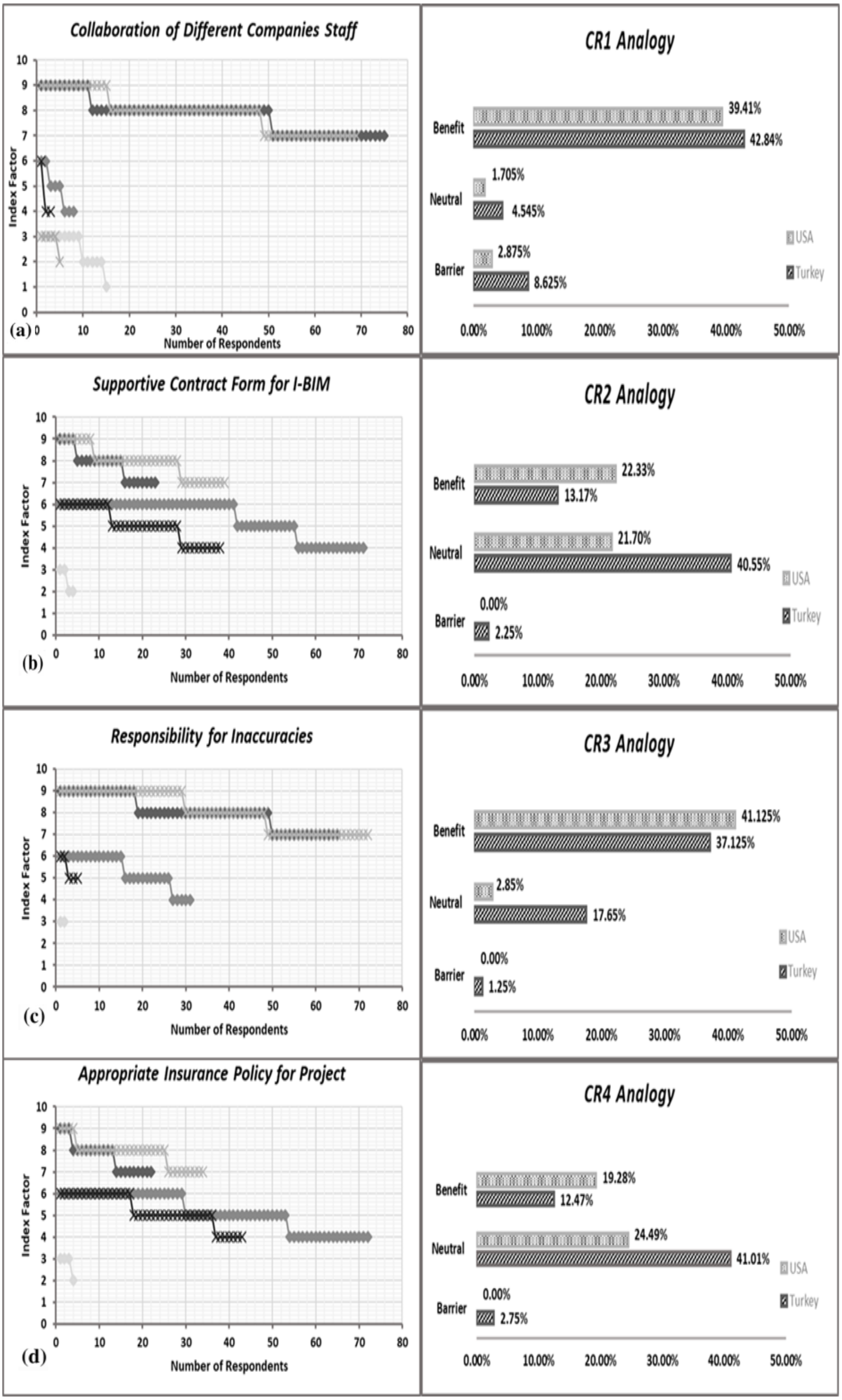


Figure 22: Contractual Relation variables for I-BIM utilization

7.4 Education

The relation of education and I-BIM is irrefutable because any new technology needed to be taught by experts and learn by apprentice to be more applicable. According to the respondent's opinions, there is lack of expert personnel around the world which cause high cost of training and education. This is easily one of the strongest barriers to utilize BIM in any sector including infrastructures. As a solution of E1 variable, industry and government as an assembly need to work to bring I-BIM to life by changing universities curriculums and organizing workshops to increase the awareness of all related parties even more of what has been stated in Figure 23 (b), because this the future of construction industry.

Afterward, it's noticeable to discuss background education of academia about I-BIM as another barrier. Due to comments of respondents, there are not enough must-take courses in universities which precisely focus on different aspects of BIM. Most of the interested apprentice need to attend in high-cost workshops to learn a new program or getting familiar with the concepts of this technology. But if the mentioned assembly gather and work properly to overcome E1 variable, both academia and industry is going to be more familiar with I-BIM. Therefore, due to availability of expert personnel, all related costs including workshops will be decrease because of high insensitive contest among parties.

The third parameter which has been asked was Information Sharing in I-BIM. This factor is easily one of the biggest advantages of I-BIM according to a high ratio of the respondent for considering it as a positive influence on I-BIM. Nowadays, Programs such as BIM 360, Tekla, VICO, Autodesk Revit and Navisworks, BIMobject, and

BIMx are assisting most of the firms around the world to organize their construction activities in a proper way. Generally, Information sharing is being done by some of these programs through the cloud-base web service which provides team members access to data to improve decision-making and avoid expensive delays. Therefore, it's noticeable to consider E3 as the only pure benefit of education category of I-BIM by refereeing to supportive facts which has been mentioned.

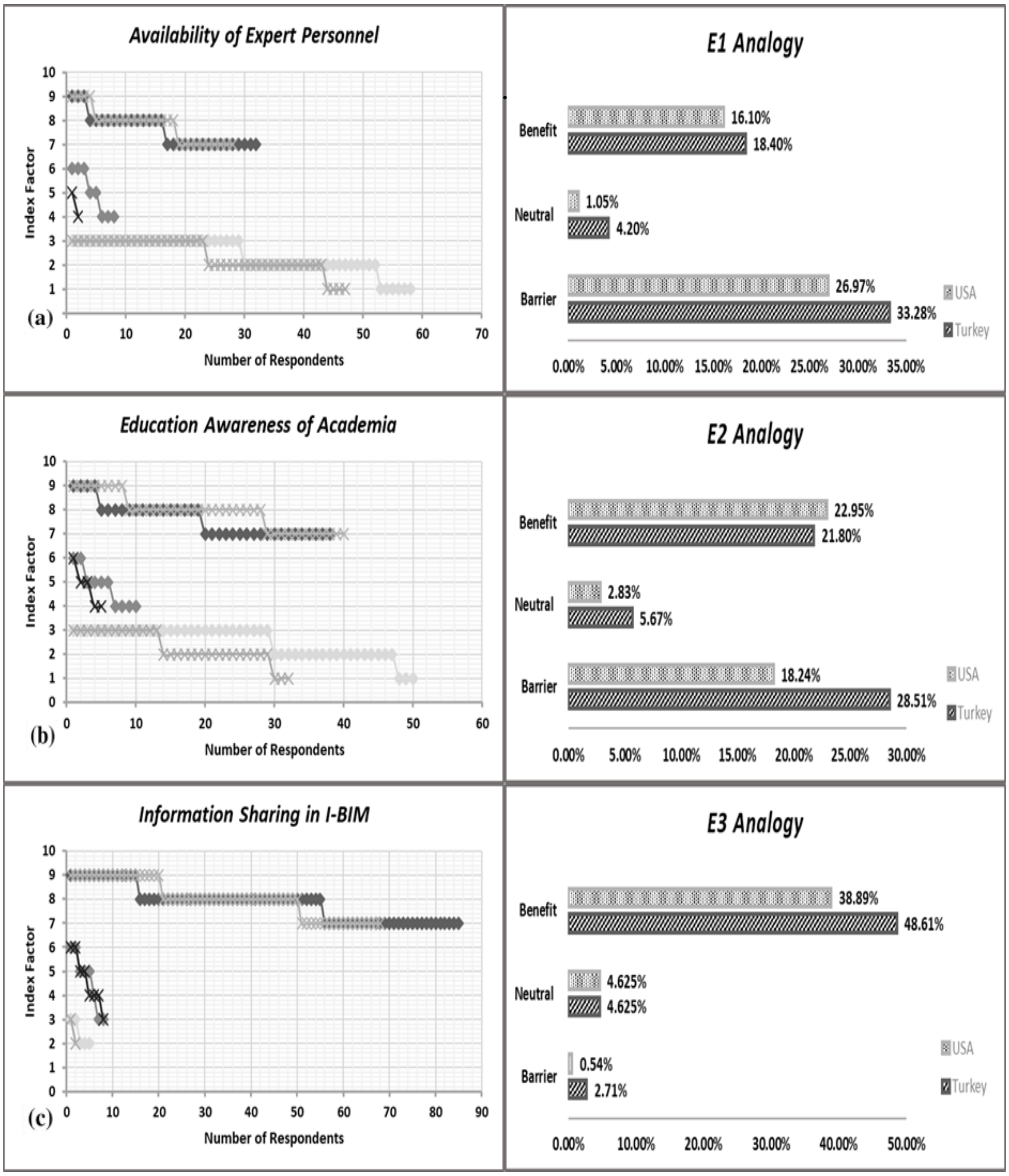
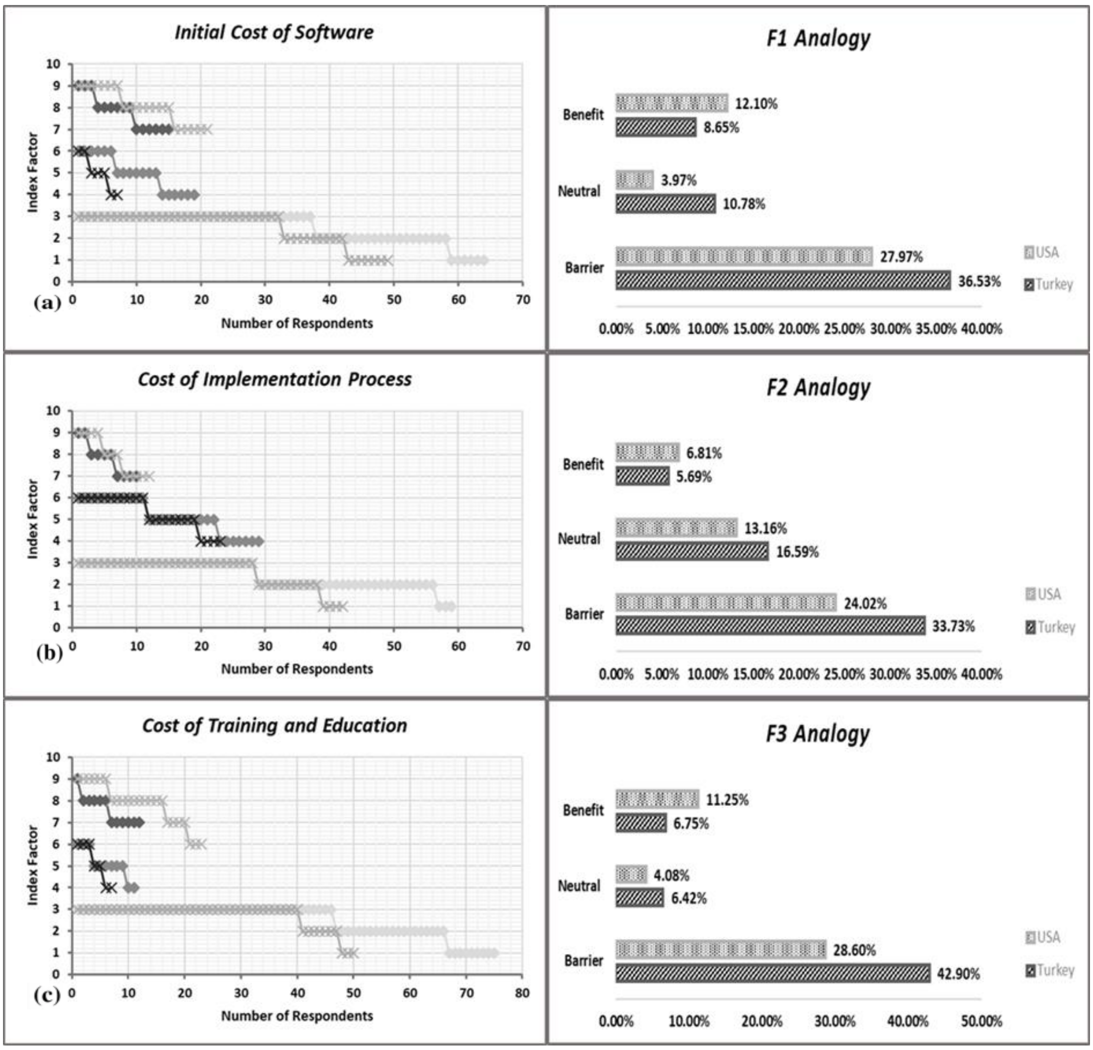


Figure 23: Educational related variables for I-BIM utilization

7.5 Financial

One of the most important investment for a successful I-BIM implementation is training and it has been the greatest barrier on the path to I-BIM adoption based on Figure 24 (c). According to study's results, respondents recognized F3 as a critical problem and firms are trying to provide more training to their staffs in order to resolve this concern. Also, Initial Cost of I-BIM software, Figure 24 (a), has been ranked as a second financial barrier for the I-BIM adoption. Indirectly, this Parameter indicates the number of I-BIM user in the industry because one of the main reasons of any expansive product could be the lack of customer or consumer which it led to high cost of the production in order to cover the expenses of manufacture products and make a reasonable profit for company. In addition to these two barriers, it is noticeable to mention the cost of development, Figure 24 (b), as another obstacle which categorized as a software upgrade and hardware maintenance. According to the literature review, American companies spent less than 2% of their net revenue on hardware, hardware maintenance, software, software upgrades, or training. Relatively, hardware and software costs funded the most to overall expenses, whereas hardware maintenance and software upgrades expenses are less than 0.5 of overall net revenue of the firms.

The survey has been tried to investigate tangible costs associated with utilization of I-BIM, software and training, companies' turnover and stakeholders' involvement. Somehow, these costs are the ones which easier to quantify and compare to the other factors. In spite of the fact that these factors and costs are undeniable, still, lots of organization and government has doubt about I-BIM utilization for their projects. Due to the respondent opinion in this survey, any companies who involved with big projects get benefits from I-BIM adoption and by following changes, the turnover of companies will increase extensively as it has been stated in Figure 24 (a) but for third world countries still there are doubts about F4 factors due to economic condition of those countries. Furthermore, public and private sectors as major stakeholders', F6 variable, could play a key role in the success of I-BIM by promoting and providing support for implementation, research, and development in the future. It is a matter of fact that in advance countries, stakeholder involvements are more passable compere to third world countries. This fact can be proving by referring to Figure 24 (c) which most of the American are consider F6 factor as a benefit but in Turkey, more than 50% of respondents were not sure about it.



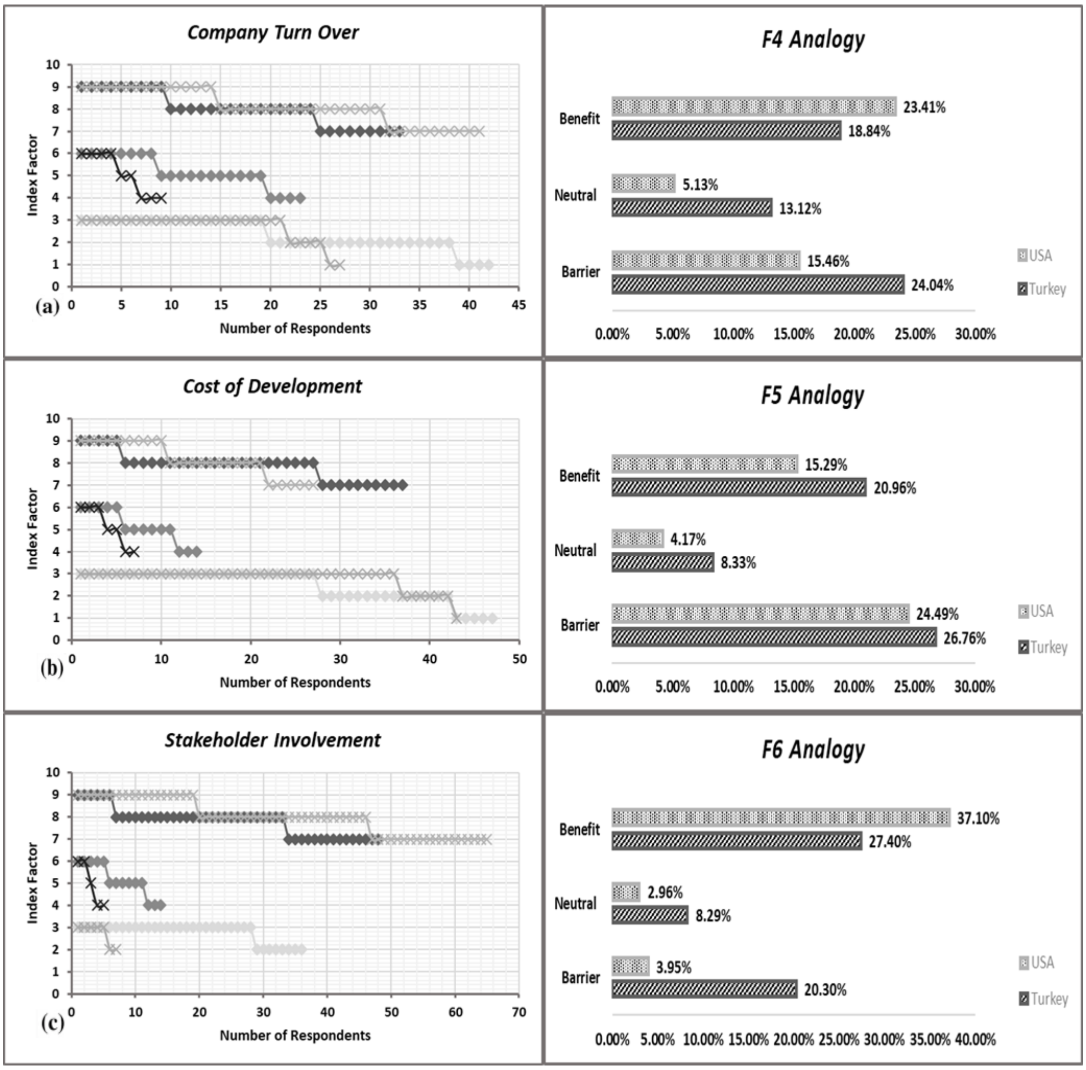


Figure 24: Financial related variables for I-BIM utilization

7.6 Managerial

In managerial aspect of I-BIM utilization, ten variables have been selected. According to the respondent opinion, BIM adoption for infrastructure projects has a positive impact on factors such as client requirements, coordination among project parties, project size and complexity, project quality management, project scheduling, and time management, Project life cycle cost and leadership and management supports as illustrated in Figure 25 and Figure 26. It’s notable to imply to relation between M1 and M2 with CR1, E3 and F6 variables which has been discussed in more details for all related factors of each case study in variables assembly section. Basically, it shows that these two managerial factors have strong link with collaboration in-between of all related parties and more specifically information sharing on I-BIM platform. This relation can lead any project to less conflicts, proper coordination and finest environments in order to fulfill all necessary requirements of project which has been asked by client. On the other hand, these relations will lead to most accurate financing of a project which has direct relation with M4 and M6 factor because it can avoid any possible cost and time overrun of a project which has effect on any potential conflict among parties including financial aspects.

