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Integrating Building Information Modeling in the Construction Sector: The Middle East and North Africa Case

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Ph.D. Thesis

This doctoral thesis is based upon writing a full dissertation in the form of a chapter by chapter, where each explains a given phase or topic of the research journey. The thesis starts with the introduction chapter that presents the core research question and aims, followed by the literature review chapter that assesses what the current research says about this question, and the methodology, results, and discussion chapters that go about undertaking new research about the thesis question and ends with the conclusion chapter that answers the core research questions.

The research journey resulted in publishing three journal papers and two conference proceedings relevant to the candidate's knowledge area. The thesis contains the articles comprising it, integrated as chapters of the thesis.

The doctoral student has complied with all the intellectual property rights relating to the dissemination of the articles used in the doctoral thesis. Publications were published in indexed journals and conference proceedings which helped with the training and development of the doctoral candidate.

The scientific articles which were published by the PhD candidate are summarized (along with their impact factor, and H index) below:

1. **Hajj, C. E.,** Jawad, D., & Montes, G. M. (2021). Analysis of a Construction Innovative Solution from the Perspective of an Information System Theory. *Journal of Construction Engineering and Management*, *147*(9), 03121003. (IF: 4.44, H-index: 114). https://doi.org/10.1061/(ASCE)CO.1943-7862.0002120.
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List of Acronyms

2D	Two-Dimensional
3D	Three-Dimensional
AEC	Architecture-Engineering-Construction
AIC	Akaike’s information criterion
BIM	Building Information Modelling
CBA	Cost-Benefit-Analysis
DMAIC	Define-Measure-Analyze-Improve-Control
GCC	Gulf Cooperation Council
IFC	Industry Foundation Class
IPD	Integrated Project Delivery
IRR	Internal Rate of Return
IS	Information System
KSA	Kingdom of Saudi Arabia
KW	Kruskal-Wallis
KMO	Kaiser–Mayer–Olkin
LC	Lean Construction
ME	Middle East
MENA	Middle East and North Africa
NPV	Net Present Value
NV	Nominalization Value
O&M	Operation and Maintenance
RFI	Requests for Information
RII	Relative Importance Index
N	Sample Size
MIS	Mean Item Score
RFID	Radio Frequency Identification
ROI	Return on Investment
RQ	Research Question
SD	System Dynamics
SS	Six-Sigma
ST	Socio-Technical
STT	Socio-Technical Theory
UAE	United Aarb Emirates
UK	United Kingdom
UNHCR	United Nations High Commissioner For Refugees
WESP	World Economic Situation and Prospects
PCA	Principal Components Analysis
RBV	Resource Base View

SPSS	Statistical Package for the Social Science
NLS	Nonlinear Least Squares
LCA	Life Cycle Assessment
SME	Small to Medium Enterprise
US	United States
UNCH	Untied Nations for Children’s Fund

Resumen

Building Information Modelling (BIM) se ha identificado como un avance notable en el modelado de procesos de construcción que lleva consigo importantes mejoras en la productividad de la construcción. La utilización del BIM está despegando en muchos países de todo el mundo, existiendo una creciente demanda de BIM en la región de Oriente Medio (ME) debido a la necesidad urgente de mejorar su productividad. Igualmente, su utilización trata de solventar problemas persistentes derivados de la naturaleza fragmentada de la industria ydel carácter multidisciplinar de los equipos de trabajo. Esta investigación tiene como objetivos (1) analizar los patrones de difusión de BIM en la industria de la construcción rn las región Oriente Medio y Norte de África - MENA, (2) presentar una visión integral de las barreras que impiden la adopción de BIM en los países en desarrollo de MENA y (3) y examinar el valor comercial de BIM dentro del entorno natural de las empresas de construcción de la región MENA a través del desarrollo de un modelo cuantitativo.

La investigación se llevó a cabo aplicando una metodología mixta (cuantitativa y cualitativa) para recopilar y analizar los datos. Se recogieron 512 cuestionarios y se realizaron un total de 15 entrevistas. El estudio estadístico se realizaó mediante el software SPSS permitiendo la interpretación de los datos recabados. Como parte del análisis de las entrevistas, se empleó el análisis de contenido.

Aunque la industria de la construcción en la región MENA camina en la dirección correcta para adoptar BIM, su utilización se está limitando a la visualización 3D y la coordinación 3D y es ajena a otras funcionalidades fundamentales como la logística y la planificación de la seguridad. El estudio confirma que la difusión de las funcionalidades BIM está impulsada principalmente por el comportamiento imitativo (factores internos) más que por los cambios en las regulaciones gubernamentales y la demanda del cliente (factores externos).

Además, a pesar del potencial de BIM, y aunque las empresas de construcción de la región MENA pueden ver en peligro su viabilidad a medio y largo plazo si deciden no invertir en BIM, las empresas siguen siendo reacias a adoptarlo. La falta de demanda de los clientes junto con los altos costos de adopción está desacelerando su difusión en la región MENA.

Es esencial una implicación de todas las partes interesadas en el sector de la construcción, incluidos el gobierno y los organismos reguladores profesionales, para proporcionar regulaciones y desarrollar estándares de la industria que guíen la implementación. Además, sería recomendable desarrollar marcos que proporcionen evidencia de los costos y beneficios de BIM para ayudar a las empresas a sopesar los riesgos frente a las oportunidades y determinar si la rentabilidad de la inversión en BIM.

Por lo tanto, un marco de costo-beneficio que tenga en cuenta todas las interacciones entre los costos y beneficios BIM dentro de la complejidad de los entornos del sistema corporativo del mundo real ayudaría a las empresas de la región MENA en su toma de decisiones hacia la adopción.

Palabras clave: Building Information Modeling, BIM, Funcionalidades, Barreras, Beneficios, Costos, Modelos de Difusión.

Abstract

Building Information Modeling (BIM) has been identified as a noticeable advancement in construction process modeling that brings revolutionary improvements in construction productivity. BIM is taking off in many countries across the world, there is an increasing demand for adopting BIM in the Middle East (ME) region due to the urgent need for improving its productivity and overcoming its persistent problems resulting from the fragmented nature of the industry and the multidisciplinary network of involved participants. This study aims at (1) analyzing the diffusion patterns of BIM in the MENA construction industry, (2) presenting a comprehensive view of BIM adoption barriers in the MENA developing countries, and (3) and examining the business value of BIM within the natural setting of MENA construction firms through developing a quantitative model that can be used to analyze the costs/benefits of investing in BIM.

A mixed methodology (quantitative and qualitative) was adopted to collect and analyze data. A sum of 512 questionnaires was collected and a total of 15 interviews were conducted. To analyze the questionnaire, SPSS was used to interpret the data. As part of the analysis of the interviews, content analysis was employed.

Although the MENA construction industry is moving on the right track for adopting BIM, it is using BIM mostly for 3D visualization and 3D coordination and is oblivious to other fundamental functionalities such as logistics and safety planning. The study confirms that the diffusion of BIM functionalities is mainly driven by the imitative behavior (internal factors) rather than the changes in government regulations and the client's demand (external factors).

Moreover, despite the potentials of BIM, and although MENA construction firms will not survive in the long term if they choose not to invest in BIM, firms are still reluctant to adopt it. The lack of client demand coupled with the high costs of adoption is decelerating its diffusion in the MENA region.

Therefore, it is recommended that MENA construction stakeholders including the government and professional regulatory bodies work together to provide regulations and develop industry standards that guide the implementation. Moreover, developing frameworks that provide evidence of the costs and benefits of BIM are recommended to support firms in weighing the risks versus the opportunities and determining whether the investment in BIM pays off in the long run or not. Therefore, a Cost-benefit framework that takes into consideration all the interactions between BIM costs and benefits within the complexity of the real-world corporate system environments will help MENA firms in their decision making towards the adoption.

Keywords: Building Information Modeling, BIM, Functionalities, Barriers, Benefits, Costs, Diffusion Models.

Part I

INTRODUCTION, AIM AND RESEARCH IMPACT

Chapter 1

An Introduction to the Study

1.1 Introduction

This opening chapter provides the reader with an introductory overview of this thesis. It sets this out its background, justification and provides an overview of the research process. This chapter presents the background of this research, demonstrating the real gap of knowledge and the opportunity to investigate implementation of Building Information Modelling (BIM) in the context of construction industry in the MENA region. The chapter also describes the problem to be investigated, stating the research aim and objectives, and briefly presents the researcher's motivation for this research and scope of this study. Finally, the chapter presents an outline of the research methodology and proposed research structure.