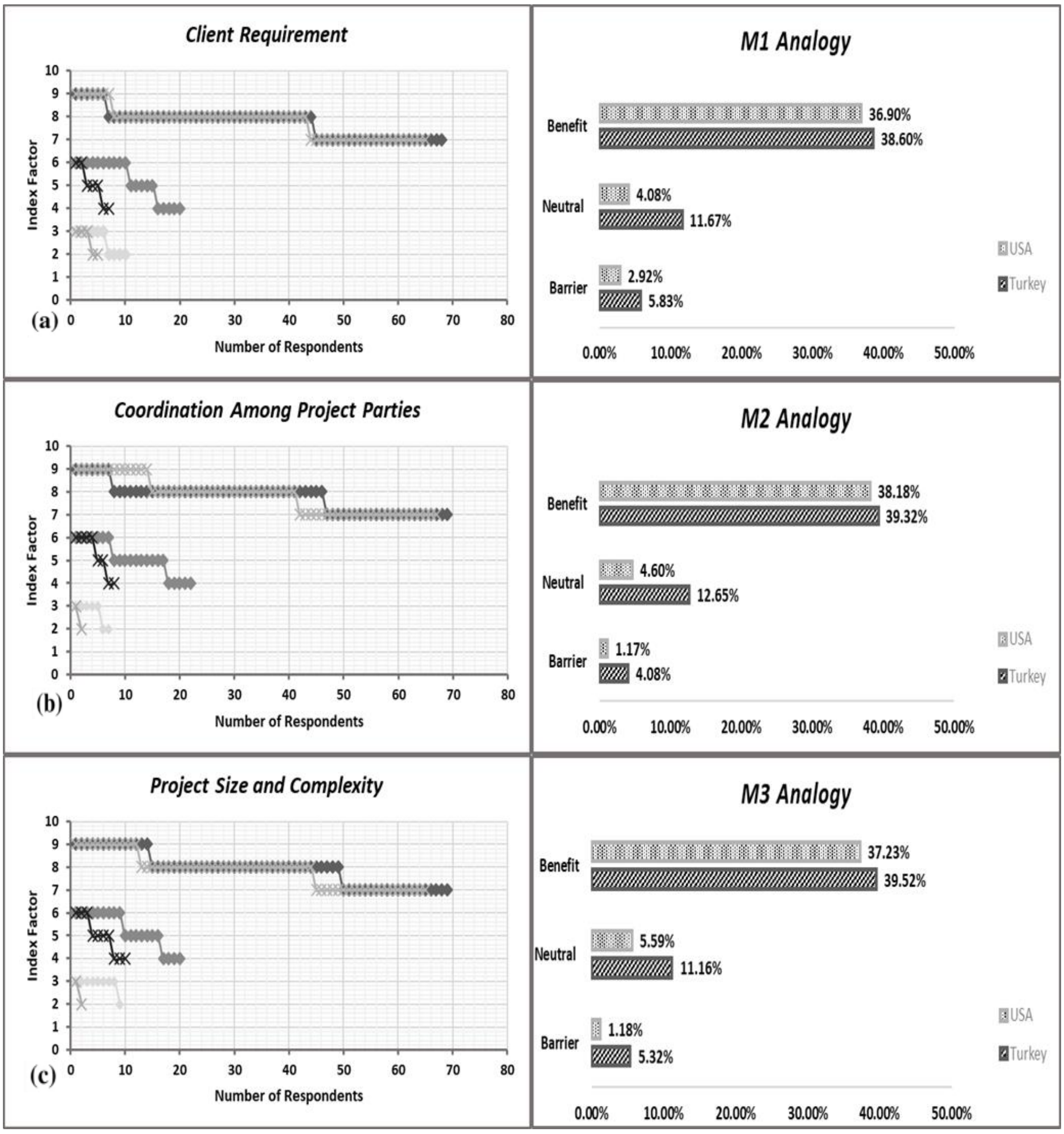


Figure 25: Managerial related variables for I-BIM utilization (Part 1)

One of the factors which need more concern in today's world is a social cost. Gilchrist and Allouche (2005) proposed it as a project contractual cost and comprised it as direct, indirect and social costs but in order to measure it for specific purposes, social cost has been grouped based on the area of impacts such as economic activity, pollution, traffic, and ecological/social/health.

According to the survey result, there is a strong belief about I-BIM assists on quantification of social cost in a more accurate way which it may lead the scholar to reach this purpose by using I-BIM in further work but this topic needs more concerns from all researchers around the world. Also, as variables M4 and M6 has been taken into consideration for BIM, there will be similar opportunity for I-BIM utilization as well since more than 90% of respondent were clarify these two factors as a benefit it which has been stated in Figure 26 (a) and (c).

One of the other important preliminarily aspects of any project is EIA reports of it which. The main purpose of using Environmental Impact Assessment is to safeguard the environment to make sure that the government when deciding whether to grant a project which may have critical impacts on the environment, does so in the full knowledge of the likely significant effects, and takes this into account in to the decision making the process. In this regards, I-BIM utilization can and will have a positive impact on EIA as it identified in Figure 27 (c) as a benefit by questionnaire responses.

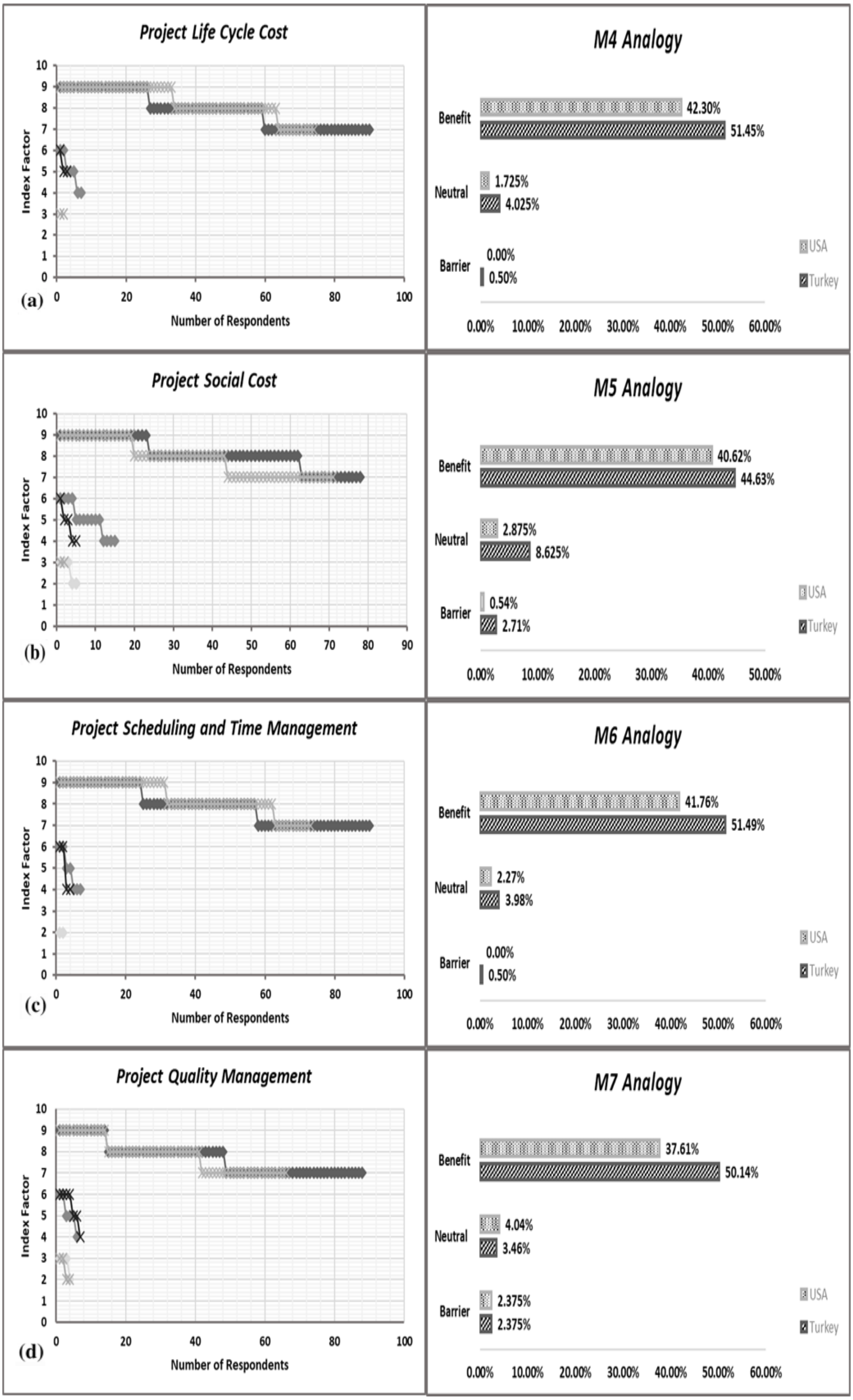


Figure 26: Managerial related variables for I-BIM utilization (Part 2)

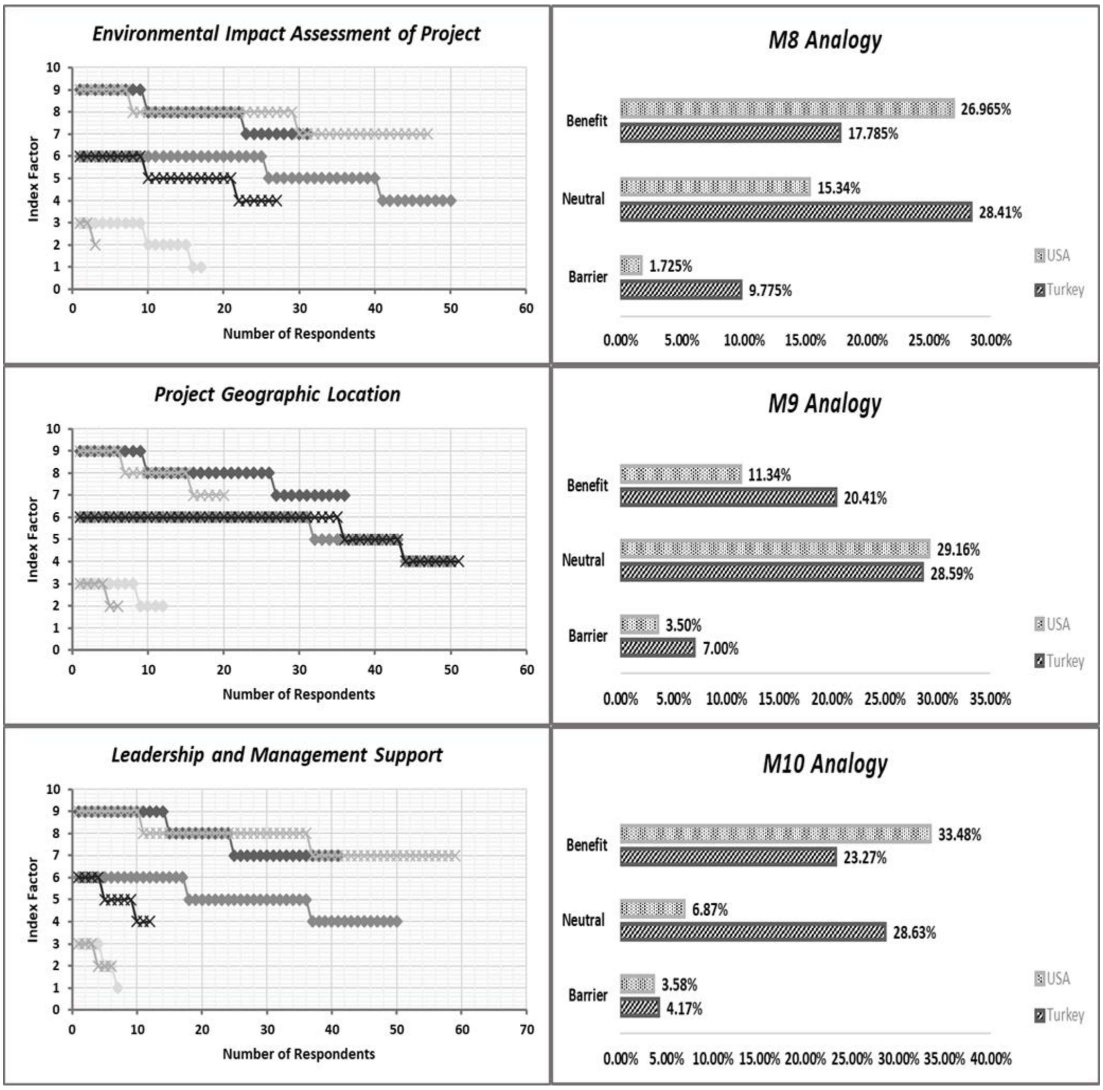


Figure 27: Managerial related variables for I-BIM utilization (Part 3)

7.7 Public Authority

Public Authority or more specifically, the governments, has a key role in the success of any nation in the path of developments. In this research, there have been three factors which have critical impacts on the success of I-BIM utilization. Every piece of information that a project owner may need about a facility throughout its life can be made available by using I-BIM as an information warehouse to produce an electronic version of any piece of documents.

The main barrier about this module is about the construction industry because it does not yet have the open standards and infrastructure to mine that information and collect it to organize it in most sufficient way and distribute it with all involved firms and companies. In May 2015, the latest edition of National BIM Standards of United States published and it contains nineteen reference standards, terms and definitions; nine information exchange standards; and eight practice guidelines to support users in their implementation of open BIM standards-based deliverables by national BIM standard of U.S. which is shown the fact of incomplete national standards as it stated for PA1 variables by Figure 28 (a).

In spite of mentioned barriers, the awareness level of the construction industry is growing by the help of academia and youth generation who are joining it. This fact can be supported by the relation between PA2 and E2 variables since both industry and academia need to have a clear understanding about all five categorize of I-BIM utilization. Moreover, this critical parameter is certainly playing an important role to merge conventional construction methods with I-BIM.

By completion of this merge, the construction industry will be led to new era which Owners, planners, realtors, appraisers, mortgage bankers, designers, engineers, estimators, specifiers, facility managers, safety engineers, occupational health providers, environmentalists, contractors, lawyers, contract officers, subcontractors, fabricators, code officials, operators, risk managers, renovators, first responders and demolition contractors all can benefit by having access to I-BIM.

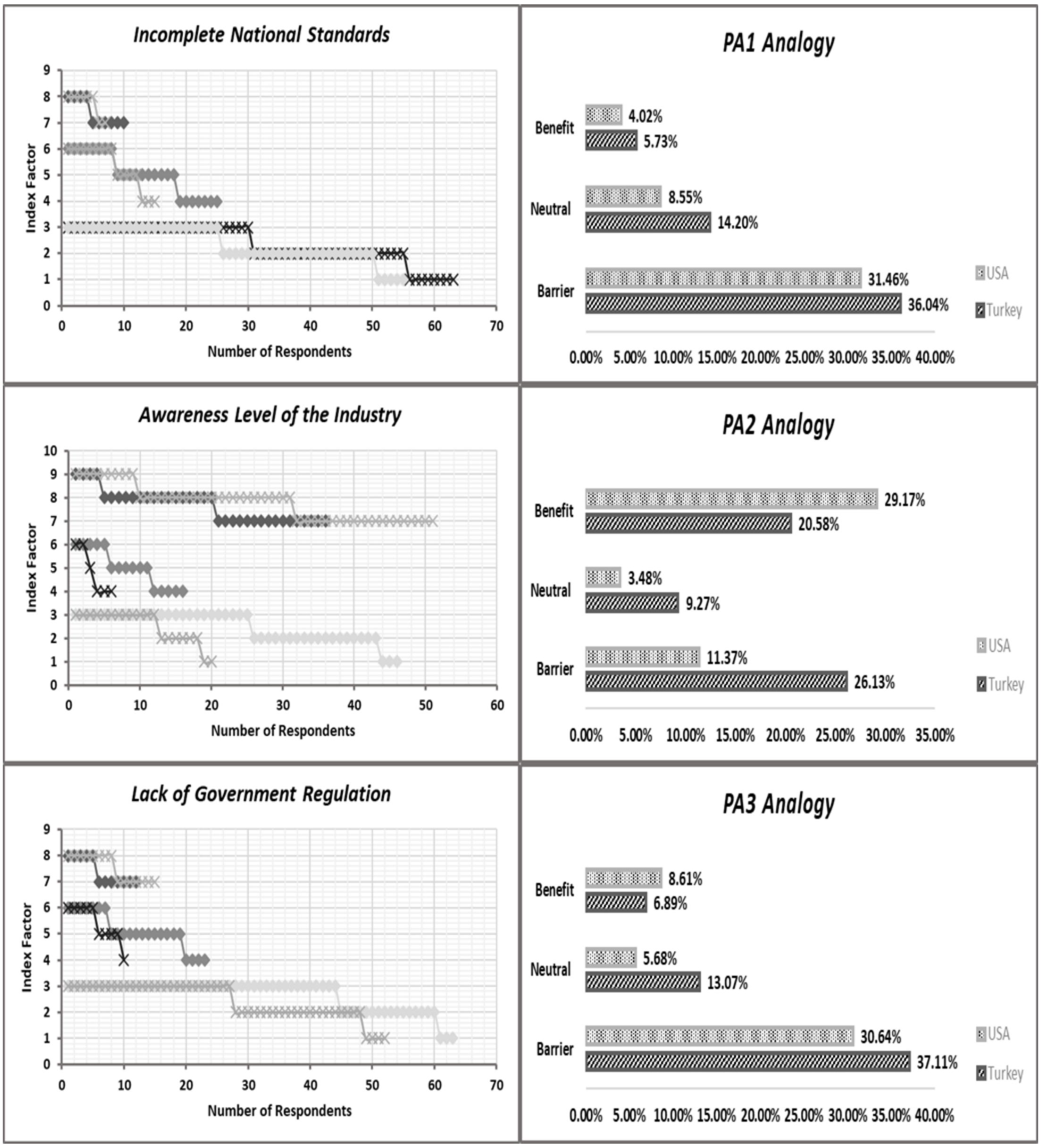


Figure 28: Public Authority related variables for I-BIM utilization

7.8 Variables Assembly

Relation of all discussed variables under each category is irrefutable. In order to prove these relations, correlation matrix for each country has been presented and Figure 29 shows it for Turkey and Figure 30 for United States of America. As it has been stated before, under the Contractual Relation category, CR1 and CR3 are considered as advantageous factors. Based on presented matrix, these two factors have a relevant relation to each other, E3 and most of the managerial factors. It is noteworthy to mention independency of CR1 variable from financial and public authorities' variables. Education, as a second category, has three independent variables. The relation among E1 and E2 proves the bond between educate of fresh engineers and lack of expert personnel. This fact can possibly lead the construction industry to compensate deficiency of educated staff for any construction project including infrastructure. On the other hand, E1 factor has a strong connection with financial and public authorities' variables. This relation can prove the role of government for both advance and third world country in order to increases awareness of industry and provide enough facilities to cover lack of regulation and standards. Therefore, this factor can lead any government to provide financial resources to support utilization of I-BIM on related projects to avoid any potential time and cost overrun for any type of infrastructure projects. It's significant to mention the independency of E3 from financial variables but conversely it has a strong link with all managerial variables including M2, M3 and M7 for both case study countries.

As respects of previous discussion, there is an interconnection between all financial variables except E4 and E6. This contradiction is a key factor to prove the importance role of stakeholders, especially in development countries. Because to gain an advantage from I-BIM in order to increase potential involved companies' turnover, the stakeholders' involvement is unavoidable. The next category is managerial variables with 10 significant factors, all related to nature of construction, time, cost, quality and labor collaboration. Environmental Impact Assessment of any project with a proper leadership and management through all team parties including government can lead any project to success and it can be defined accordingly on the way of I-BIM utilization based on correlation of M8, M9 and M10 with all other 23 variables, especially with CR2, E3, F6, M3 and PA2. It's noteworthy to mention that M1 to M7 variables are independent from financial and public authority variables. This fact proves that by utilization of I-BIM for infrastructure, any project can be delivered by time with the most adequate budget and parties without interfering of government or more specifically project's client. It is interesting to mention about solid link in-between of all Public Authority factors with financial variables. This irrefutable fact demonstrates the path on the way of I-BIM in order to untie knot of this issue, Therefore, all infrastructure project be able to gain enough benefit out of I-BIM.

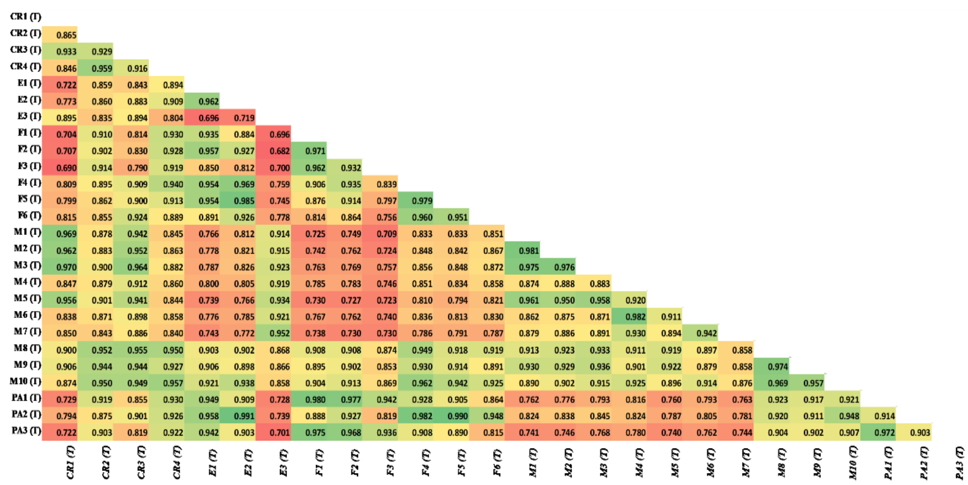


Figure 29: Correlation matrix of I-BIM variables for Turkey

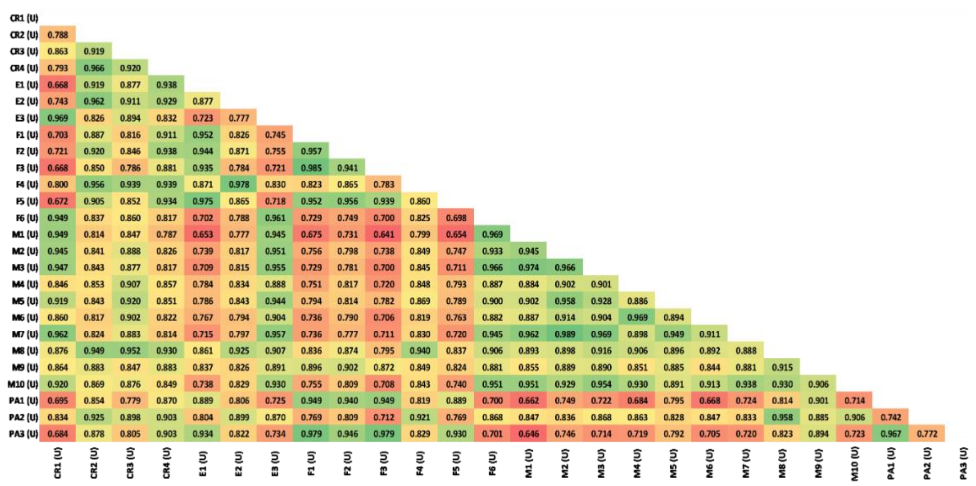


Figure 30: Correlation matrix of I-BIM variables for United States of America

Aforementioned relations are all proof of needs to establish a framework to be able to utilize BIM in infrastructure sectors which is going to be explained in following chapters with the respect of summery of I-BIM implementation components regarding to collected data through the respondents in both selected countries. This ranking has been shown in Table 10.

Table 10: I-BIM implementation components

Indicators	Variables	Mean Score	Ranking
CR1	Collaboration of different companies' staff for same project	7.109	9
CR2	Supportive contract form for I-BIM	6.161	13
CR3	Responsibility for inaccuracies	7.483	3
CR4	Appropriate insurance policy for project	6.005	16
E1	Availability of expert personnel	4.360	21
E2	Education awareness of academia	5.050	19
E3	Information sharing in I-BIM	7.441	5
F1	Initial cost of software	4.015	22
F2	Cost of implementation process	3.997	23
F3	Cost of training and education	3.879	24
F4	Company's turn over	5.387	18
F5	Cost of development	4.891	20
F6	Stakeholder involvement	6.452	12
M1	Client requirement	6.942	10
M2	Coordination among parties	7.110	8
M3	Project size and complexity	7.129	7
M4	Project life cycle cost	7.932	1
M5	Project social cost	7.473	4
M6	Project scheduling and time management	7.862	2
M7	Project quality	7.341	6
M8	Environmental impact assessment of project	6.144	14
M9	Project geographic location	6.006	15
M10	Leadership and management support	6.509	11
PA1	Incomplete national standard	3.489	26
PA2	Awareness level of the industry	5.488	17
PA3	Lack of government regulation	3.817	25

Chapter 8

IMPLEMENTATION OF META VARIABLES FOR THE DOMAIN COMPETENCY FRAMEWORK OF I-BIM

8.1 Introduction

The use of Infrastructure Building Information Modeling (I-BIM) is becoming more important in the construction of transport infrastructure. The aim of using I-BIM modeling is to enhance all stages of design, leading to cost reduction and control, and improving data awareness, design information availability, and usability throughout the life cycle of the infrastructure. While the benefits of advanced modeling of building components and systems are well-established, it is important to critically analyze whether the use of this design methodology in transportation infrastructure also produces the same advantages.

Due to its wide scope and the multiple interferences, it presents with the environment, infrastructure design is more complex than building design. As a result, accurate geo-referencing is crucial and may be accomplished by integrating I-BIM with Geographical Information Systems (GIS). This makes it possible to create a database that connects I-BIM parametric objects with graphical representations of geometric elements from GIS (dots, lines, and polygons) (walls, windows, and doors). As a result, this data is kept in a database, and I-BIM is able to manage any data changes needed over the project's lifespan (Teng, et.al., 2022).

As shown in Figure 31, the design or preconstruction, construction, and management phases of infrastructure projects are the three key phases in which I-BIM can be effective. The preconstruction phase also involves engineering analysis, project scheduling, material management, road planning, design, and site preparation. The I-BIM platform offers a means of simulating the loads necessary to guarantee the structural safety and serviceability. Construction stage activities include quality control, cost management, progress tracking, and construction inspections. After the project has been turned over to the customer, the management phase involves transportation management tasks, planned maintenance, system analysis, asset management, and an emergency plan.

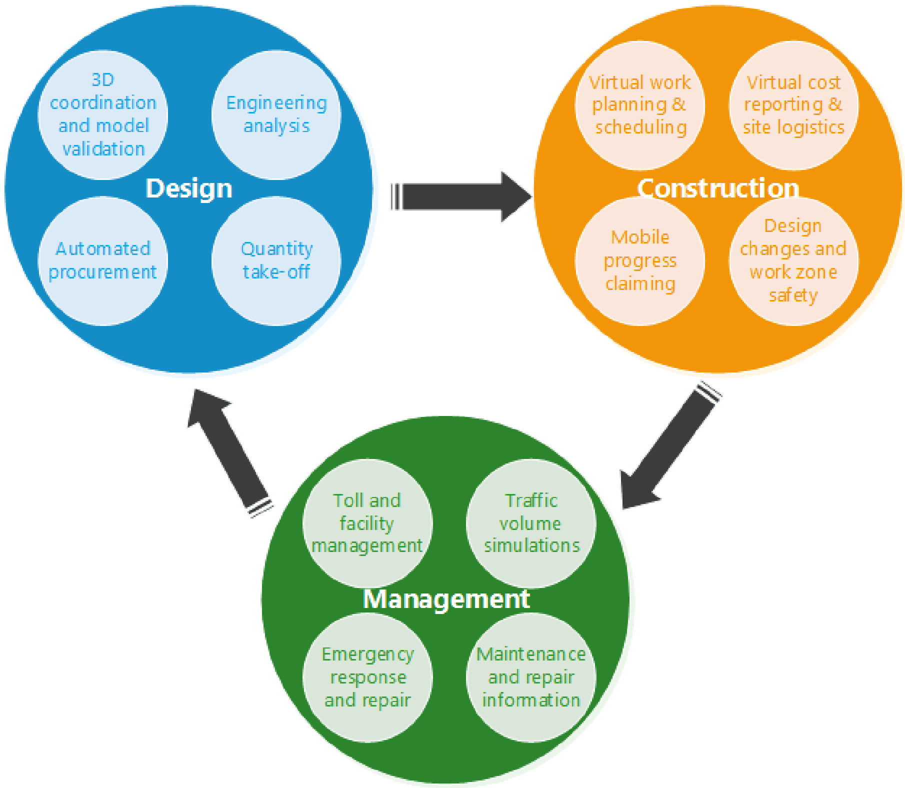


Figure 31: I-BIM uses throughout an infrastructure lifecycle

8.2 Meta Variables (Domain Competency)

According to previous discussion in chapters 2 and 5, a total of 26 variables have been selected under the five main categories. In the previous chapter, the relation among all these variables has been discussed comprehensively, but the gap still needs some improvement, even for the existing advantages. It is necessary to analysis and evaluate the condition of each variable among themselves and to be able to achieve this resolution the meta variable approach has been proposed as a domain competency section of proposed framework in Chapter 5.

The term "Meta Variable" can have slightly different meanings depending on the context but in general, a meta variable is a variable that stands for other variables or elements in a system. It allows for abstraction and generalization of concepts, and is often used in formal systems and mathematical notation to express complex ideas in a concise and precise way.

Therefore, in this research, each one of the main five categories has been named as a meta variable in accordance with their own individual variable that is going to stand for each single element within the concept of I-BIM framework. This analysis is going to help the author to simplify the calculation by making it in to only five meta variables in accordance with the effect of each individual sub meta variables. Figure 32 has been used to illustrate all I-BIM meta variable including the Meta Management, Meta Educational, Meta Financial, Meta Contractual Relations and Meta Public Authority.

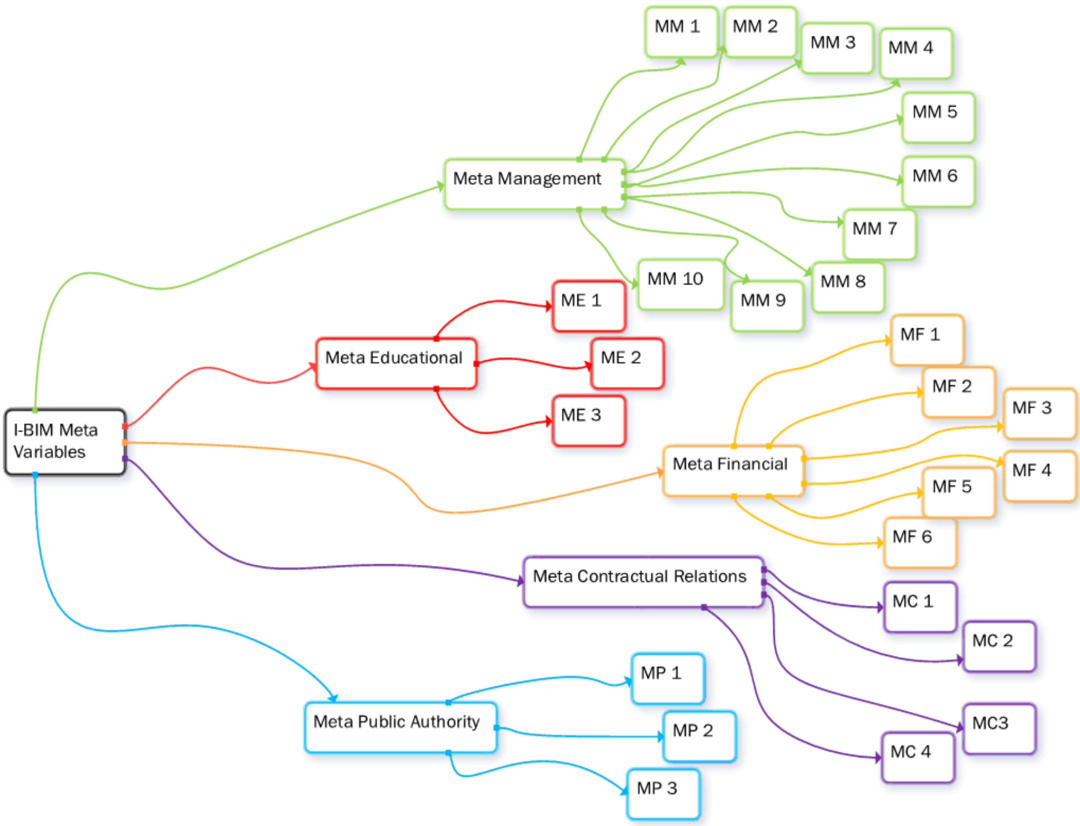


Figure 32: I-BIM meta variable

8.3 I-BIM Meta Variables of Turkey

8.3.1 I-BIM Meta Contractual Relations

One of the most crucial elements of any successful project is the agreements reached by all parties involved throughout the building of any facility. The use of BIM in the construction sector raised the degree of precision for all construction-related tasks. The total of four factors has been choose to be assessed along the I-BIM use path in this segment. In the respondents' perspective, the most significant and advantageous features of I-BIM, which is now being utilized by contractors and architectural firms on their projects, are responsibility for errors on project tasks and collaboration of workers from several companies on the same project. In these situations, every project participant has access to an online cloud system where they may create, change, and keep track of any tasks.

Figure 33 shows that the lack of regulations makes it impossible to avoid the uncertainty regarding MC2 and MC4, and even when taking into account MC3 variables as a benefit, which can direct any irresponsibility to the associated construction party, there are still additional tasks to be completed regarding planning logistics and administration. In addition, BIM enhanced the contractual relations sector of the construction industry by supporting better coordination among the firms collaborating in the same project. More than that, it helps to look into any errors at any point in a project and simply identify the person or group accountable for the mistake so that any component of a project can be readily controlled. Hopefully in the near future, the world's legal professionals will develop appropriate insurance policy for enterprises implementing BIM and I-BIM.

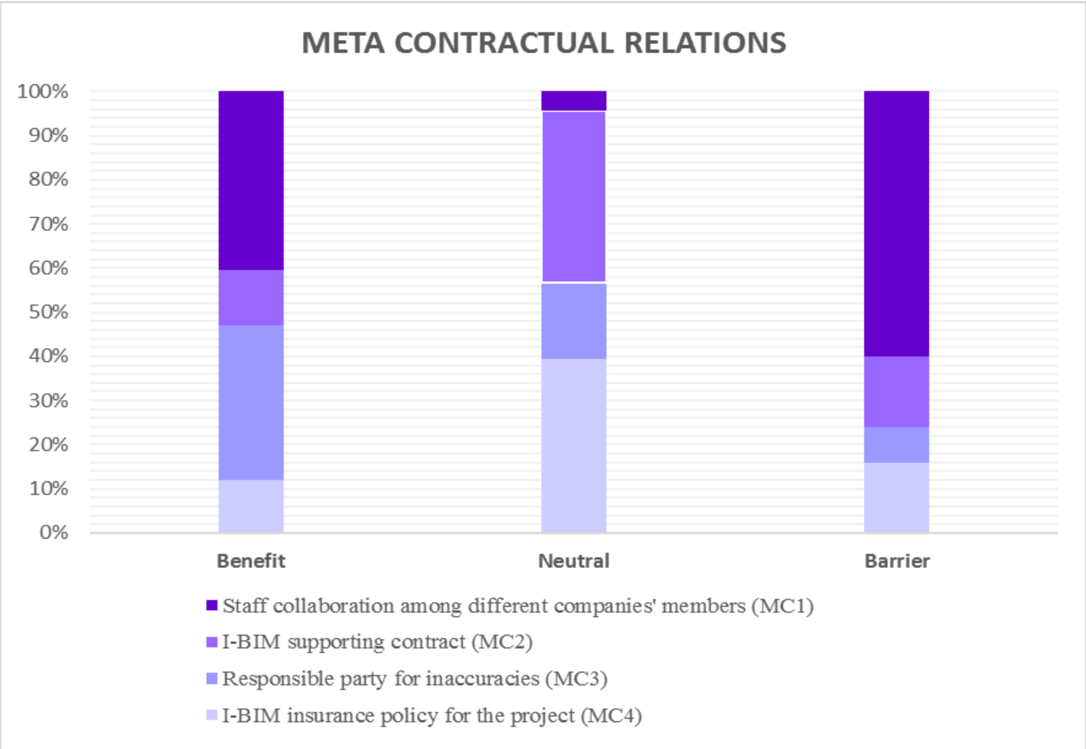


Figure 33: I-BIM Meta contractual relation variables (Turkey)

8.3.2 I-BIM Meta Educational

I-BIM and education run simultaneously while every new technology needs to be taught by professionals and acquired by apprentices to be more relevant. The responder believes that there is a global shortage of skilled labor, which raises the price of training and education. This is undoubtedly one of the biggest obstacles to the use of BIM in any industry, including infrastructure. Because I-BIM represents the future of the building industry, therefor industry and government must work together to implement it by altering university curriculum and holding workshops to raise awareness of it among all stakeholders involved. This will address the ME1 variable as it’s been illustrated in Figure 34.

One of the key educational variables that I-BIM affects is curriculum development. It requires a new set of skills and knowledge, and as a result, universities and other educational institutions have had to adapt their curriculums to meet the changing needs of the industry. This has involved introducing new courses and programs in I-BIM, as well as incorporating I-BIM into existing courses in architecture, engineering, and construction management. By doing so, educational institutions are helping to ensure that the next generation of construction professionals is equipped with the skills and knowledge they need to succeed in a rapidly changing industry. Figure 34 demonstrate how meta-educational variables can be used to determine the respondent's level of uncertainty about ME2.

Finally, I-BIM also has an impact on the professional development of construction professionals. By providing access to advanced technologies and information management systems, it enables professionals to enhance their skills and knowledge throughout their careers. This helps to ensure that they remain competitive in a rapidly changing industry, and that they are able to continue delivering high-quality construction projects which is one of the main benefits of I-BIM adoption as a meta education value.

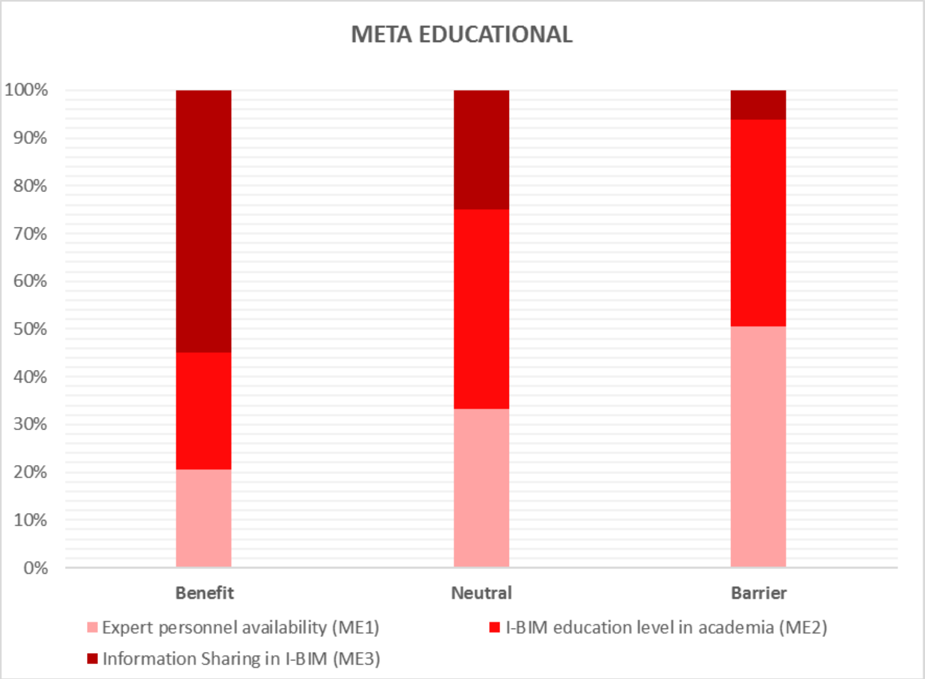


Figure 34: I-BIM meta contractual relation variables (Turkey)

8.3.3 I-BIM Meta Financial

Training is one of the most crucial investments for a successful I-BIM implementation, and Figure 35 reveals how it has been the biggest hurdle to I-BIM development. The study's findings show that respondents identified MF3 as a significant issue, and businesses are endeavoring to address this issue by increasing staff training. I-BIM adoption has been classified as having a second financial barrier due to the initial expense of the I-BIM software. Since one of the primary causes of any expanded product might be the absence of customers or consumers, which led to a high cost of production to meet the costs, this parameter indirectly identifies the number of I-BIM users in the construction industry sector.