1.2 Background of the Study

Building Information Modelling (BIM) is a collaborative way of working, underpinned by the digital technologies, which unlock more efficient methods of designing, creating and maintaining firms' assets (Merschbrock & Munkvold, 2015). It is a major technological advance that has been attributed for its ability to enhance the collaboration among stakeholders, increase the efficiency of the procedures, and reduce the project's costs and mitigation risks (Aibinu & Venkatesh, 2013). BIM proved to enhance the design, collaboration, and communication among parties (Alhumayn et al., 2017).

The global Architecture, Engineering, and Construction (AEC) is currently experiencing a transitional phase towards BIM adoption as the technology has proved its ability in revolutionizing the work processes thru changing the planning and design activities from two-dimensional (2D) drawing toward three-dimensional (3D) models.

The integration of BIM is on the rise due to figuring out its potentials in creating a procedural evolution in the construction industry (Liu et al., 2017) The European Union has mandated the use of BIM in construction projects (Eadie et al., 2013). Finland, Norway, UK, and Sweden are considered leading countries in developing and implementing BIM (Group, 2015) within Europe. BIM in the US is required in all governmental projects and the US Army Corps of Engineers (USACE) have worked with BIM models since 2003 (Ghaffarianhoseini et al., 2017). Singapore is one of many countries leading to develop BIM standards and introduce the tools into practice. The Building Construction Authority (BCA) developed the "Singapore BIM Guide" which is used as a reference for BIM implementation (Rogers, 2015). In Australia, 70% of stakeholders have participated in BIM-related projects (Aibinu & Venkatesh, 2013). In the Middle East (ME), Dubai is the leader in terms of mandating the use of BIM in the region (Gerges et al. 2017). BIM in Qatar has not yet been requested as an obligation; however, its implementation has increased during the last years especially in stadium projects for FIFA 2022. The proven benefits of BIM and a growing global trend for implementing BIM have also influenced the Gulf Cooperation Council GCC construction market, creating significant growth and trend towards BIM adoption, especially in the United Arab Emirates (UAE) and Kingdom of Saudi Arabia (KSA). Other countries in the MENA have shown a shy level of BIM integration in construction projects namely Lebanon and Jordan where the penetration rate does not exceed 12% (Ahmed, 2018) (Jawad et al., 2019).

The Architecture-Engineering-Construction (AEC) in the Middle East (ME) region is still seen as a fragmented and waste-producing industry and there are growing calls for that to change. Therefore, the shift towards a digitized sector (the BIM movement) was brought about in response to calls for required change in the MENA construction sector to profit from the various benefits BIM brings to the construction industry. However, the regional construction industry in the MENA region lacks the needed experience to invest and adopt BIM and lacks strategic and technical expertise required to manage the change in work practices with BIM implementation.

Therefore, although the introduction of BIM to MENA region will bring potential for new opportunities for the construction companies in terms of cost savings and productivity improvements, it will also introduce a new line of fears and concerns in the local construction market related to capacity building to deliver BIM requirements and effective implementation of BIM on the projects.

This research is designed to study the BIM implementation practices in the MENA construction industry. It attempts to examine BIM adoption practices in the studied region and assess its implication on the firm's business value.

1.3 Research Motivation and Justification

While the movement towards supporting technological innovations and employing full digitization have lately governed the manufacturing environment of many sectors (Kagermann, 2015), the AEC industry in the MENA region is mainly still following the conventional project delivery method in which the design and documentation are non-parametric, manual, and paper-based (Leviäkangas et al., 2017).

Moreover, the MENA construction industry has been continuously criticized for its traditional practices leading to delayed projects, waste in production, unsatisfied clients, over-budgeted projects, poor health and safety merits, and inefficient use of resources (Abolghasemzadeh, 2013) (Alaloul et al., 2018).

To push the industry to move forward, BIM adoption is being advocated (Alaloul et al., 2018) mainly because the construction industry in the MENA region is passing through an exceptional growth, where the construction projects have become extensive, complex, and highly competitive due to the presence of multinational companies especially in countries such as UAE, Qatar, and KSA. It is home to some of the most innovative building projects in the world. Not only are these projects iconic, but they are also complex and demanding for the project teams, which are often based around the globe.

Previous studies have emphasized that the demand for tight schedules on projects in this region is particularly restrictive. The project delivery time is a critical factor in the MENA construction industry due to its dependency upon expat labor and technical experts. Project delays has been a major and consistent problem in the MENA construction industry where 70% of the project are found not to be finished on schedule, for which inefficient planning and control, lack of site management and poor resource management are the key reasons (Gerges et al., 2017).

Therefore, the MENA construction industry must adopt modern project management techniques and the latest digital techniques that can improve the work practices, and eventually the productivity of the MENA Architecture Engineering and Construction (AEC) industry.

1.4 Research Problem

With today's increasing demands in the construction sector coupled with public scrutiny and stringent financial resources, MENA companies can no longer afford to rely on traditional methods and use CAD techniques to conduct their business, thus they need to adopt new technologies such as BIM to manage their operation more efficiently and meet clients demand (Doumbouya, Gao, G., & Guan, 2016).

BIM adoption can be the solution for the inherent problems in the MENA construction industry as discussed in the above section and offers a set of benefits to improve the productivity of the sector. Yet, despite the variety of benefits that BIM provides, its full benefits have not yet been fully realized (Dainty et al., 2017). One of the reasons for such a divergence between the expected benefits and the realized benefits of BIM can be justified by the difficulties regarding how to implement BIM and by the type of BIM functionalities that are adopted at the organizational level.

BIM adoption is not straightforward it requires the collaboration of various parties through the work process at both the project level and at the organizational level to change the traditional construction project delivery practices, and enhance the multidisciplinary and complex, nature of the construction value chain that often results in quality problems as well as time and cost overruns (Bygballe and Ingemansson 2014; Foster 2008). Several challenges are confronting BIM adopting firms. Adoption of collaborative technologies such as BIM impacts every component of the social and technological infrastructure of the adopting organizations (Bosch-Sijtsema et al., 2017). The profound changes introduced by BIM can lead to complex interoperability issues in many organizations (Murphy, 2014). One of the key reasons that many construction firms have only realized marginal benefits from BIM is that it is currently being treated as a project-level initiative rather than an innovation. (Murphy, 2014).

Moreover, the lack of experienced personnel and problems with financial support, raise questions related to finance and resource commitments for the companies making a move towards BIM adoption, especially in developing markets like Lebanon, Algeria, Morocco, and Syria.

The main questions are related to:

1) What are BIM adoption barriers?
2) Are they perceived identically by all stakeholders?
3) How to overcome them?
4) What are the benefits of the adoption?
5) Is the adoption of BIM worth it?
6) What are the financial implications of the investments are
7) What are the patterns affecting the diffusion of various BIM functionalities?

A substantial body of ~~scientific~~ academic literature focuses on the factors influencing BIM adoption and implementations, including identification of the benefits, challenges, and criteria to be assessed. However, there has been little research into the financial implications of BIM on the firm's business value. Studies that provide a clear framework that assess BIM business value are dearth. Moreover, full successful implementation of BIM requires the adoption of various BIM functionalities. However, there is limited use of various functionalities in the MENA region, and there is a lack of research about the factors (external and internal) that affect the broader adoption of BIM functions and may influence the rate of BIM diffusion among the potential adopters (Panuwatwanich & Peansupap, 2013).

The above-mentioned issues and the varying level of BIM experiences of construction companies illustrate the need for a comprehensive analysis of the issues associated with BIM adoption in the MENA construction sector.

Therefore, the problem being addressed in this research is the need to investigate BIM applications in the context of the MENA construction industry.

1.5 Research aim

The overall aim of this research is to investigate how the MENA construction firms are implementing BIM technology. To achieve this aim, the following specific research question needs to be answered:

- *RQ1: What are the most frequently reported barriers to widespread adoption of BIM within the global AEC industry and in the particular MENA context?*

- *RQ2: How can these barriers be explained by means of established theoretical foundations from IS research to enhance the understanding of their implications for practice and research?*
- *RQ3: What BIM functionalities are mostly used in the MENA region?*
- *RQ4: What are the most significant diffusion patterns of various BIM functionalities across the Middle East (ME) construction industry.*
- *RQ5: What are the costs and benefits associated with the adoption of Building Information Modelling (BIM) at the corporate level?*
- *RQ6: How can the complex interrelations between benefits, costs, and the elements of the corporate system be identified and visualized more effectively before quantifying the overall economic impact of BIM on a corporate level within a cost-benefit analysis (CBA)?*

Based on these research questions, the objectives of this study are to:

1. *Identify the key barriers hindering for successful BIM implementation in construction organizations.*
2. *Examine the barriers from the lens of the Socio-technical theory.*
3. *Assess the adoption rate of various BIM functionalities.*
4. *Compare BIM adoption barriers to other innovative solutions in the construction industry.*
5. *Examine the diffusion patterns of various BIM functionalities across the Middle East (ME) construction industry using the innovation diffusion models.*
6. *Develop a quantification model that is based on design science research and provides an enhanced understanding of cost and benefit implications arising from BIM investments from a systems theory perspective.*
7. *Examine the interplay of costs and benefits of BIM with the subsystems of the organization.*

1.6 Justification of the Study

This study aims to examine the adoption and implementation of BIM in the AEC industry if the MENA region. An extensive review of the literature show that no previous studies had been undertaken specifically with regards to BIM implementation and adoption in the construction industry of MENA region and none of the previous studies has developed a framework to assess the financial implications of BIM within the MENA context. The goal of the study was to provide insight into the benefits, barriers, diffusion patterns of BIM functionalities, and the cost-benefit analysis of BIM within construction companies in the MENA region.

1.7 Research Methodology

Firstly, this research carried a comprehensive literature review about BIM technology. The literature review presents a critical analysis of the experiences of the use of BIM technology in the global construction industry, and the benefits and barriers to implementing this technology in the world.

Then subsequently the research adopted a mixed-methods approach through the combined use of quantitative and qualitative strategies by conducting a questionnaire survey to study the diffusion pattern of BIM technology in the MENA construction industry. To develop the quantitative framework that assesses the financial implications of BIM and its impact on the firm's business value within the context of the MENA construction firms, the researchers conducted semi-structured interviews to collect the primary data. It also entailed the analysis of the collected primary data using inferential statistics for the quantitative data and thematic content analysis for the qualitative data. All of the above-mentioned made it possible to provide justification, draw conclusions and make recommendations regarding the future use of BIM technology in the MENA construction industry.

1.9 Structure of the Thesis

The thesis is composed of this introduction, aims and research impact, five main chapters and the final chapter of general and combined conclusions. In turn, each main chapter comprises an introduction, methodology, results and discussion, and conclusions so that they can be read individually.

Due to the variety of topics and approaches used in the five main chapters, it was preferable to construct each independently for its optimal understanding.

Chapter 1 provides an overview of the entire research process. It begins by setting out the background to the research. This is then followed by the problem statement, the gap in knowledge, research aim, objectives, and a brief explanation of the research methodology adopted. This leads to the significance of the research. Finally, the summary of the chapter is stated.

Chapter 2 reviews the literature regarding the background to the construction industry innovative solutions. The chapter presents an introduction to BIM, and then goes on to discuss the principles of how BIM is developed to aid projects in the construction industry. It also presents an evaluation of studies on how BIM is used in countries across the globe. This chapter goes on further to review the benefits of BIM as well as the barriers to its adoption within the construction industry in general, besides the challenges of BIM adoption and implementation particularly in the MENA region. moreover, The chapter introduces some theories that are widely used to examine BIM diffusion.

Finally, this chapter presents an overview of the literature on the nature and characteristics of the MENA construction sector.

Chapters 3, 4, 5, 6, and 7 each present an analysis of a given BIM topic. Chapter 3 presents a bibliometric analysis of BIM benefits, with its temporal and global evolution. Chapter 4 presents a meta-analysis of BIM adoption barriers based on a regional comparison. Chapter 5 presents a comparative analysis of BIM with other innovative solutions such as Lean, Six Sigma, and ID and analyze BIM barriers from the lens of the Information System Theory. Chapter 6 presents the findings of the quantitative data analysis which was carried out using the statistical software SPSS to conduct cross-tabulation and correlations to analyze the relationships amongst the variables and evaluate the pattern of BIM functionalities diffusion and determine the factors that affect the adoption of BIM functionalities in the MENA region. Chapter 7 and 8 present the findings of the qualitative data analysis which was undertaken by thematic content analysis method to establish the costs and benefits of BIM adoption in the MENA region. Then successively a framework is created based on the interplays of BIM costs and benefits to assess the financial implications of BIM on the firm’s business value.

Chapter 9 presents the findings, conclusions, and recommendations of the research, outlining the key findings contributions, and limitations, making recommendations for BIM policies and practice and proposing recommendations for future research development.