One of the other key financial variables that I-BIM affects is project cost management. By providing detailed and accurate information about the building design, structure, and systems, I-BIM enables stakeholders to better understand the costs associated with different options and make informed decisions about how to allocate resources as it has been determined in MF4 and MF6 variables. This leads to improved cost predictability and greater control over project budgets, reducing the risk of cost overruns and improving profitability. Another financial variable that BIM influences is project financing. BIM provides lenders and investors with increased visibility into the project, enabling them to assess the risk associated with the project and make informed decisions about funding.

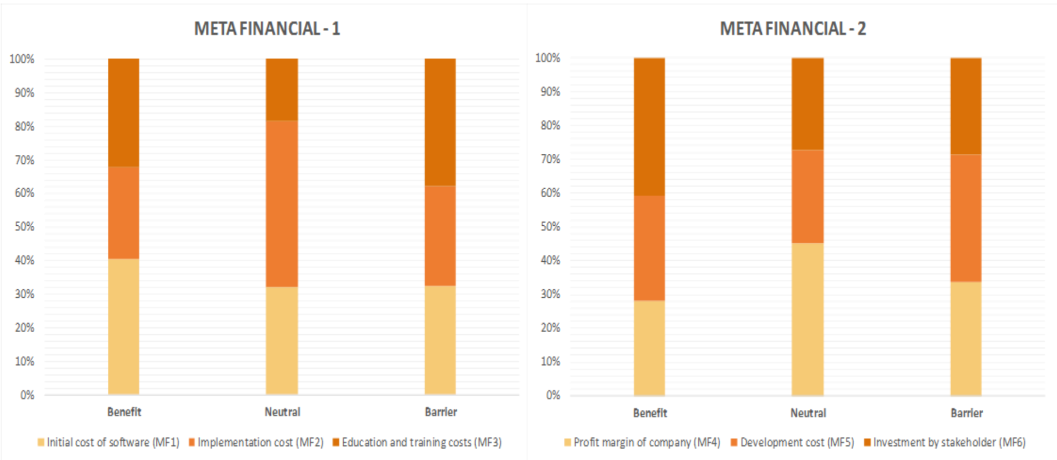


Figure 35: I-BIM meta financial variables (Turkey)

8.3.4 I-BIM Meta Management

One of the key managerial variables that I-BIM affects is communication and collaboration (MM2). As the respondents stated in Figure 36, It provides a common platform for all stakeholders to access and share information, reducing the risk of misunderstandings and ensuring that all parties have the same understanding of the project. This improved collaboration leads to faster decision-making and more efficient use of resources, reducing the overall duration of the project and improving its quality.

Cost control and predictability are two important managerial variables that are positively impacted by I-BIM. By providing detailed and accurate information about the building design, structure, and systems, BIM enables stakeholders to better understand the costs associated with different options and make informed decisions about how to allocate resources. This leads to improved cost predictability and greater control over project budgets, reducing the risk of cost overruns and improving profitability.

I-BIM also has an impact on the negotiation of contracts and project delivery method. It provides stakeholders with a greater understanding of the project, enabling them to negotiate contracts that are fair and equitable for all parties. It also enables the use of alternative project delivery methods, such as integrated project delivery and public-private partnerships, which can improve the overall efficiency and effectiveness of the project.

Finally, I-BIM has an effect on environmental performance and sustainability. It gives stakeholders a platform to evaluate the environmental effects of various design solutions, empowering them to make better educated choices about how to lessen the building's environmental impact. It also offers useful data on a building's energy efficiency, enabling stakeholders to improve the design to cut down on energy use and carbon emissions.

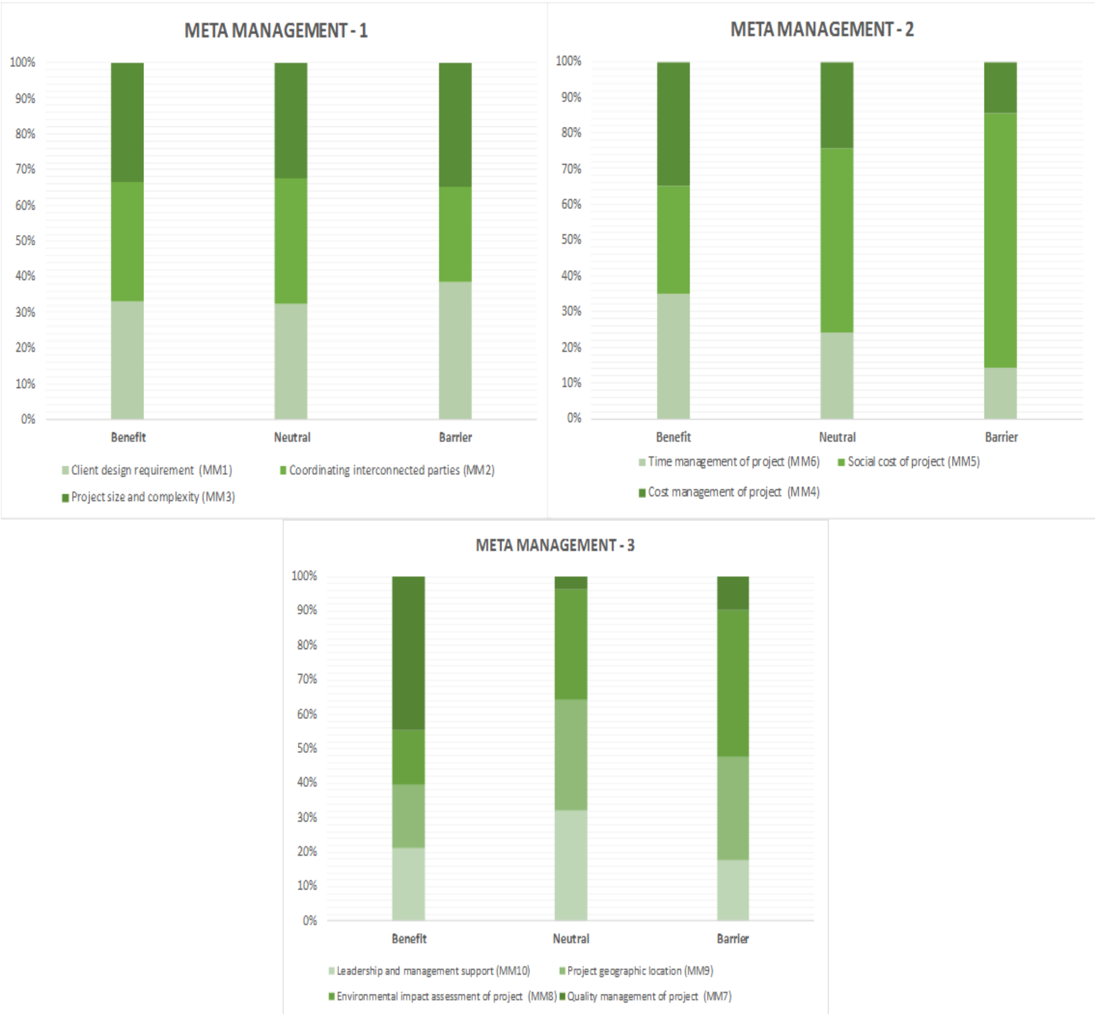


Figure 36: I-BIM meta management variables (Turkey)

8.3.5 I-BIM Meta Public Authority

The success of any country on its pathway to growth depends heavily on public authority, or more precisely, the governments. Three criteria have been shown to have a significant influence on how to utilize I-BIM in this research. I-BIM can be implemented as an information warehouse to generate a digital version of every piece of documentation, making it possible to provide any kind of data a project owner would want about a building throughout its lifetime. According to Figure 37, the primary obstacle to this module is the lack of open standards and infrastructure in the construction sector (MP1) that would enable it to mine that data, gather it, arrange it in the most effective manner, and disseminate it to all the businesses and corporations involved.

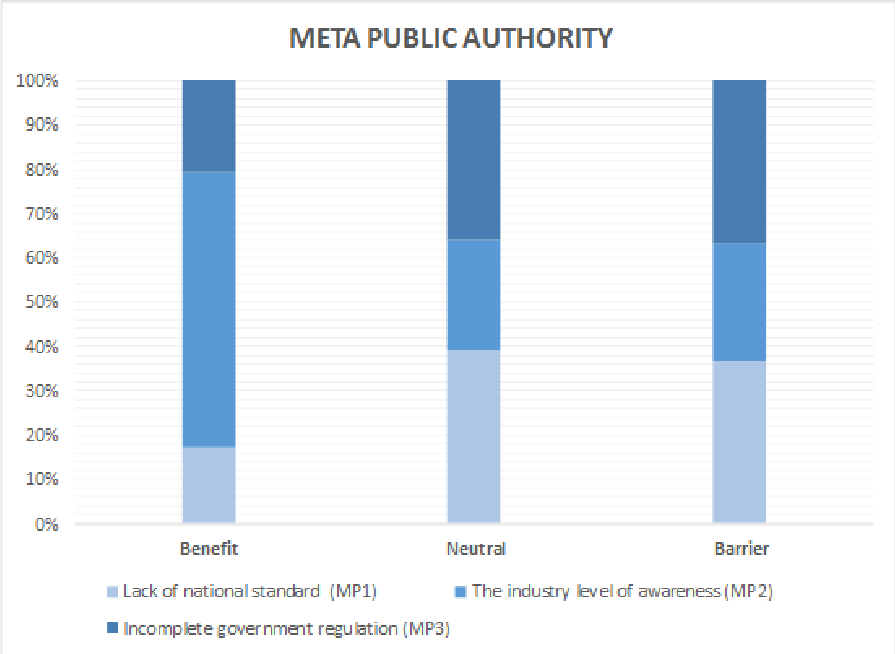


Figure 37: I-BIM meta public authority variables (Turkey)

The legislative environment and incomplete regulation (MP3) is one of the key factors influencing jurisdiction relationships that I-BIM affects. It gives public authorities access to a variety of building-related data, allowing them to decide on building standards and regulations in an educated manner. As a result, the regulatory process becomes more effective and efficient, improving compliance and lowering the likelihood of legal issues and conflicts. By providing a transparent and auditable record of the building and its adherence to rules, I-BIM also aids in enhancing transparency and accountability in the regulatory process.

8.3.6 I-BIM Meta Variables Classification

It will be critical to investigate all meta variables of I-BIM utilization at the same time in order to conclude their relationship, create a more practical path for its implementation, and gradually move closer to a more advanced framework that will be adoptable by all firms worldwide. Figure 38 has been illustrated in order to conduct this investigation with more detail. The first thing that becomes clear from Figure 39 is that the Meta Managerial (MM) is the strongest category of meta variables because, as previously noted, it has a favorable influence on infrastructure quality management (MM10), cost management (MM4), and time management (MM6). On the other hand, as both have been identified as barriers to the implementation of I-BIM in better suited systems, Meta Financial (MF) and Meta Public Authority (MP) are at the same level and both require considerable development. It's important to note that according to Table 11 there were 588 total responses for MF and 294 for MP. The total number of sub-meta variables in each category explains this variation. Furthermore, Meta Contractual (MC) is the most uncertain meta variable, as 46.42% of respondents don't comprehend how it would affect I-BIM, even though 185 answers considered it a benefit, which is about 47.20%. Last but not least, Meta Educational (ME), which received 39.12%, demonstrates the necessity for advancement in a variety of areas, including curriculum development, which raises the overall number of specialists.

The author chooses to analyze the I-BIM characteristics at three distinct levels in order to further data mining. In first level, each meta variable has been examined independently and in accordance with the Total Number of Meta Variable (TNMV), as it was shown in the previous figures and summarized in Table 11. This value has been found according to the total number of sub meta variables. ME and MP both have TNMV-1 values of 294 because, as illustrated in Figure 32, these two meta variables each include a total of three sub meta variables and determined independently according to the individual number of TNMV-1 for benefit/neutral/barrier as it’s been shown for each meta variables in Figure 38.

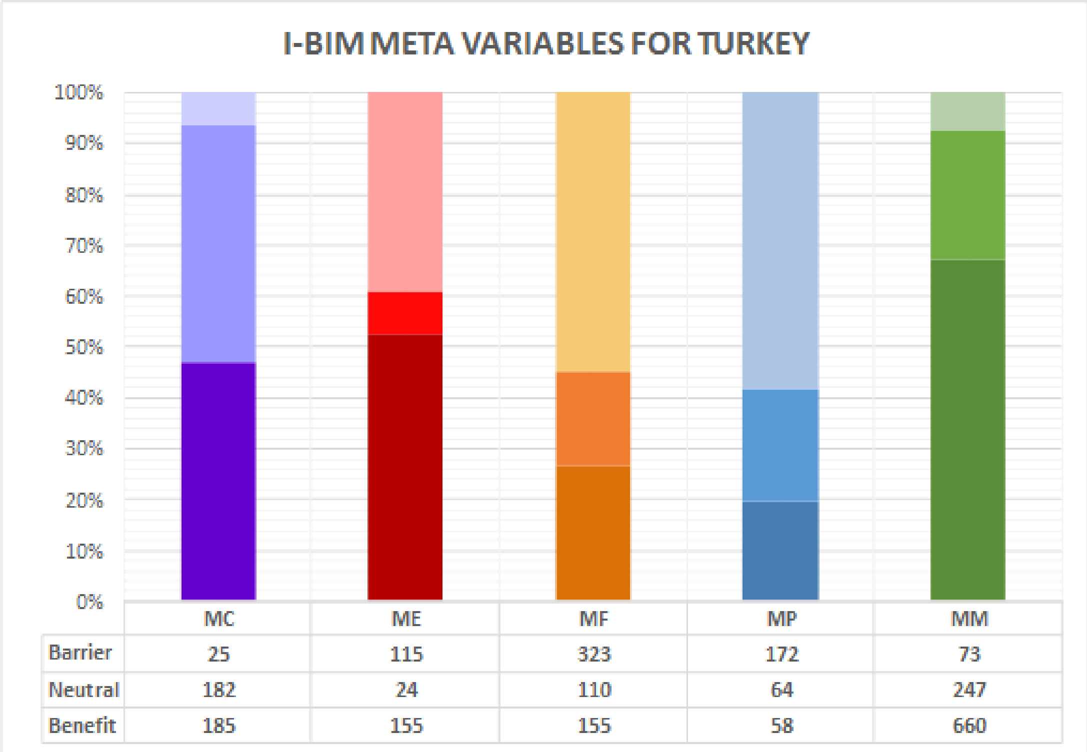


Figure 38: I-BIM meta variables for Turkey – detailed comparison

Table 11: I-BIM data mining of each individual meta variables

Meta Variables	Benefit	Neutral	Barrier	I-BIM TNMV-1	Percentage
MC	47.20	46,42	6,38	392	100
ME	52.72	8,16	39,12	294	100
MF	26.36	18,70	54,94	588	100
MP	19.73	21,77	58,50	294	100
MM	67.35	25,20	7,45	980	100

Second level of data mining has been presented in Table 12. In this table the total number of benefit/neutral/barrier has been considered as the category of analysis to examine the state of meta variables in more detail. For instance, MC has been discovered to be one of the level's second-highest perks, although it was ranked third in level one. The individual TNMV-1 values of these meta variables are the cause of this variation, and since the analysis at the second level was done using the TNMV-2, the findings are different in certain situations.

Table 12: I-BIM data mining among each individual category using meta variables values

Meta Variables	**Benefit**	**Neutral**	**Barrier**
MC	15.25	29,03	3,53
ME	12,77	3,83	16,24
MF	12,77	17,54	45,63
MP	4,78	10,21	24,29
MM	54,43	39,39	10,31
Percentage	100	100	100
I-BIM TNMV-2	1213	627	708

The last and third level of I-BIM data mining has been reflected in Table 13. The analytical result was produced using TNMV-3, and each individual total number of benefit/neutral/barrier for each meta variable was taken into account independently in this set of data. The total number of sub-meta variables and the I-BIM TNMV-3 value are used in this analysis to determine an accurate weight for each meta variable. For instance, the difference between the MF and MP as a barrier was one of the most significant outcomes of this level of study since, although it was just 3.56% in level one, it now stands at 5.92%, representing a 60% increase over level one. This demonstrates that since the TNMV-3 has been implemented, the findings at the third level of I-BIM data mining are more accurate and reliable than the other two levels as it has been illustrated in Figure 38 with respect to the applied TNMV values in each level. Notably, all value is expressed as a percentage.

Table 13: I-BIM data mining among each individual category using meta variables values

Meta Variables	Benefit	Neutral	Barrier	Total
MC	7.26	7.14	0.98	15,38
ME	6.08	0.94	4.52	11,54
MF	6.08	4.32	12.67	23,07
MP	2.28	2.51	6.75	11,54
MM	25. 90	9.69	2.87	38,46
I-BIM TNMV-3	-	-	-	2548

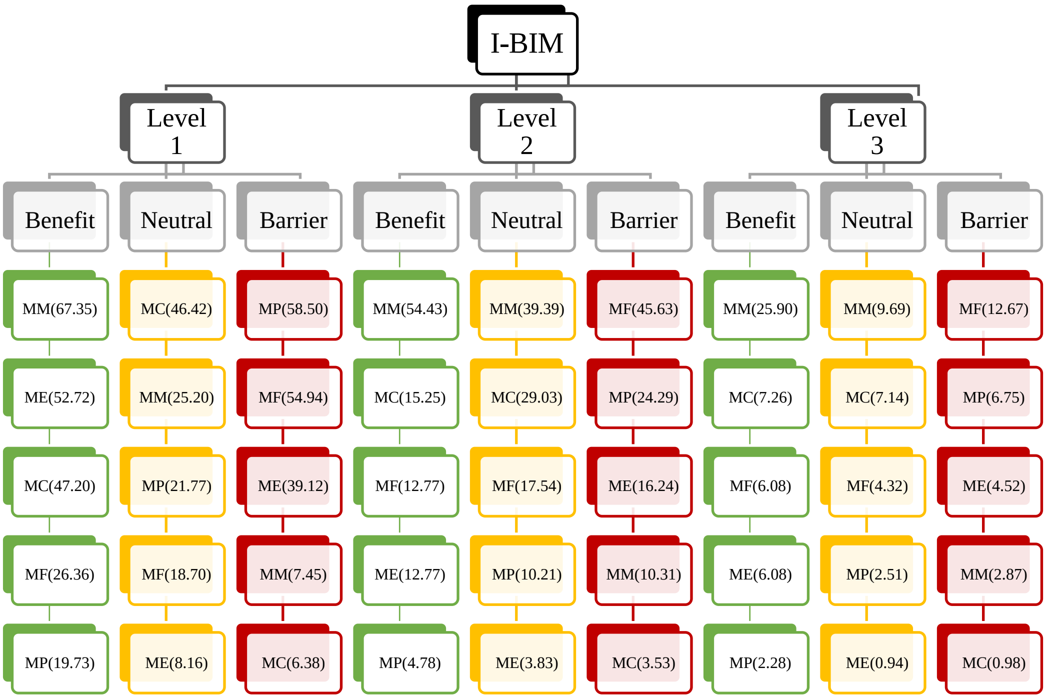


Figure 39: I-BIM meta variables for Turkey – detailed comparison

8.4 I-BIM Meta Variables of the United States of America

8.4.1 I-BIM Meta Contractual Relations

The agreement obtained by all parties involved during the construction of any facility is one of the most important aspects of any successful project. The level of precision for all jobs relating to building has increased thanks to the usage of BIM. The I-BIM usage route in this section was evaluated with regard to selection of four parameters.