Part II

<u>REVIEW OF THE RESEARCH TOPIC</u>

Chapter 2

A Review of the Literature

The literature review is aimed to establish a theoretical understanding of the concept of Building Information Modeling (BIM), its benefits, its uses, and the barriers limiting its adoption. It has been used in two stages, first to assure the researcher's understanding of the prior knowledge in the subject, and secondly to be used in comparison with the empirical data. The areas of interest for the literature review are: Trending innovations in the construction industry, BIM as a concept, benefits of BIM, and BIM adoption, and BIM use. The sources have mainly been refereed academic research journals, refereed conferences, dissertation/ theses, reports/ occasional paper/ white papers, government publications, and books.

2.1 Background of Building Information Modeling (BIM)

2.1.1 BIM Definitions

Building Information Modeling (BIM) is one of the significant tools that is changing the dynamics of the construction industry and promoting the use of collaborative-based information methodologies. BIM was firstly introduced in the form of product modeling in late 1970s research (Howard & Björk, 2008), aiming at integrating processes throughout the whole project lifecycle (Aouad & Arayici, 2010). It is argued that the fundamental idea of BIM is to provide information on a shared database to enable better collaboration and communication among stakeholders (Azhar, 2011; Bryde et al., 2013) and to enable a network of interdependent companies in the form of a supply chain to collaboratively develop a virtual building information model (Taylor, 2007).

BIM is perceived as a platform of information that assists in synchronizing and visualizing production (Tezel et al. 2015). The term BIM appeared in 1992 when Van Neverdeen and Tolman proposed modeling information building based on multiple features such as spatial design and building structures (Van Nederveen & Tolman 1992). Since then, different definitions of BIM that fit different applications are introduced in the literature. Earlier definitions of BIM perceived it as computer-aided modeling technology that serves as a storing tool of all the information of a facility (Ibrahim et al. 2004), it is a shared knowledge of all the data needed to coordinate the exchange of information between practitioners (Di Giuda et al. 2015). A more specific definition portrays BIM as a digital representation of the functional characteristics of a project, which refers to the process of generating and managing building data throughout the life cycle of a facility and form a reliable basis for decision making (Eastman et al. 2011; Nawi et al. 2014). Currently, BIM is referred to as a “model of information that comprises sufficient information to support all lifecycle processes” (Chan et al. 2019). BIM is not only a tool that promotes coordinating among practitioners but also allows the attachment of the facility components to parametric data that describes its attributes (CIFE 2007; Lee et al. 2015; Lu et al 2017; Zhou et al. 2017) and virtually building the project (Stanley & Thurnell 2014; Saieg et al. 2018). Thus, eliminates the inefficiencies through its intelligent multi-dimensional model-based process (Ustinovičius 2005; Reizgevičius et al. 2018). Ideally, a BIM model includes digital information related to all phases of construction projects in the form of a data repository (Gu et al., 2010). Project participants within a BIM environment no longer share traditional two-dimensional design and construction documents. Instead, they share multi-dimensional models with parametric capabilities (Bryde et al., 2013). BIM allows involved parties to insert, extract, update or modify information at the same time . In addition, information required for each particular phase of a building, such as scheduling and planning, can be extracted from the building information model (Čuš-Babič et al., 2014; Eastman, 2011). Eastman (2011, p. 1) points out that BIM offers “the basis for new construction capabilities and changes in the roles and relationships among a project team”. Hence, BIM creates the opportunity for a more integrated design and construction process. Various definitions of BIM have been presented in the literature, and there is no universally accepted definition of BIM (Aranda et al., 2009). While some consider BIM as software that provides 3D modeling, others consider it as a process. Yet BIM can be considered in a broader perspective (Barlish & Sullivan, 2012b; Succar, 2009. The National Building Information Modelling Standard (NBIMS) defines BIM as a repository of information that presents all the physical and functional characteristics and information of a building throughout its lifecycle for building owners and operators. Taylor and Bernstein (2009) define BIM as the “parametric three-dimensional (3D) computer-aided design (CAD) technologies and processes” in the AEC industry. However, BIM is not merely a technology that provides paramount visualization and intelligent models

(Azhar, 2011). BIM allows the team members to insert, extract, update, or modify information in a shared digital representation. It enables them to reuse the building information throughout the lifecycle of a building. Moreover, BIM transforms traditional construction processes. Therefore, BIM can be considered a process that facilitates integration, interoperability, and collaboration among the members (Vanlande et al., 2008).

2.1.2 BIM Levels and Dimensions

Today, the construction industry is experiencing a gradual shift from paper-based 2D CAD drawings to object-oriented 3D digital models which is driven by the application of BIM, as reflected in Bew-Richard's BIM maturity model shown in figure 2.1.

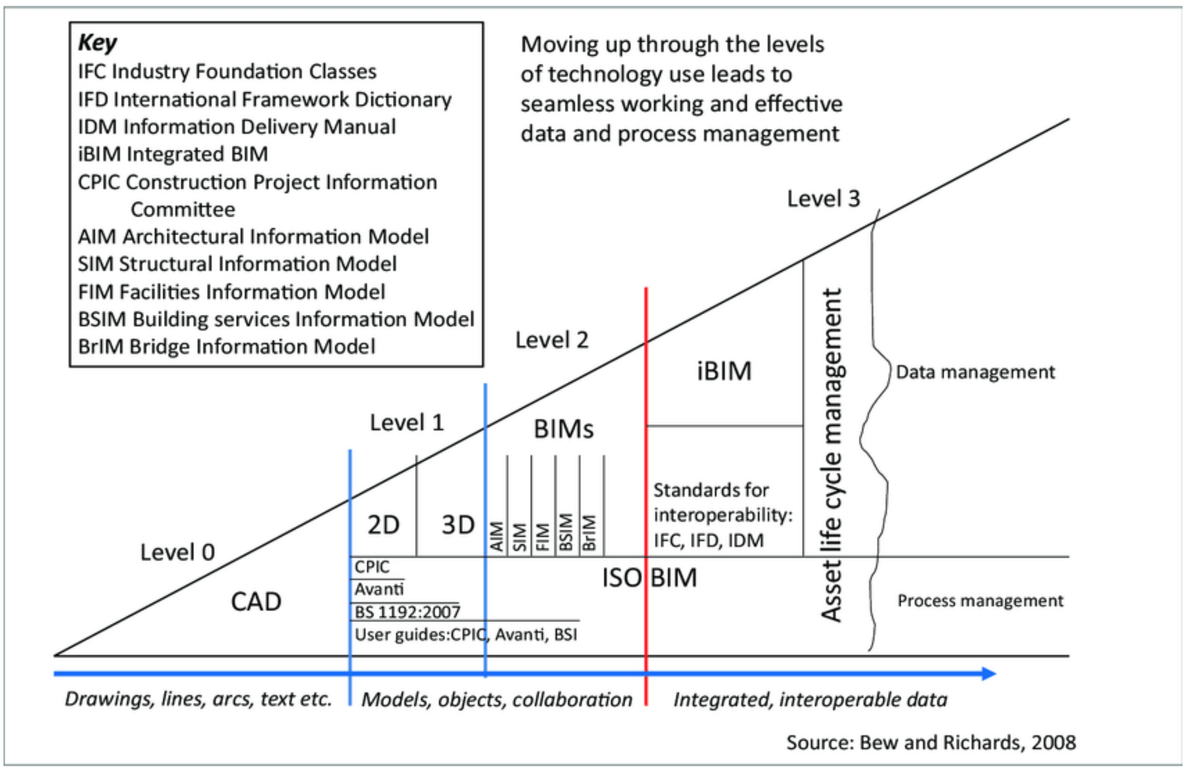


Figure 2.1: BIM maturity Model (Bew-Richard's, 2008)

BIM maturity level determines the degree of efficiency in implementing the technology and process to collaborate the building information in a project environment. Level 0 BIM maturity reflects unmanaged CAD in 2D that is represented and exchanged in paper documents (including electronic documents). Level 1 explains a managed CAD environment using 2D and 3D representations of the building information. Information content at level 1 is created by using standardized approaches to data structures (CAD standards), and stored in standard formats that can be exchanged among different CAD applications.

Level 2 maturity represents a managed BIM environment that contains intelligent BIM models held in separate disciplines (discipline models), shared and coordinated using a structured approach on a CDE and integrated using proprietary or bespoke middleware software for design (e.g. Architectural structural etc.), analysis (e.g. Energy analysis, clash detection), project 29 management (e.g. 4D, 5D) and maintenance purposes (PAS 1192-2, 2013). Level 3 BIM represents fully integrated and collaborative BIM-enabled by web services to collaborative building information using open standards without interoperability issues and extending BIM applications towards lifecycle management of building projects.

A basic Building Information Model is an object-oriented 3D model which has various applications and uses in different project stages but it is not limited to that, it can be a 4D, 5D or nD model (Aouad et al., 2005) extending the BIM applications throughout the project life cycle. These are called BIM dimensions in literature (AGC, 2006), and are briefly explained in the following points:

• 2D BIM: BIM model is 3D but it can be used to generate 2D drawings and documents (Autodesk, 2002).