The accountability for errors on project tasks and the participation of employees from many organizations on the same project are, in the respondents' opinion, the most important and desirable characteristics of I-BIM, which is being used by contractors and architectural firms on their projects. In these scenarios, every project member has access to an online cloud system where they may create, modify, and maintain any tasks.

Figure 40 demonstrates how the absence of regulations makes it impossible to avoid the uncertainty surrounding MC2 and MC4, and even when considering MC3 variables as a benefit, which can direct any negligence to the associated construction party, there are still additional tasks to be completed regarding planning logistics and administration. Additionally, BIM improved contractual ties in the construction business by fostering greater coordination between the companies working together on a same project. More than that, it is beneficial to investigate any mistakes made at any stage of a project and to easily pinpoint the individual or group responsible for the fault so that any part of the project may be easily handled, therefore, the main barrier of I-BIM utilization in this meta category has been resulted as MC1.

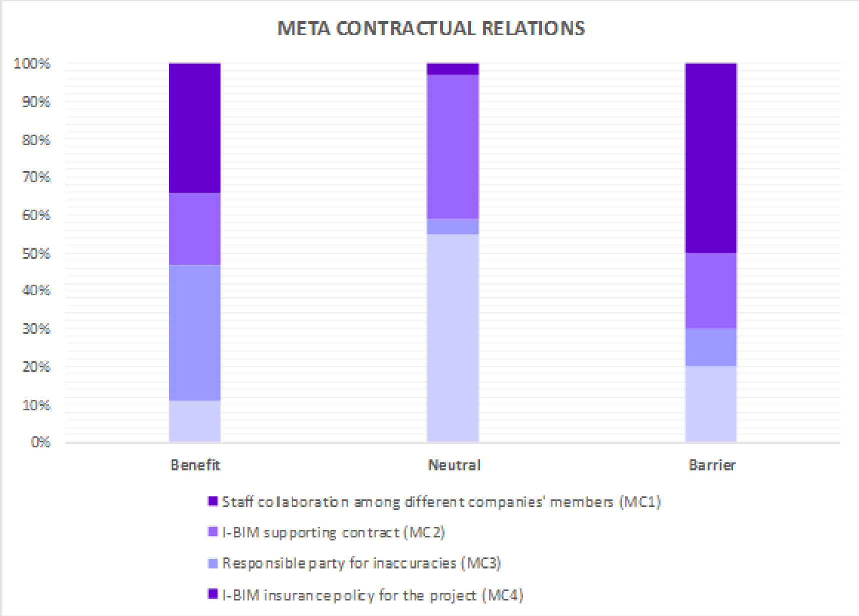


Figure 40: I-BIM meta contractual relation variables (United States of America)

8.4.2 I-BIM Meta Educational

I-BIM and education coexist, despite the fact that apprentices have to investigate every new technology and be taught by experts in order for it to be more useful. According to the respondent, the cost of training and education is rising due to a lack of trained personnel over United States of America. In every industry, including infrastructure, this is without a doubt one of the major barriers to using BIM. I-BIM represents the future of the construction sector, thus professional and government must collaborate to put it into practice by changing the curriculum at universities and hosting workshops to educate all relevant parties. According to Figure 41, this will handle the ME1 variable.

Curriculum development is one of the major educational factors that I-BIM influences. Universities and other educational institutions have had to modify their educational programs to match the evolving requirements of the business since it necessitates a new set of skills and knowledge. In order to do this, new I-BIM courses and programs have been developed, and I-BIM has also been integrated into already-existing courses in architecture, engineering, and construction management. The next generation of construction professionals will be better prepared to compete in a sector that is changing quickly thanks to the efforts of educational institutions. Figure 41 demonstrates how to utilize meta-educational factors to determine a respondent's level of doubt regarding ME2.

I-BIM also has an effect on how construction workers advance their careers. It helps professionals to upgrade their skills and knowledge throughout their careers by giving them access to innovative technology and information management systems. One of the key advantages of I-BIM adoption as a meta education value is that it helps to guarantee that they are able to continue providing high-quality building projects while also being competitive in a sector that is changing constantly and significantly.

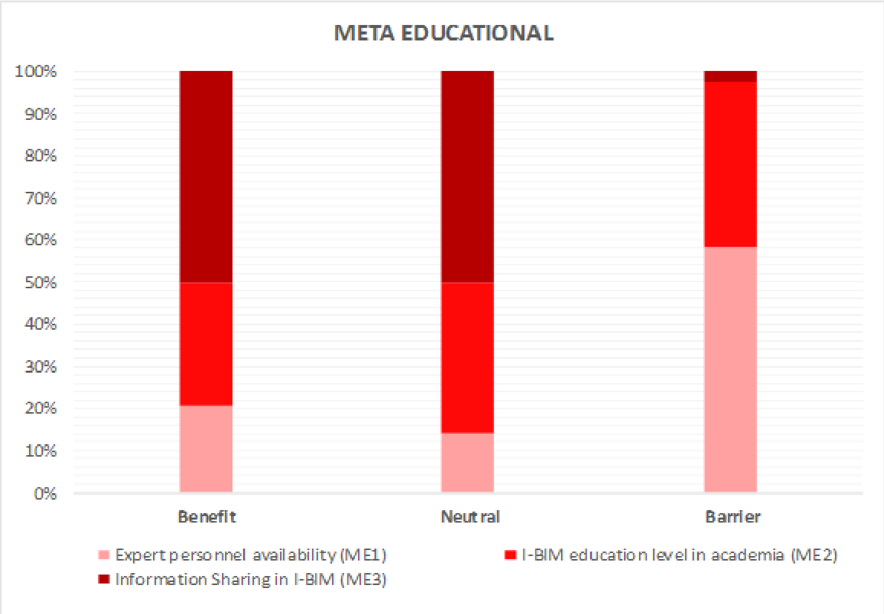


Figure 41: I-BIM meta contractual relation variables (United States of America)

8.4.3 I-BIM Meta Financial

Figure 42 demonstrates how training has been the main barrier to I-BIM development and why it is one of the most important investments for a successful I-BIM deployment. The study's results demonstrate that respondents recognized MF3 as a big challenge, and firms are making an effort to deal with it by boosting employee training. Due to the initial cost of the I-BIM software, it has been determined that there is a second financial barrier to I-BIM adoption. This parameter inadvertently indicates the number of I-BIM users in the building industry sector since one of the main causes of any enlarged product might be the lack of clients or consumers, which led to a high cost of production to match the costs.

Project cost management is another important monetary factor that I-BIM influences. I-BIM allows stakeholders to better understand the costs associated with various options and make informed decisions about how to allocate resources as it has been determined in MF4 and MF6 variables by providing detailed and accurate information about the building design, structure, and systems. As a result, project budgets are better managed and costs are more predictable, lowering the chance of cost overruns and boosting profitability. Project funding is another monetary factor impacted by BIM. Having more information about the project thanks to BIM gives lenders and investors the ability to evaluate the risk involved and decide on funding.

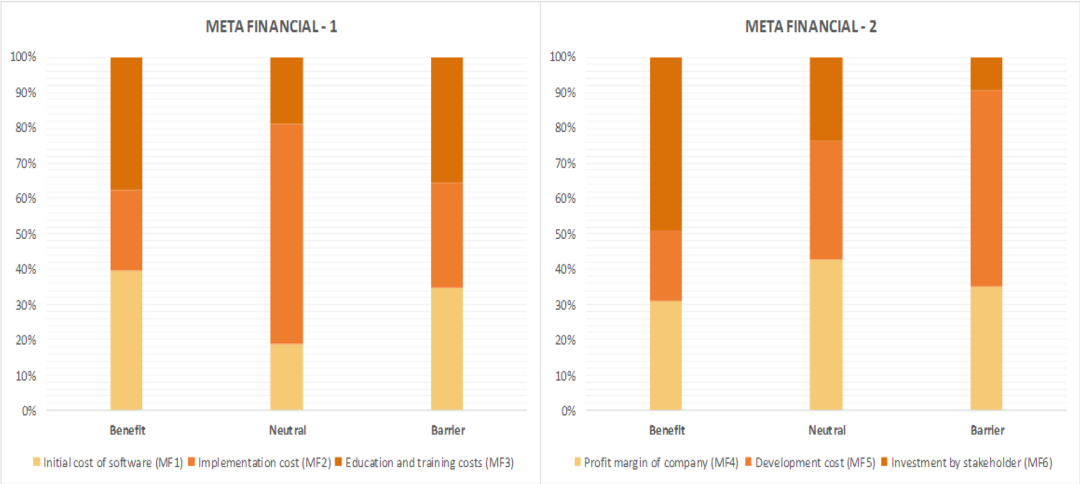


Figure 42: I-BIM meta financial variables (United States of America)

8.4.4 I-BIM Meta Management

The managerial variable of communication and cooperation (MM2) is one of the main ones that I-BIM influences. It offers a shared platform for all stakeholders to access and exchange information, minimizing the probability of miscommunication and ensure that everyone is on the same page with regard to the project, as mentioned by the respondents in Figure 43. Because of the better cooperation, decisions are made more quickly and resources are used more effectively, shortening project time and raising project quality.

I-BIM also affects contract negotiations and how projects are delivered. Stakeholders can develop contracts that are just and equitable for all parties since it gives them an improved understanding of the project. Additionally, it makes it possible to apply alternate project delivery strategies like integrated project delivery and public-private partnerships, which can increase the project's general efficacy and efficiency.

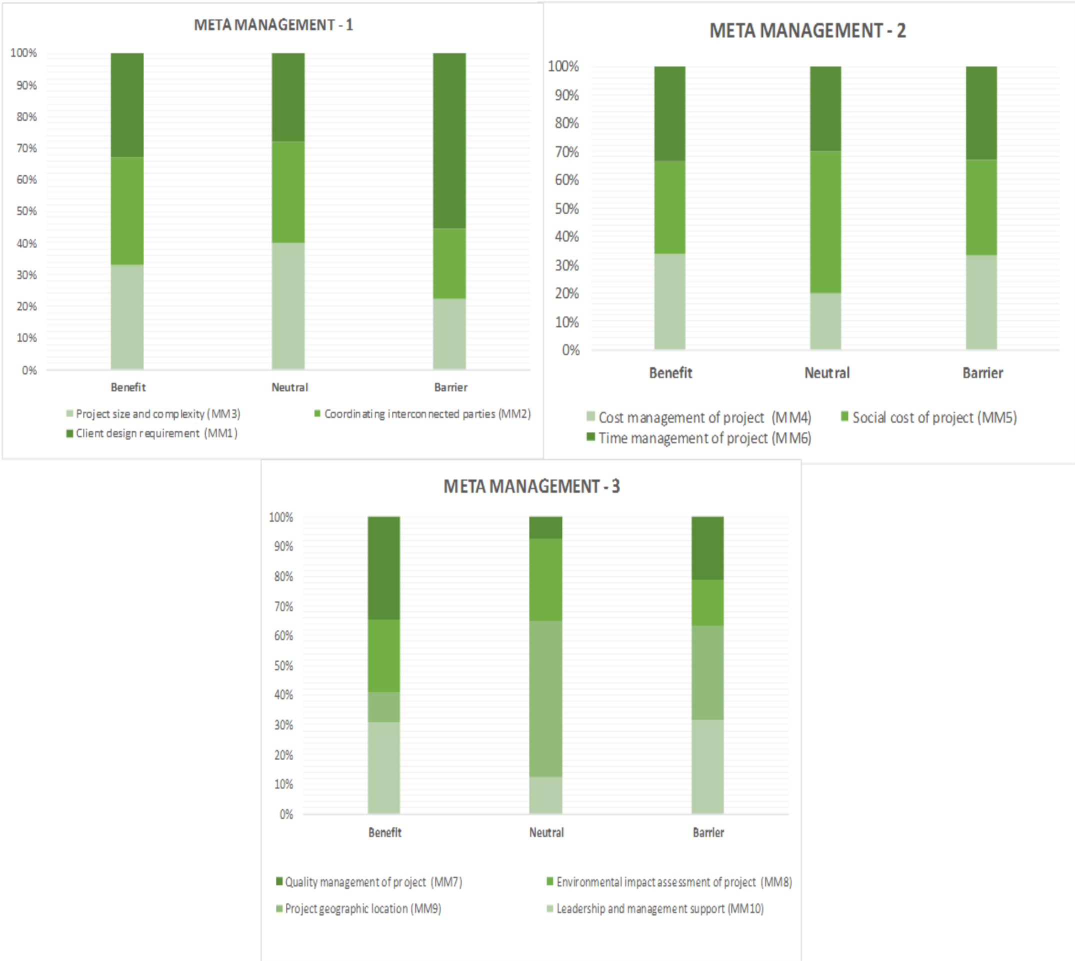


Figure 43: I-BIM meta management variables (United States of America)

I-BIM has a good effect on two significant managerial variables: cost management and predictability. BIM helps stakeholders to more clearly comprehend the costs associated with various choices and make wise resource allocation decisions by supplying comprehensive and accurate data on the building's design, structure, and infrastructure systems. As a result, project budgets are better managed and cost predictability is increased, lowering the possibility of cost overruns and boosting profitability.

The performance and sustainability of the environment are impacted by I-BIM. It provides stakeholders with a platform to assess the environmental impacts of various design options, enabling them to make more informed decisions about how to reduce the building's environmental impact. Additionally, it provides insightful information on a building's energy efficiency, allowing stakeholders to enhance the design to reduce energy consumption and carbon emissions.

8.4.5 I-BIM Meta Public Authority

Any nation's growth-related success is primarily reliant on public authority, or more specifically, the governments. In this study, it was discovered that three factors significantly affect how I-BIM should be used. I-BIM may be used as an information warehouse to create digital versions of all paperwork, enabling project owners to access any type of information they need about a building at any time. The lack of open standards and infrastructure in the construction industry (MP1), which would allow it to mine that data, aggregate it, organize it in the most efficient way, and distribute it to all enterprises and organizations, is shown in Figure 44 as the main barrier to this module's success.

One of the main variables impacting authority relationships that I-BIM impacts is the legislative environment and insufficient regulation (MP3). It provides public authorities with access to a range of building-related data, enabling them to make informed decisions on building regulations and standards. As a result, compliance improves, legal concerns are less likely to arise, and the regulatory process is more effective and efficient. I-BIM also contributes to improving accountability and transparency in the regulatory process by offering an accurate and auditable record of the building and its conformance to regulations.

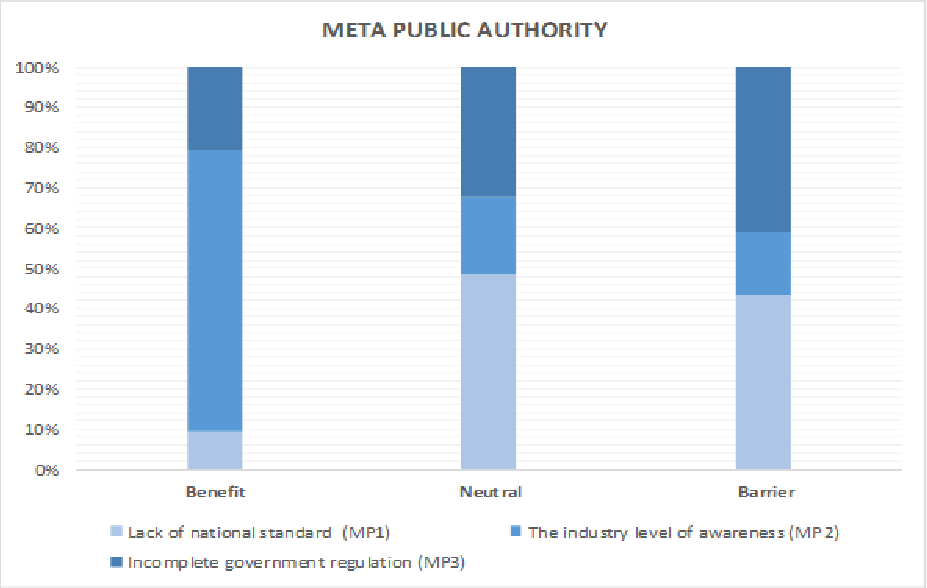


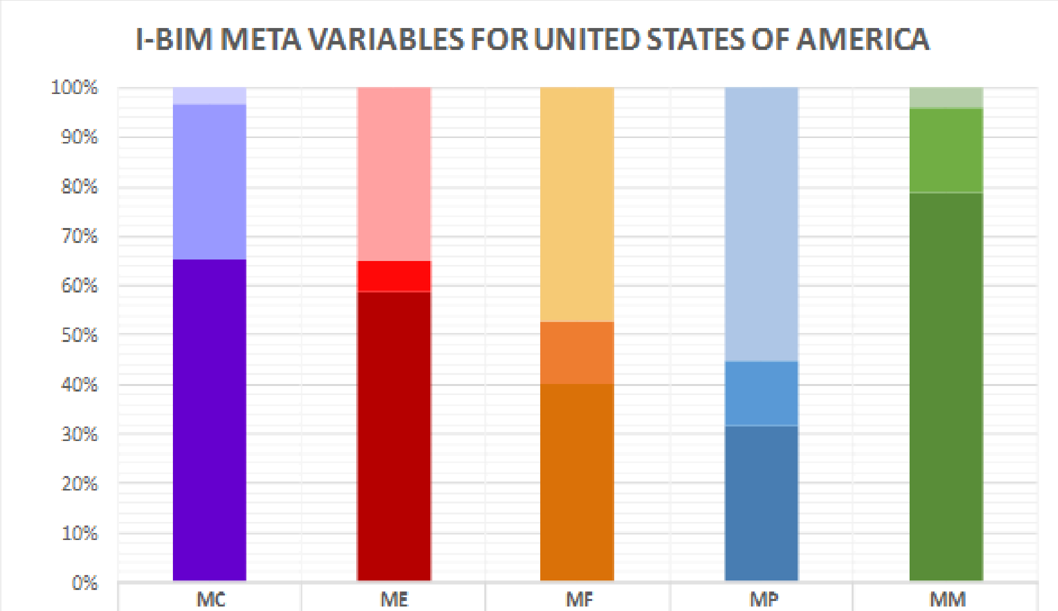
Figure 44: I-BIM meta public authority variables (United States of America)

8.4.6 I-BIM Meta Variables Classification

It will be crucial to analyze all I-BIM utilization meta variables at once in order to come to conclusions about their relationships, develop a more feasible plan for its implementation, and gradually get closer to a more sophisticated framework that will be adopted by all businesses across the world. To carry out this inquiry in further detail, Figure 45 has been presented. The first conclusion drawn from Figure 46 is that the Meta Managerial (MM) category of meta variables is the most powerful one since, as already said, it has a positive impact on infrastructure life cycle cost of project (MM4), social cost of project (MM5), and scheduling and time management (MM6). In overall, this meta variable has been faced by 11.5% raised compare to what has been concluded in Turkey.

Meta Financial (MF) and Meta Public Authority (MP), on the other hand, are both at the same level and need a lot of work since both have been highlighted as obstacles to the deployment of I-BIM in better suited systems. It's important to note that according to Table 14. there were 462 total responses for MF and 231 for MP. The total number of sub-meta variables in each category explains this variation. It is noteworthy to mention that the MF total results as barrier have been decreased for more than 7.5% but for MP, 55% of respondent believe that there are concerns about issues such as lack of regulation or national and international standards.

Furthermore, Meta Contractual (MC) is the most uncertain meta variable, as 31.49%, which it has been reduced 15% from what Turkey is experiencing according to Table 11. It is noteworthy to mention that in the United States of America people consider MC as the second highest important meta variable with more than 18% rise compare to Turkey. Last but not least, Meta Educational (ME), which received 58.87%, demonstrates the necessity for advancement in a variety of areas, including curriculum development, which raises the overall number of specialists and in the United States of America they are clearly ahead of education system in turkey regarding the BIM utilization since according to respondent the benefit of this meta variables has been found out more than 19%.



	MC	ME	MF	MP	MM
Barrier	10	81	218	127	31
Neutral	97	14	58	31	132
Benefit	201	136	186	73	607

Figure 45: I-BIM meta variables for the United States of America – detailed comparison

The I-BIM features have been chosen to be analyzed at three different levels, as was described in the preceding section related to Turkey. Each meta variable has been separately analyzed at the first level in line with the TNMV, and the results are described in Table 14. The total number of sub-meta variables has led to the establishment of this figure. ME and MP both have TNMV-1 values of 231, which is due to the fact that, as shown in Figure 32, each of these two meta variables includes a total of three sub meta variables. These two meta variables were also determined independently based on the individual number of TNMV-1 for benefit/neutral/barrier, as it is shown for each meta variable in Figure 46. The MC, MF, and MM have TNMV-1 values of 308, 462 and 770, respectively, which demonstrate the difference in the effectiveness weight of each meta variable for the United States of America in the same way and with the same mentioned justification.

Table 14: I-BIM data mining of each individual meta variables

Meta Variables	Benefit	Neutral	Barrier	I-BIM TNMV-1	Percentage
MC	65.26	31.49	3.25	308	100
ME	58.87	6.06	35.07	231	100
MF	40.26	12.55	47.19	462	100
MP	31.60	13.42	54.98	231	100
MM	78.83	17.14	4.03	770	100

In Table 15, the second level of data mining is presented. The total number of benefit/neutral/barrier has been taken into consideration as the analysis category in this table to take a deeper look at the status of the meta variables. For instance, MF, which was ranked fourth in level one, has now been found to be one of the level's second-highest benefits. Since the analysis at the second level has been done using the TNMV-2, the individual TNMV-1 values of these meta variables are what are causing this variance. We are going to discuss these findings in more detail in accordance with Figure 46 in following section.

Table 15: I-BIM data mining among each individual category using meta variables values

Meta Variables	Benefit	Neutral	Barrier
MC	16.71	29.22	2.14
ME	11.30	4.21	17.34
MF	15.46	17.47	46.68
MP	6.07	9.34	27.20
MM	50.46	39,76	6.64
Percentage	100	100	100
I-BIM TNMV-2	1203	332	467

Table 16 shows the results of the third and final level of I-BIM data mining. Each unique total number of benefit/neutral/barrier for each meta variable was taken into consideration separately in the aforementioned set of data, and the analytical result was generated using TNMV-3. This analysis yields a precise weight for each meta variable based on the total number of sub-meta variables and the I-BIM TNMV-3 value. As an example, one of the most important results of this level of study was the decrease in the barrier between the MF and MP, which, although it was 7.75% in level one, has now decreased to 4.55%, or a total of 50% reduction from level one.

Another example to support this statement is that, between MM and MP, the gap between the greatest and lowest benefit at level one is 47.23%; however, by level three, this disparity has decreased by nearly 65% and is now just 26.68%. This indicates that the third level of I-BIM data mining developments are more accurate and dependable than the other two levels because the TNMV-3 has been implemented, as it is shown in Figure 46 with respect to the applied TNMV values in each level and every statistic is given as a percentage in respected figure in accordance to each level.

To conclude the domain competency section of the proposed framework, there has to be a comparison between Table 13 and Table 16, which represent the I-BIM TNMV-3 results for both target countries. Among the benefits according to the data mining in Chapter 7 and TNMV-3 in this chapter, MM and MC are the top 2 but in United States of America MF and ME are the third and fourth prime category while in Turkey both of these meta variables ranked with the exact same amount.

In the neutral section or uncertainty zone, if we exclude the MM as a first rank due to the high number of variables, MC and MF are going to rank in the top 2 with a 2.29% and 1.41% difference between Turkey and the United States of America, respectively. Moreover, for the barrier section, MF is by far the meta that needs concerns to ease the implementation of I-BIM. Second and third ranks also go to MP and ME, which shows that the government needs to take action regarding all that has been discussed in Chapter 7, and for ME, both academia and industry need to walk side by side and step by step to make changes such as university curriculum, more funded workshops to motivate conventional construction firms to make the transition, and moreover, proper policy from the government will motivate all infrastructure firms to utilize I-BIM and take the most out of it.

Table 16: I-BIM data mining among each individual category using meta variables values

Meta Variables	**Benefit**	**Neutral**	**Barrier**	**Total**
MC	10.04	4.85	0.50	15,35
ME	6.79	0.70	4.06	11,55
MF	9.29	2.91	10.89	23,09
MP	3.65	1.55	6.34	11,54
MM	30.33	6.59	1.55	38,47
I-BIM TNMV-3	-	-	-	2002

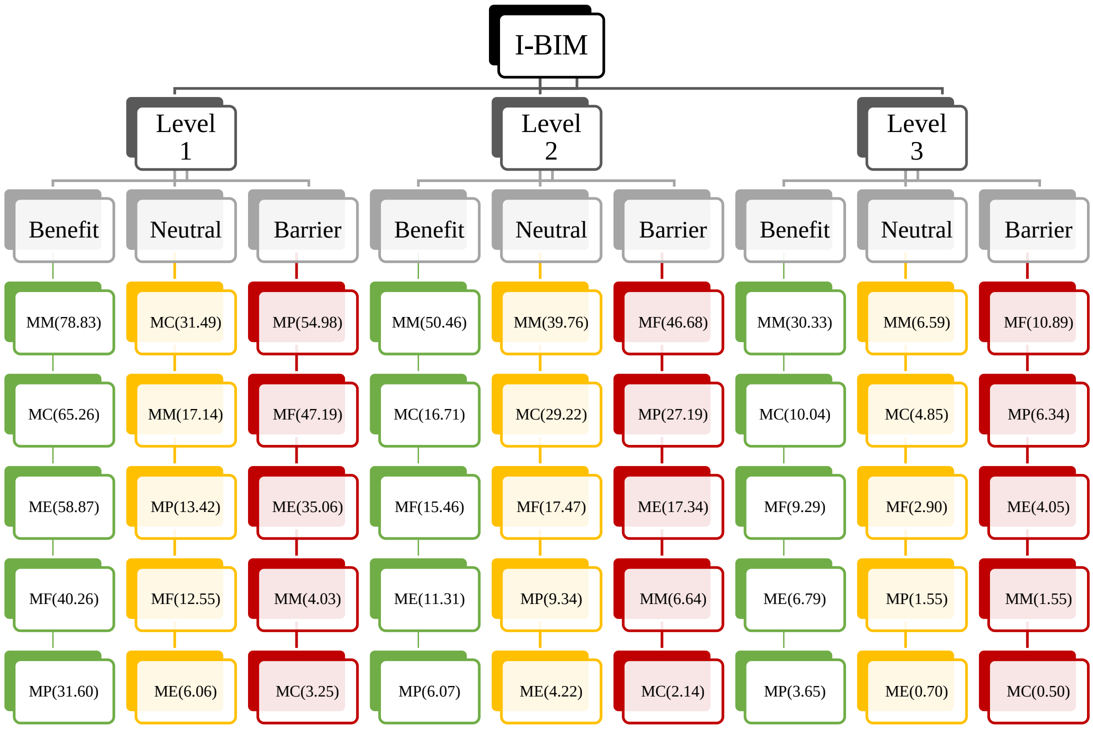


Figure 46: I-BIM meta variables for United States of America – detailed comparison

8.5 Summery of I-BIM Domain Competency Tire

Totally there are three effectiveness level has been defined for I-BIM framework as it has been stated in Chapter 6, Table 4. Thus, Table 17 to 19 has been prepared to summarize and conclude the discussion in this chapter for each one the effectiveness level including benefit, neutral and barrier. Moreover, as it has been discussed in this chapter, the most accurate level of domain competency analysis is TNMV-3 (Level3), therefore all following discussion has been explained according to level 3 of domain competency analysis but in following tables all collected data for three level of TNMV analysis has been gathered to be able to prove the differentiate among each level more clearly.

According to Table 17, both American and Turkish respondents declare that MM and MC meta variables are the greatest benefits provider for I-BIM implementation with around 15% and 28% lower positive feedback and perspective among Turkish respondents. On the hand this difference for ME is around 10% which is the lowest one among all five selected meta variables but for MF and MP are 35% and 38%, respectively. Therefore, this data proves that most American consider selected variables to be more applicable and constructive for I-BIM framework compare to Turkish respondents which can be consider as pin point to prove the differences in fundamental socio-economic structural level among both target countries. It is noteworthy to mention that the average differences among all five meta variables in this effectiveness level is calculated as 25%. Therefore, in this level, this difference is equivalent to the same Q-factor that has been assumed in chapter 6, Table 5, with total of 25% difference among United States of America and Turkey.

Table 17: Detailed domain competency comparison among target countries (Benefit)

Meta Variables	Target Countries	TNMV-1 (Level 1)	TNMV-2 (Level 2)	TNMV-3 (Level 3)
MM	United States of America	77.83%	50.46%	30.33%
	Turkey	67.35%	54.43%	25.90%
MC	United States of America	62.26%	16.71%	10.04%
	Turkey	47.20%	15.25%	7.26%
ME	United States of America	58.87%	11.31%	6.79%
	Turkey	52.72%	12.77%	6.08%
MF	United States of America	40.26%	15.46%	9.29%
	Turkey	26.36%	12.77%	6.08%
MP	United States of America	31.60%	6.07%	3.65%
	Turkey	19.73%	4.78%	2.28%

Table 18 is targeting the second level of effectiveness which is Neutral percentage of each meta variables for both target countries. In this case, 16.83% of Turkish respondents have uncertainties about MM and MC, while American were more certain about these meta variables with 5.39% lower uncertainties level compare to Turkish citizen. Moreover, there were 1.41% differences for MF and less than 1% for variance for MP and ME among all questioned respondents.

Table 18: Detailed domain competency comparison among target countries (Neutral)

Meta Variables	Target Countries	TNMV-1 (Level 1)	TNMV-2 (Level 2)	TNMV-3 (Level 3)
MM	United States of America	31.49%	39.76%	6.59%
	Turkey	25.20%	39.39%	9.69%
MC	United States of America	17.14%	29.22%	4.85%
	Turkey	46.42%	29.03%	7.14%
ME	United States of America	13.42%	4.22%	0.70%
	Turkey	8.16%	3.83%	0.94%
MF	United States of America	12.55%	17.47%	2.90%
	Turkey	18.70%	17.54%	4.32%
MP	United States of America	6.06%	9.34%	1.55%
	Turkey	21.77%	10.21%	2.51%

The data analysis of last effectiveness level of domain competency has been gathered in Table 19. It is interesting that the highest percentage differences in target countries is among MM and MC with 46% and 49% lower rate American to consider these meta variables as a barrier. But in general, a total of 23.56% of respondents believes that MF is the greatest barrier with 14% less American to deliberate it as a negative impact for I-BIM framework. Additionally, ME and MP are the next top two barriers with a difference of 10% and 6% among American and Turkish respondents. It is noteworthy to mention that the summation of all these differences is equal to 125% and if this number get divided by total of five meta variables, is going to be equal to 25%. This is going to proves that once again, the selection Q-Factor as 25% difference among United States of America and Turkey were a correct assumption.

Table 19: Detailed domain competency comparison among target countries (Barrier)

Meta Variables	Target Countries	TNMV-1 (Level 1)	TNMV-2 (Level 2)	TNMV-3 (Level 3)
MM	United States of America	4.03%	6.64%	1.55%
	Turkey	7.45%	10.31%	2.87%
MC	United States of America	3.25%	2.14%	0.50%
	Turkey	6.38%	3.53%	0.98%
ME	United States of America	35.06%	17.34%	4.05%
	Turkey	39.12%	16.24%	4.52%
MF	United States of America	47.19%	46.68%	10.89%
	Turkey	54.94%	45.63%	12.67%
MP	United States of America	54.98%	27.19%	6.34%
	Turkey	58.50%	24.29%	6.75%

Chapter 9

EXECUTION COMPETENCY OF I-BIM FRAMEWORK BY APPLYING ARTIFICIAL NURAL NETWORK (ANN)

9.1 Introduction

Many intelligence- or pattern-related jobs are highly challenging to automate, but seem to come effortlessly to people. For instance, it seems to take very little effort for people to distinguish different things and make sense of the enormous quantity of visual information in their environment. It seems sense that knowing how humans execute these jobs and, to the degree it is physically possible, resembling these processes will be extremely beneficial for computing systems that try comparable tasks. Neural network research and modeling are therefore required. A human's neural network is a component of their nervous system and is made up of several linked neurons (nerve cells).

According to Dongare et al. (2012), "Network" refers to a structure that resembles a graph, while "neural" is an adjective for a neuron. Artificial neural networks are computer programs whose main idea is modeled after biological brain networks. Other names for artificial neural networks include "Neural Nets," "parallel distributed processing systems," and "connectionist systems." A computer system must have a labeled directed graph structure with nodes that carry out certain basic operations in order for it to go by these attractive headings. A "Directed Graph" is made up of a set of "Nodes" (vertices) and a set of "Connections" (edges/links/arcs) linking pairs of nodes, as we recall from introductory graph theory. Each node in a neural network conducts certain basic computations, and each connection sends a signal from one node to another. The "Connection Strength" or "Weight" of a connection indicates how much an amplified or attenuated signal is caused by the connection. The replacement for human knowledge and skill is this system. Since Artificial Neural Networks closely mimic the brain, a lot of terminology from neuroscience is used in them.

According to Flood et al. (1994), Flood et al. (1996), and Jeng et al. (2003), artificial neural networks are a typical example of a contemporary multidisciplinary field that aids in addressing a variety of engineering issues that cannot be handled by conventional modeling and statistical approaches. Neural networks have the capacity to gather, store, analyze, and interpret a sizable amount of data obtained from various experiments or numerical calculations. They serve as an example of an advanced modeling method that may be used to many other challenging challenges. For any input data that were not included in the network's learning process, the trained neural network acts as an analytical tool for accurate prognoses of the outcomes. Their functioning is actually simple and straightforward, yet accurate and exact.

9.2 Artificial Neural Networks

The fuzzy logic, genetic algorithms, and artificial neural networks (sometimes referred to as "neural networks") are all symbolic techniques of intelligent computation and data processing that function in accordance with the principles of "soft computing." Data processing, neuro-biology, and physics are three study areas that have advantages that have led to the development of neural networks. According to Flood et al. (1996) and Jeng et al. (2003), they are a typical illustration of a modern interdisciplinary field that provides the fundamental knowledge principles required to address a wide range of intricate engineering issues. These issues cannot be resolved using conventional modeling and statistical techniques.

In an effort to better understand how the human brain functions and in an effort to construct an artificial "intelligent" system capable of doing the data calculating and processing tasks that the human brain is known for, artificial neural networks were founded, developed, and applied. The biological neural networks and artificial neural networks are remarkably similar, mostly because of this. The structure, purpose, data processing mechanism, and design of the two networks are comparable. The mathematical model of artificial neural networks is described as being simplified and related to the mathematical model of biological neural networks. The fundamental traits of the organic nervous system are simple for them to imitate. The networks have the capacity to collect, store, and analyze a wide variety of experimental data. In following section all aspects of ANN are going to be explain comprehensively.

9.2.1 Neuron

Biological neural network processes are extremely complicated, and as a result, they have not yet been fully analyzed and understood. It is very difficult to develop a mathematical model that will be exactly the same as the biological neural network since there are hundreds of distinct types of biological neurons in the human brain. However, elaborate neuron models are not required for the usage of artificial neural networks in practical applications. Because of this, the generated models for artificial neurons simply serve to serve as a reminder of the biological ones' structure and do not claim to replicate their actual state (Lazarevska, et al. 2014).

The artificial neuron takes in inputs and then produces output signals. Any information from external sources or a signal from another neuron can be utilized as an input signal. Figure 47 displays the model for an artificial neuron.

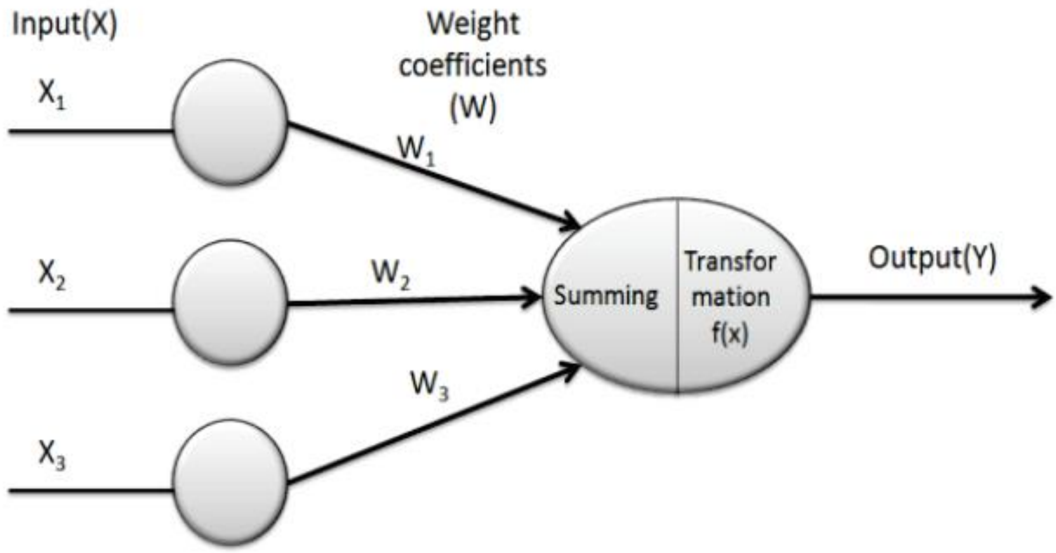


Figure 47: Artificial neuron model sample

9.2.2 Neural Network

A neural network is a structure made up of many interconnected neurons arranged in layers. The number of layers determines how cooperative the network is. A network may also include one or more hidden layers in addition to the input (first) and output (last) layers Figure 48. The input layer's function is to receive data from the outside world. The hidden layers process such data before sending them to the output layer. The network's ultimate outputs, which are the neurons from the topmost network layer, contain the answer to the problem under study. Any form or kind of data can be used as input. The fundamental rule is that each piece of data can only have one input value. The network may have a single output or a number of them, depending on the sort of problem statement.

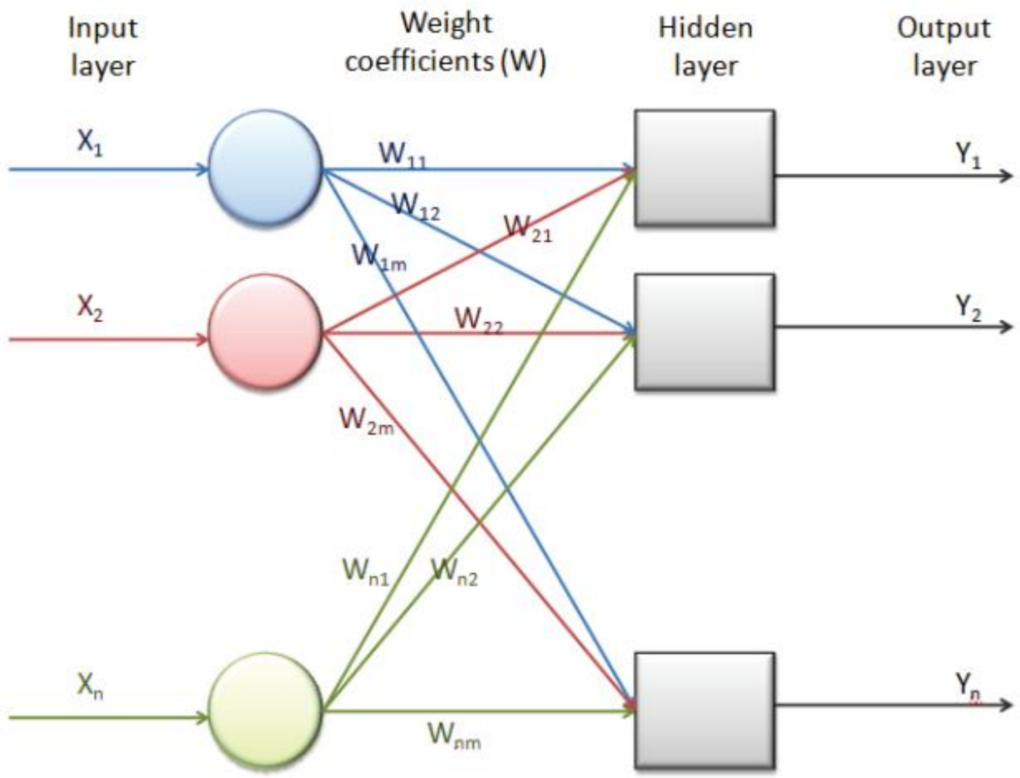


Figure 48: One layered ANN model sample

A matrix of W that has total number of m columns and n rows is going to shape the weight coefficients. For instance, as it has been illustrated in Figure 48, the weight coefficient Wnm is actually the mth output of the nth neuron. The weight coefficients determine the correlation between the source of the signal and the neurons. Positive weight coefficients speed up synapses, whereas negative coefficients slow them down. If Wij = 0, that means these two neurons do not have any connection with one another.

9.2.3 Weight Coefficients

The fundamental components of any neural network are weight coefficients. They convey the relative significance of each neuron's input and establish how well the input can stimulate the neurons (Flood, I. 1990). There is a unique weight coefficient for each input neuron. This can be determined by the input signal from each neuron by multiplying those weight coefficients by the input signals and adding them together.

According to Figure 47, X is representing the input data and each input appointed to a coefficient weight as W, therefore the input impulses neuron can have calculated by multiplying X by W. Moreover, Equation 5 and Equation 6 are samples representing the total sum of all input impulses and the output signal from the neuron, where $f(x)$ is activation function to retrieve impulse in an appropriate transformation function process.

$$X = W_1X_1 + W_2X_2 + \cdots + W_nX_m \tag{5}$$

$$Y = f(x) = f(W_1X_1 + W_2X_2 + \cdots + W_nX_m) \tag{6}$$

9.2.4 Activation Function

The activation or transformation function's primary goal is to evaluate whether the output from the summary impulse X can be generated. It is primarily a non-linear function that is connected to the neurons in the hidden layers. Practically every non-linear function can be used as an activation function, but a common practice is to use the sigmoid function (hyperbolic tangent and logistic) with the following equation form:

$$Y_t = 1/(1 + e\hat{\ }(-Y)) \tag{7}$$

Where:

- Y_t = *Normalized value summary function's result
- Y = output signal from the neuron.

According to Flood (1990), the meaning of normalized is that the value of each output after applying the activation function will be within a practical limit between 0 and 1. Therefore if there will be no transformation function to activate the process, there is high chance for the complex networks with hidden layers that calculate an output value with a large number.

9.2.5 Architecture of Neural Networks

How to link the network components is a key feature of neural networks. Neural network models come in a wide variety, and there are several classification techniques for them as well (Jeng et al., 2003). In general, different types of networks are classified based on factors like the number of layers (single-layer and multi-layered networks), the type of connection between neurons (layered, fully connected, and cellular), the learning process (feedforward and feedback), the type of data (binary and continuous networks), the way information spreads (supervised, partially supervised, and unsupervised networks), etc.

9.2.6 Networks Training Process

Artificial neural networks have a number of fundamental properties, among which their learning ability ranks highly (this ability brings them closer to the real world and human thinking), along with their capacity for finding relationships between erratic and incomprehensible data, and their generalizing capability (the network will produce accurate results even if the input data are incomplete). It has been demonstrated that neural networks do calculations more accurately than traditional techniques in many circumstances, primarily because they can analyze data with mistakes, find solutions to issues that have no plausible answer, and learn from previous data.

Therefore, in order to train (learn), neural networks periodically transmit data through the network and compare the received input values to the predicted values. If the values differ, the weight coefficient must be adjusted, which requires changing the connections between the neurons. This procedure is performed several times until the network responds as desired or until all weight coefficients derived from all training data have been modified. We may refer to a network as trained when it produces accurate results for all of the training data. After training, the network should be able to produce results for new inputs that are distinct from those used during training. For neural networks to be useful in solving engineering challenges, learning and training must take place inside of them.

9.3 I-BIM Variables Treatment

In this dissertation, ANN is used to forecast respondents' perspectives using I-BIM variables, which are equivalent to Meta Variables in order to consider each meta as barrier or benefit. Artificial neural networks (ANNs) strive to simulate the fundamental operations of biological neurons through the use of artificial neurons and propose a computational device to approximatively calculate output given an input set. The output is stored in an output layer, while the input is structured as a layer of neurons with each neuron representing one of the input variables. Numerous neurons are found in intermediate, hidden levels where they receive information from the input layer and transmit it to higher layers. Trained ANN can anticipate the complex link between a collection of input data, set as modeling parameters including average of each respondents' feedback for each meta variables according to Appendix C and D for both United States of America and Turkey, and a set of output data, set as I-BIM variables corresponding to respondents' total average for all 26 variables. The neurons in each layer are connected to the neurons in next layer by links which are characterized by a weight (W). A transfer function (h) processes the input data to a neuron before sending it on to the neurons in the following layer. The outcome of Equation (8) may be shown for a network with a single hidden layer.

$$Output = h\left(\sum_{K=0}^{J} w_{kj} h\left(\sum_{i=0}^{N} w_{kj} (X)_i\right)\right) \quad (8)$$

Where:

- h = Transfer function
- w = weights
- $(X)_i$ = Input variables
- N = Number of neurons in input
- J = Number of intermediate layers.

The ANN's training process involves choosing the transfer functions, defining the network's design, and altering weight values. Typically, just a portion of the data is utilized for training (for instance, 60%), and the remaining amount is used to verify the predictions made by the neural network. The hidden layer must have an adequate number of neurons to predict output values with the fewest possible errors, but not too many that the network could give incorrect values for input combinations that don't exist in the training set of data. To minimize the prediction error, weight matrices and bias vectors are modified. Equation (9) presents the mean square function as a common metric of neural network error.

$$E = \sum_m \frac{1}{m}(Y(x^m) - t^m)^2 \quad (9)$$

Where:

- m = Number of training pairs (x, t)
- x^m= Number of inputs
- t^m = Target data
- Y = Value predicted by neural network
- J = Number of intermediate layers.

The minimization problem is solved to determine the network's optimal weights, which reduce network error. Back propagation method, a popular minimization approach that is also used in this dissertation, updates the weights over a number of iterations in the direction of steepest descent. The weights of the network in iteration t + 1 are calculated by Equation 10 and the updating part of Δw^t is calculated by equation 11:

$$w^{(t+1)} = w^t + \Delta w^t \quad (10)$$

$$\Delta w^t = \alpha \,.\, \Delta w^{t-1} + \eta \,.\, d^t \quad (11)$$

Where:

- w^t = Weight matrix in iteration t
- d^t = Search direction in accordance with partial derivatives of error function with respect to weights
- α = Corresponding step size
- η = Momentum term defined in [0,1).

The test data are used to develop the MSE as Mean Square Error, RMSE as Root Mean Square Error and R2 as R-square statistic measures as the precision criteria, in order to assess the precision of the mean. The MSE, RMSE, and R^2 values for the discrepancy between the accurate and predicted results are provided in Equations (12–14).

$$MSE = \frac{1}{n}\sum_{i=1}^{n} |y - \hat{y}_i|^2 \quad (12)$$

$$RMSE = \frac{n_i \sum_{i=1}^{n_i}(y_i - \hat{y}_i)^2}{(n_i - 1)\sum_{i=1}^{n_i}(y_i)^2} \quad (13)$$

$$R^2 = 1 - \left[\frac{\sum_{i=1}^{n_i}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n_i}(\hat{y}_i)^2}\right] \quad (14)$$

Where:

- n_i = The test samples number
- $\hat{y}_i$ = Predicted values
- y_i = Actual values.

Different ANN configurations with varying numbers of neurons in each layer are investigated to attain the best results. Each ANN configuration was trained, and the performance error was determined using equation (9). The optimum ANN model matching to the least error measure is obtained using this trial-and-error technique. As a consequence, a 5-45-45-1 neural network with two hidden layers of 45 neurons each is eventually chosen.

9.3.1 United States of America

Figure 49 illustrate the mean values estimated using the ANN to clarify the execution competency level of proposed framework with the help of average respondent answers for MC, ME, MF, MM and MP as well as values determined by direct analysis taking into account three realizations of the modeling data and output as a respondent answers average to all 26 variables for all 77 participants. The calculated mean are well-fitted to the accurate ones in these diagrams. These diagrams demonstrate values that were determined through direct ANN evaluation on the horizontal axis and values that were estimated using the I-BIM meta variables approach on the vertical axis. While approximations equal to average respondents’ answers for all meta categories, included by 77 respondents, values are indicated by a solid Black line for all target (100%), Blue for training (68%) Green for prediction (16%) and Red for test (16%). Moreover, the performance metrics used trained I-BIM variables to estimate mean and the metrics has been calculated to evaluate the application results of MSE, RMSE and R^2 which is presented in table 20.

Table 20: The performance metrics of I-BIM meta variables from ANN (Untied States of America)

I-BIM Meta Variables Parameter	MSE	RMSE	R^2
Mean (United States of America)	0.00691	0.00243	0.99360
Mean (Turkey)	0.00843	0.00459	0.99794

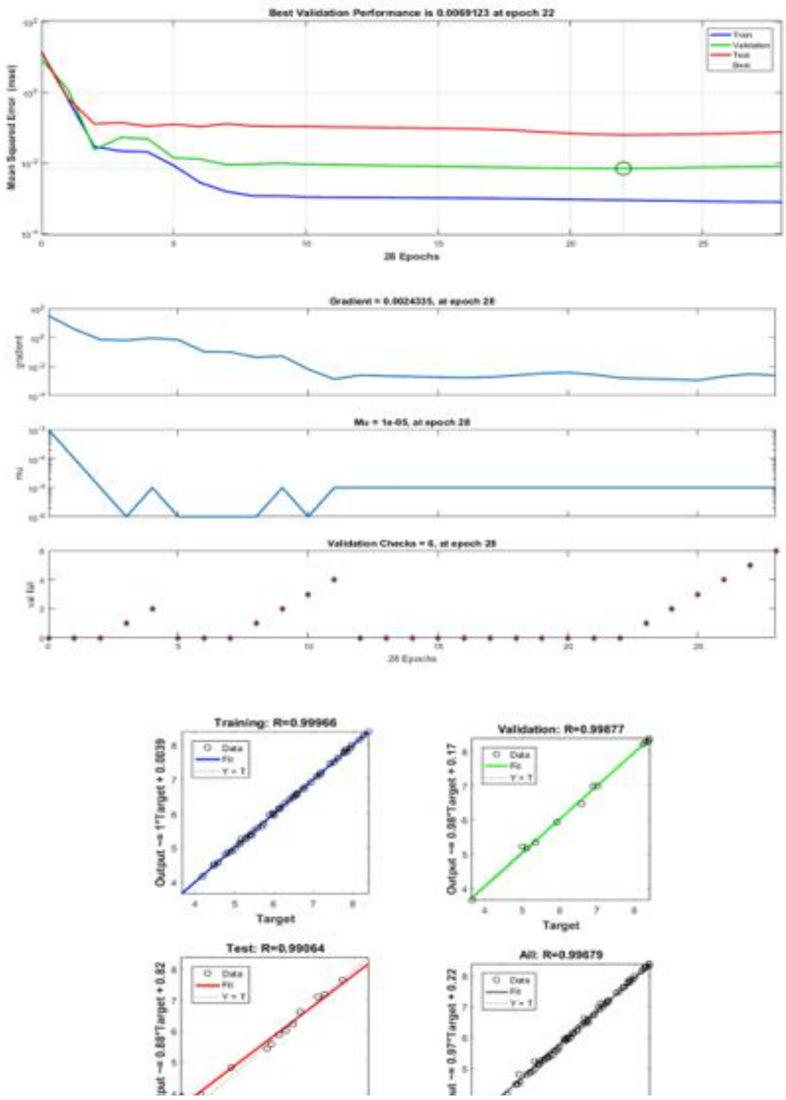


Figure 49: The correlation values obtained mean of I-BIM domain competency from ANN for United States of America

9.3.2 Turkey

Figure 50 shows the mean and values estimated by the ANN to clarify the execution competency level of the proposed framework using average respondent answers for MC, ME, MF, MM, and MP, as well as values determined by direct analysis using three realizations of the modeling data and output as a respondent answers average to all 26 variables for all 98 participants. The estimated mean in this graph is well-fitted to the accurate ones. On the horizontal axis, these figures show values derived through direct ANN assessment, and on the vertical axis, values calculated using the I-BIM meta variables technique. While approximations are equal to average respondent replies for all meta categories, values are shown by a solid Black line for all target (100%), Blue for training (60%) Green for prediction (20%) and Red for test (20%). Furthermore, trained I-BIM variables were utilized to estimate mean values, and the metrics were produced to assess the application outcomes of MSE, RMSE, and R^2, as shown in table 21.

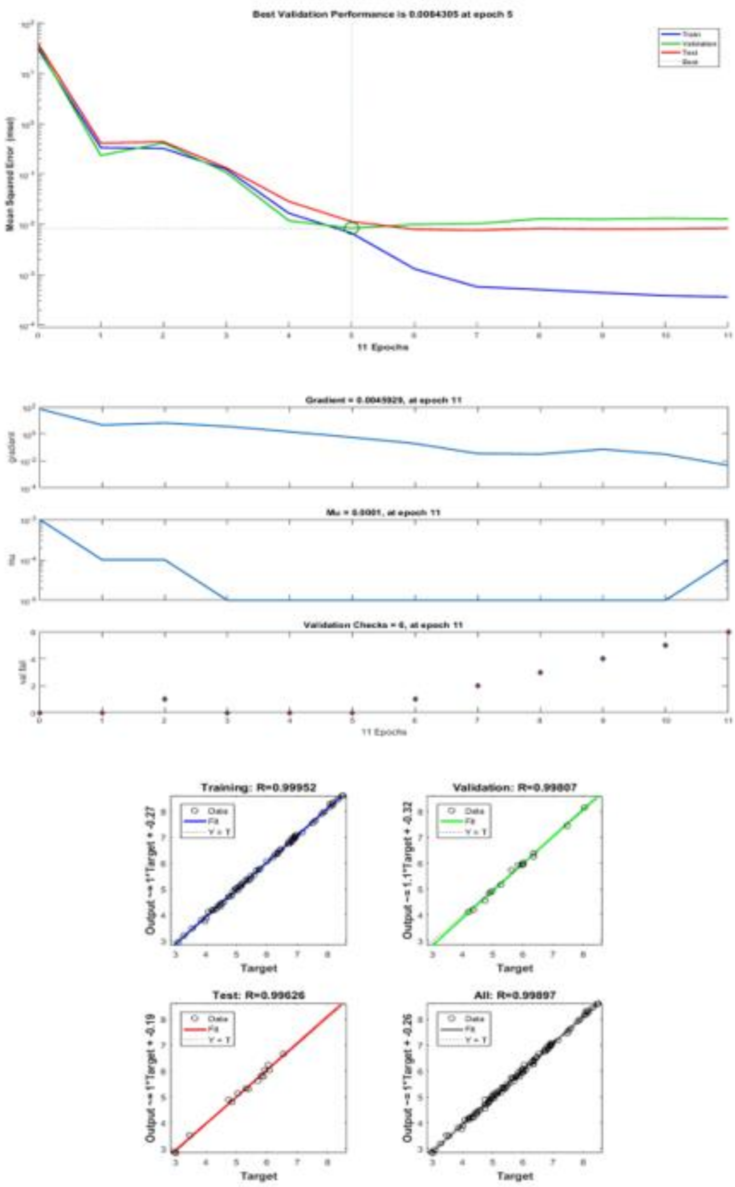


Figure 50: The correlation values obtained mean of I-BIM domain competency from ANN for Turkey

9.4 Summery of I-BIM Execution Competency

The target of I-BIM execution competency is establishing a system or network to train, test, and validate the data that has been gathered in the domain competency tire. Therefore, for each target country, a network has been designed and trained by the Levenberg-Marquardt algorithm, with a total of 28 epochs for the United States of America and 11 epochs for Turkey. It is noteworthy to mention that an epoch is defined as the number of times a dataset passes through the algorithm. The Input data were the average of a respondent's answers to each meta category's variables, with a total of five answers per respondent. The aforementioned percentage of each collected country's data has been considered with respect to the amount for each part of the network, including the training, testing, and prediction processes.

According to the result of MSE with respect to Table 20, the best prediction has been achieved after conducting 22 epochs in the network for the United States of America and 5 epochs for Turkey. Moreover, RMSE has been found according to the 28 and 11 epochs gradients to be as low as 0.0024 and 0.0045, respectively. Additionally, R2 as shown in Figures 49 and 50, has been tried to be utilized as a statistical measurement tool that proves how the model is fit based on the context of regression. Therefore, an individual regression line has been demonstrated for each part of the network, including train, test, prediction process, and all input data. It's noteworthy to mention that all R2 data has been found within the proposed framework to be greater than 0.99, which proves how closely the data in the designed regression line are fit to the input data of this dissertation.

To conclude the final phase of the I-BIM implementation framework, it can be stated that execution competency has been designed in a manner to be a benchmark for target countries regarding all of the advanced algebraic analysis that has been conducted in previous tires and at this level with the assistance of ANN because the designed network has been tried to predict that each single meta category (MC, ME, MF, MM, and MP) respondent point of view with a regression line to make sure that each category is located in which I-BIM effectiveness level. Therefore, Table 21 has summarized this I-BIM effectiveness level, and later on, according to the progress level of each firm or company that is located in target countries, the new set of numbers according to the respondent's point of view can be set in the network and compared with the initial run. That is why it can be stated that the I-BIM framework is the foundation for future adoption of BIM for infrastructure projects.

Table 21: I-BIM Meta category effectiveness level summarized by ANN

I-BIM Meta Category	I-BIM Effectiveness Level		
	Benefit	Neutral	Barrier
MC	7.06 (USA) -	- 6.34 (Turkey)	-
ME	-	5.80 (USA) 5.42 (Turkey)	-
MF	-	5.15 (USA) -	- 4.38 (Turkey)
MM	7.27 (USA)	6.83 (Turkey) -	-
MP	-	-	4.48 (USA) 4.04 (Turkey)

Chapter 10

CONCLUSION AND RECOMMENDATIONS

10.1 Conclusion

In recent times economic growth and social improvement of any nation is tied to infrastructure which it needs a proper and efficient management system. Automated and modern management systems are needed more than ever and they need to be replaced of conventional and traditional management methods. Using different information modeling terms such as BIM, BrIM or I-BIM in correlation with any infrastructure technologies like Unmanned Systems Technology (UAS) or GIS can construct safe environment and more sustainable and reliable network to decrease reworks, delays, risks and costs of project in accordance with better time and quality management which leads to bring extensive revenues to all stakeholders including owners, designers and other related parties and authorities.

There is a significant relationship between building construction and infrastructure construction when it comes to addressing information technology needs. This relationship is particularly important in the context of creating smart buildings and smart cities, where information technology infrastructure plays a critical role in enhancing efficiency, connectivity, and sustainability. information technology is an integral part of modern building and infrastructure construction. It not only enhances the functionality and efficiency of these projects but also plays a key role in creating smart, connected environments that improve the quality of life for residents and users.

Collaboration between construction professionals and IT experts is essential to ensure that the infrastructure meets the evolving needs of the digital age.

Therefore, it is essential to present different frameworks and BIM adoption strategies based on different construction project categories because different types of construction projects have unique characteristics, requirements, and challenges. Tailoring BIM frameworks and strategies to specific project categories including infrastructures helps maximize the benefits of BIM and improves project outcomes in the different ways such as data collection and analysis, risk mitigation, connectivity and communication, efficiency and cost saving, regulatory compliance, performance metrics, project lifecycle and facility management. So, it can state that presenting different frameworks and BIM adoption strategies based on different construction project categories recognizes the diversity within the construction industry and acknowledges that a one-size-fits-all approach to BIM is not suitable. Customization ensures that BIM is applied effectively, resulting to justify the need to propose a generic conceptual BIM adoption framework for infrastructure projects

As it has been stated, BIM is among the commonly accepted way of achieving integration in the different stage of the construction projects and its benefits enhanced the schedule and planning stage alongside coordination and operation. In order to increase the quality of the project and save more time and cost, I-BIM is the best solution but implementation of it has its own challenges and it is a risky path due to multiple factors including lack of expert personnel, insufficient budget, inadequate national standards and regulation issues. The major objective of this study were to identify and prove the existing lack of using BIM for infrastructure projects at selected countries in order to mitigate the existing barriers on the way of I-BIM by identifying obstacles and privilege of it. Based on the findings of data mining, factors such as incomplete national standards, lack of government regulation, initial cost of software, availability of expert personnel, and cost of training and education are the most considerable barriers on the way of I-BIM utilization. However, factors such as information sharing, staff collaboration, inaccuracies responsibility, client requirement, cost and time control, quality management and social costs are considering as the most important privilege of I-BIM which can make client, contractor, consultant team and governments, as an assembly and they will be able to share benefit of collaboration, representation, process & lifecycle to create an innovative and efficient project environment.

It can be concluded that, in the literature, there have been numerous factors which contribute to BIM implementation for infrastructure projects in different categories. I-BIM can therefore facilitate this process by serving as a digital representation of the structural and functional attributes of infrastructure projects. I-BIM is a collaborative process that involves all stakeholders in the design, construction, and maintenance of an infrastructure project. The fundamental aims of this research were to define five meta variables with a total of 26 sub-meta variables, analyze the connections among these variables, and identify exceptional results to enhance the contemporary I-BIM framework. Moreover, in this study, three different level of I-BIM has been created according to the TNMV values and each one of the five meta variables in each level has been ranked according to the respondent point of view with a comprehensive discussion and detailed data mining for both the United States of America and Turkey. MM has been found as the greatest benefit of I-BIM framework. Also, there is a major uncertainty about MC and both meta variables of MF and MJ has been ranked as the greatest barriers which needs improvement and development.

Furthermore, both American and Turkish respondents state that the MM and MC meta variables are the main advantages providers for I-BIM deployment, with around 15% and 28% lower favorable feedback and viewpoint among Turkish respondents, respectively. On the one hand, the difference for ME is roughly 10%, which is the lowest of the five selected meta variables, while it is 35% and 38% for MF and MP, respectively. As a result, this data shows that more Americans believe chosen indicators to be more appropriate and constructive for the I-BIM framework than Turkish respondents, which may be used to demonstrate basic socioeconomic structural disparities between the two target nations. In terms of the neutral zone, 16.83% of Turkish respondents are unclear about MM and MC, but Americans are more certain about these meta variables, with 5.39% less uncertainty than Turkish citizens. Furthermore, among all questioned respondents, there were 1.41% variances in MF and less than 1% variance in MP and ME. It's important to note that the largest percentage discrepancies among the target countries are between MM and MC, with 46% and 49% of Americans viewing these meta characteristics as a barrier, respectively. However, 23.56% of respondents say that MF is the most significant obstacle, with 14% believing that it has a negative influence on the I-BIM framework. Furthermore, ME and MP are the next two most common hurdles, with a 10% and 6% difference between American and Turkish respondents, respectively.

The purpose of I-BIM execution competency is to create a system or network for training, testing, and validating the information obtained in domain competency. As a result, a network using the Levenberg-Marquardt algorithm has been created and trained for each target nation, with a total of 28 epochs for the United States of America and 11 epochs for Turkey. It is important to note that an epoch is defined as the number of times a dataset is processed by the algorithm. The input data were the average responses given by each respondent to the five variables in each meta category. With regard to the sum for each network component, the aforementioned percentage of each data collection for the targeted nations has been taken into account. To summarize and sum up the I-BIM implementation framework, it can be said that execution competency has been designed for the purpose of being a benchmark for target countries as the foundation of BIM utilization for infrastructure projects regarding all of the advanced algebraic analysis that has been carried out in the past and at this level with the help of ANN because the designed network has been tried to predict each individual meta category (MC, ME, MF, MM, and MP) respondent point of view with a regression line.

10.2 Recommendations for Future Works

The main attempt of this research was to produce a framework in order to help industry decrease the duration of adoption and utilization of BIM by proposing I-BIM regarding the multiple competency tire, but future research might consider the following suggestions:

- To select European countries or China and implement the suggested I-BIM framework and compare the results with the proposed ANN system. This could significantly boost the implementation of the proposed I-BIM framework worldwide
- Designed similar ANN system but more specifically and individually for different type of infrastructure categories such as road, bridge, utility, aviation system and etc
- To apply the TNMV factor to a larger number of respondents in multiple countries and evaluate the data according to the suggested framework in order to increase the adoptability of it for more countries

- To find and choose more potential variables for I-BIM implementation, define different Q-factors and E-factors regarding the nature of target countries, and expand what has been done in this dissertation for different part of the world
- To utilize the optimization engine in current study but with more data set and use fuzzy approach to develop more advance system and globalize the fundamental of proposed I-BIM framework.

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APPENDICES

Appendix A: Questionnaire Survey/General Information

1. What is your educational qualification?

Bachelor ☐ Master☐ Ph.D.☐ Academia ☐

2. How many years of experience do you have in construction industry?

1-5 years ☐ 5-10 years☐ 10-15 years☐ more than 15 years ☐

3. How many projects do you regularly involve per year?

1-2 projects ☐ 2-5 projects ☐ 5-10 projects ☐ more than 10 project☐

4. How many permanent personnel do you have in your company?

5-10☐ 10-20☐ 20-50☐ more than 50 ☐

5. What is your approximate annual turnover? (Million USD)

Less than 1☐ 1-5☐ 5-10☐ 10-50 ☐ 50-100 ☐

6. What is the main field of interest for your organization?

Residential☐ Institutional and Commercial☐ Industrial ☐ Infrastructure☐ Other☐

7. What type of organization do you work?

Design consultant ☐ Owner ☐ Contractor☐ BIM Consultant ☐ Academic☐ Student ☐ Subcontractor☐ Engineering ☐ Architecture ☐ Other☐

8. Which one of the following countries are you living and working in?

United States ☐ China ☐ Turkey ☐ North Cyprus ☐

9. What is your company's proficiency levels about Building Information Modeling?

No BIM Experience ☐ Preliminary level ☐ Intermediate level ☐ Advance level ☐

10. What type of project(s) have you used BIM for? (Multiple selection is allowed)

Commercial ☐ Residential ☐ Educational ☐ Industrial ☐ Airport ☐ Transportation ☐ Public and Government ☐ Sports and Entertainment ☐ Water Supply and Resources ☐ Bridges ☐ Power Generation and Transmission ☐ Tunneling ☐ Pipeline Infrastructure ☐

11. What is the value of projects for which BIM has been used?

$0 - $10 million ☐ $10 - $30 million ☐ $30 - $50 million ☐ more than $50 million ☐

12. What BIM programs are you using for your projects? (Multiple selection is allowed)

Autodesk Revit ☐ Autodesk Navisworks ☐ TEKLA ☐ VICO ☐ Graphisoft ☐ Archicad ☐ Other ☐

13. What BIM dimension (task) is your company involved with? (Multiple selection is allowed)

Visualization (3D) ☐ Scheduling (4D) ☐ Cost Estimating (5D) ☐ Sustainability (6D) ☐ Facility Management (7D) ☐

14. What was the effect of BIM on your company's profitability?

Increase ☐ Doesn't Change ☐ Decrease ☐ Doesn't know ☐

- ❖ It is understood and agreed to that the above identified discloser of confidential information may provide certain information that is and must be kept confidential.

Appendix B: Questionnaire Survey/I-BIM Effectiveness Ranking Method

Identifier	Components	I-BIM effectiveness ranking method									E-Factor weighting system for each category (rate between 0 to 1)
		1	2	3	4	5	6	7	8	9	
F1	Initial Cost of Software										
F2	Cost of Implementation Process										
F3	Cost of Training and Education										
F4	Company Turn Over										
F5	Cost of Development										
F6	Stakeholders' involvement										
E1	Availability of Expert Personnel										
E2	Education Awareness of Academia										
E3	Information Sharing in BIM										
M1	Client Requirements										
M2	Coordination Among Project Parties										

M3	Project Size and Complexity
M4	Project Life Cycle Cost
M5	Project Social Cost
M6	Project Scheduling and Time Management
M7	Project Quality Management
M8	Environmental Impact Assessment of Project
M9	Project Geographic Location
M10	Leadership and management
P1	Incomplete National Standard
P2	Awareness Level of the Industry
P3	Lack of Government Regulation
C1	Collaboration of Different Companies staff for Same Project
C2	Supportive Contract Form for BIM
C3	Responsibility for Inaccuracies
C4	Appropriate Insurance Policy

Appendix C: ANN Input and Output Data for United States of America

Respondent NO.	Respondent answers average	Average MC	Average ME	Average MF	Average MM	Average MP
1	8.385	2.150	2.767	1.417	0.859	2.533
2	8.154	2.113	2.783	1.333	0.854	2.133
3	7.769	1.925	2.833	1.017	0.849	2.667
4	8.385	2.100	2.717	1.417	0.849	2.467
5	7.962	2.163	2.833	1.242	0.841	2.067
6	6.577	1.613	2.150	0.800	0.829	1.533
7	7.923	2.075	2.883	1.117	0.837	2.333
8	6.077	1.613	1.367	0.742	0.795	1.200
9	7.808	1.975	2.833	1.450	0.827	1.267
10	5.115	1.613	2.033	0.500	0.582	1.400
11	5.885	1.875	1.917	0.783	0.737	0.733
12	6.923	2.075	1.917	0.742	0.809	2.333
13	7.154	2.113	2.600	1.267	0.755	0.867
14	6.731	1.575	2.600	0.992	0.789	1.200
15	5.962	1.913	1.033	0.533	0.797	1.267
16	6.385	1.963	2.600	0.992	0.707	0.600
17	8.269	2.163	2.600	1.408	0.810	2.733
18	5.385	1.575	1.083	0.742	0.694	0.933
19	5.115	1.875	1.033	0.467	0.639	1.267
20	7.615	1.963	2.717	1.367	0.807	1.133
21	5.154	1.825	1.033	0.450	0.692	0.867
22	6.769	2.013	1.250	1.050	0.781	1.333

23	4.192	1.825	1.083	0.458	0.477	0.600
24	5.731	1.788	1.133	0.475	0.784	1.000
25	7.077	2.163	2.500	0.767	0.789	2.400
26	6.269	1.575	1.417	0.967	0.823	0.867
27	5.154	1.675	1.083	0.467	0.711	1.000
28	4.462	1.875	1.083	0.433	0.549	0.667
29	5.000	0.963	1.083	0.717	0.706	0.733
30	6.962	2.025	1.417	1.133	0.823	1.200
31	5.577	0.863	0.700	0.458	0.822	2.467
32	5.000	1.838	1.083	0.500	0.676	0.533
33	6.115	1.738	0.967	0.800	0.774	1.600
34	6.000	1.825	1.083	0.558	0.799	1.200
35	7.000	2.163	2.883	1.417	0.660	0.733
36	3.154	1.025	1.267	0.450	0.341	0.533
37	6.885	2.013	2.617	0.958	0.749	1.600
38	4.500	1.563	1.050	0.625	0.524	0.933
39	5.423	1.688	1.800	0.667	0.685	0.600
40	5.462	0.963	1.033	0.500	0.749	2.267
41	6.538	2.125	1.917	0.842	0.782	1.133
42	4.769	1.475	0.817	0.450	0.622	1.267
43	4.923	1.263	0.933	0.558	0.656	0.867
44	7.154	1.975	2.717	0.950	0.770	1.867
45	3.654	1.825	1.200	0.433	0.336	0.533
46	7.769	1.963	2.717	1.367	0.803	1.600
47	6.154	2.163	2.550	0.550	0.764	0.600
48	6.115	1.825	1.750	0.683	0.724	1.867
49	6.538	1.575	1. 133	1.133	0.795	1.200

50	5.885	2.113	2.550	0.842	0.602	0.867
51	6.462	1.725	1.917	1.033	0.803	0.867
52	5.308	1.725	0.767	0.533	0.721	1.133
53	4.577	1.675	1.867	0.450	0.535	0.867
54	7.423	2.163	2.717	1.375	0.739	1.133
55	6.577	1.963	2.550	0.517	0.755	2.267
56	5.923	1.675	1.083	0.658	0.805	1.200
57	6.577	2.075	1.083	0.575	0.784	2.467
58	4.538	1.025	0.650	0.417	0.697	0.933
59	7.654	2.163	2.833	1.250	0.823	1.200
60	5.538	1.225	0.750	0.475	0.824	1.533
61	5.692	1.863	1.083	0.617	0.716	1.133
62	5.962	1.725	1.083	0.750	0.756	1.467
63	5.654	1.538	0.800	0.850	0.718	1.133
64	6.462	2.163	2.550	0.583	0.784	1.133
65	5.269	1.575	0.917	0.458	0.736	1.133
66	7.615	2.113	2.600	1.358	0.806	1.133
67	3.692	1.575	0.500	0.425	0.409	1.333
68	6.154	1.863	1.917	0.583	0.794	1.133
69	4.846	1.625	0.600	0.517	0.701	0.800
70	7.846	2.163	2.833	1.450	0.805	1.133
71	6.269	1.625	1.917	0.917	0.765	1.133
72	5.346	1.625	1.083	0.583	0.697	1.133
73	7.500	1.838	2.717	1.417	0.772	1.267
74	8.308	2.113	2.767	1.442	0.796	2.733
75	8.231	2.063	2.833	1.383	0.845	2.267
76	7.192	1.713	1.917	1.033	0.820	2.600

77	8.385	2.188	2.883	1.450	0.824	2.533

Appendix D: ANN Input and Output Data for Turkey

Respondent NO.	Respondent answers average	Average MC	Average ME	Average MF	Average MM	Average MP
1	8.462	2.088	2.833	1.383	0.872	2.733
2	8.500	1.988	2.833	1.442	0.869	2.733
3	8.077	1.888	2.767	1.250	0.870	2.400
4	7.808	1.838	2.550	1.200	0.867	2.133
5	6.923	1.725	1.867	0.850	0.843	2.400
6	6.192	1.525	1.917	0.825	0.837	0.867
7	5.731	1.588	1.317	0.392	0.799	1.600
8	8.077	2.113	2.950	1.450	0.774	2.533
9	6.077	1.825	1.200	0.825	0.788	0.867
10	5.385	1.738	2.450	0.367	0.668	1.000
11	6.692	1.738	2.433	0.825	0.774	2.133
12	5.846	1.700	1.867	0.367	0.822	1.200
13	5.154	1.763	1.367	0.467	0.593	1.667
14	7.577	1.988	2.717	1.433	0.856	0.533
15	4.885	1.563	1.867	0.467	0.611	0.867
16	6.808	1.563	1.867	0.850	0.843	2.133
17	6.346	1.825	1.150	0.833	0.846	1.067
18	5.692	1.525	1.250	0.700	0.752	1.133
19	4.846	1.625	1.033	0.425	0.648	0.867
20	8.308	2.200	2.717	1.342	0.850	2.600
21	7.500	2.050	2.667	0.967	0.860	1.533
22	6.923	1.550	1.250	1.117	0.829	2.000

23	5.269	1.825	2.600	0.417	0.614	0.800
24	6.962	1.825	2.717	1.175	0.709	1.667
25	4.731	1.513	1.200	0.450	0.663	0.400
26	5.000	1.950	2.267	0.367	0.622	0.400
27	5.462	1.663	0.800	0.658	0.684	1.533
28	5.462	1.688	1.250	0.408	0.803	0.800
29	4.577	1.688	1.033	0.317	0.626	0.800
30	8.154	2.200	2.600	1.442	0.814	2.267
31	5.577	1.788	1.200	0.567	0.790	0.733
32	4.462	1.113	1.033	0.308	0.672	0.733
33	6.808	1.788	2.383	1.117	0.739	1.533
34	6.731	1.688	2.600	0.958	0.753	1.533
35	5.038	1.663	0.967	0.442	0.721	0.733
36	6.346	1.725	2.383	0.725	0.775	1.200
37	4.962	2.038	2.267	0.450	0.555	0.600
38	6.423	1.663	0.800	1.108	0.764	1.533
39	4.231	1.488	1.017	0.442	0.507	0.867
40	6.346	1.788	1.933	0.867	0.705	2.000
41	5.923	1.688	1.483	0.883	0.641	1.867
42	4.462	1.900	0.967	0.450	0.532	0.733
43	6.038	1.850	0.850	0.883	0.701	1.667
44	3.538	1.688	0.867	0.425	0.352	0.667
45	5.192	1.013	1.200	0.675	0.648	1.800
46	4.769	1.300	1.250	0.433	0.657	0.867
47	5.769	1.800	1.033	0.758	0.726	1.133
48	4.308	0.963	1.083	0.433	0.609	0.800
49	6.462	1.700	1.083	1.042	0.785	1.400

50	5.000	1.763	1.133	0.775	0.553	0.800
51	5.615	1.725	0.917	0.842	0.649	1.400
52	3.962	1.338	0.917	0.425	0.472	0.600
53	6.885	1.888	2.550	1.000	0.760	1.400
54	4.346	0.963	0.917	0.433	0.645	0.733
55	6.000	2.038	1.133	0.750	0.709	1.400
56	4.000	0.863	1.033	0.308	0.600	0.733
57	6.000	1.888	1.583	0.633	0.725	1.667
58	5.077	0.963	0.917	0.483	0.718	1.467
59	5.385	1.988	1.200	0.492	0.704	0.800
60	3.846	1.675	1.133	0.383	0.370	1.200
61	5.654	0.863	0.967	1.117	0.662	1.667
62	4.308	1.863	0.967	0.425	0.499	0.733
63	5.308	1.575	1.083	0.492	0.715	1.333
64	6.269	2.125	2.617	0.750	0.716	0.867
65	5.154	1.625	2.217	0.458	0.627	0.933
66	6.731	1.825	2.383	1.000	0.755	1.400
67	4.500	1.125	1.033	0.367	0.685	0.733
68	6.538	2.013	2.500	0.992	0.701	1.067
69	4.885	1.663	1.150	0.508	0.633	0.800
70	4.846	0.813	0.650	0.700	0.691	1.133
71	6.000	1.763	2.600	0.850	0.630	1.067
72	3.269	0.863	0.983	0.358	0.416	0.733
73	6.846	1.938	1.917	1.000	0.737	2.000
74	4.192	0.813	1.583	0.500	0.533	0.933
75	5.385	1.775	1.133	0.467	0.740	1.067
76	4.077	0.538	0.833	0.625	0.585	1.000

77	7.462	2.125	2.717	1.125	0.744	2.400
78	5.308	1.888	0.817	0.658	0.690	0.867
79	3.077	0.888	0.833	0.367	0.387	0.600
80	6.923	1.925	2.600	1.300	0.680	1.200
81	5.962	1.975	2.500	0.475	0.723	1.133
82	2.962	0.850	0.767	0.408	0.341	0.800
83	7.154	1.738	2.383	1.158	0.755	2.000
84	4.731	1.500	0.717	0.300	0.740	0.867
85	4.385	0.900	0.833	0.417	0.685	0.867
86	4.962	1.988	2.500	0.533	0.483	0.800
87	4.731	0.863	0.717	0.467	0.735	1.200
88	4.192	1.588	1.583	0.317	0.531	0.600
89	3.000	1.013	1.583	0.342	0.276	0.667
90	3.462	1.413	0.717	0.400	0.399	0.867
91	6.923	1.838	2.383	1.000	0.849	0.733
92	5.038	1.600	0.717	0.417	0.709	1.533
93	5.808	1.588	2.550	0.458	0.749	1.267
94	6.346	1.838	1.783	0.750	0.687	2.400
95	5.885	1.425	1.250	0.625	0.842	1.133
96	7.885	1.863	2.717	1.158	0.870	2.400
97	8.038	1.838	2.550	1.383	0.843	2.400
98	8.154	1.838	2.600	1.367	0.856	2.600