• 3D BIM: Object-oriented 3D geometric models with embedded intelligence, semantic, functional, and performance information which can be used for visualization, navigation, clash detection, design interrogation, etc, (Autodesk, 2002; Azhar et al., 2012; Nederveen et al., 2010).

• 4D BIM: Associating time (Schedule) with geometry turn a 3D BIM model into a 4D mode that can be used to simulate production assembly and progress monitoring, (Turkan et al., 2012; Zhou et al., 2013).

• 5D BIM: Adding cost and budged information to a 4D BIM model is called 5D modeling, creating a 5D BIM model for automated estimation and cost management (Mitchell, 2012; Popov et al., 2010).

• 6D BIM: 6D BIM model contains procurement, supply chain information, and production information. An as-built model or FM model is also called a 6D model, (Hardin, 2009).

• 7D BIM: Integration of sustainability components and related information in a BIM model makes it a 7D model (Nederveen et al., 2010).

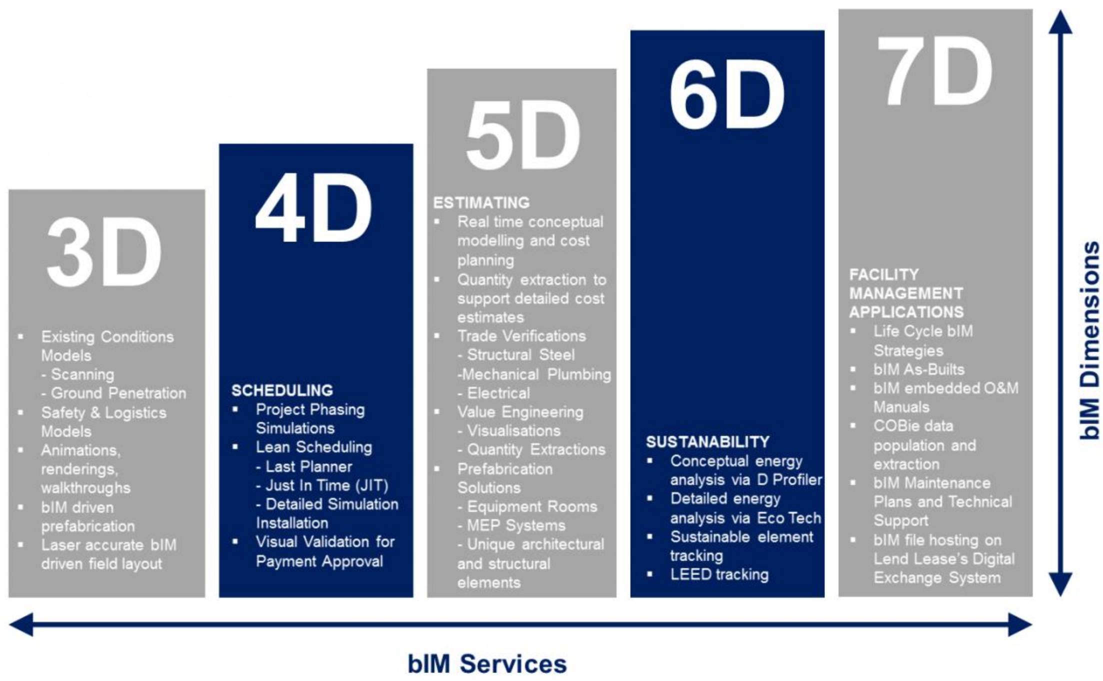


Figure 2: Seven Dimensions model of BIM

• nD BIM: An nD BIM model is theoretical and indicates that the applications of the BIM model are numerous and can achieve any number of dimensions in the future (Aouad et al.,2005 and Fu et al., 2006). 6D & 7D BIM are not yet clear and therefore their definitions are often overlapped or confused. This study is limited to investigating BIM uses and applications up to 5D models, mainly focusing on BIM applications in construction planning and production which are achieved with 4D models. Therefore, this study will limit itself to exploring 3D, 4D, and 5D aspects of BIM and their application and impact on productivity, with a focus on 4D, in the later sections.

2.1.3 BIM Benefits

The construction industry has long sought to overcome the construction challenges and increase construction productivity. It is argued that BIM is a solution to achieve these long-standing objectives (Azhar & Brown, 2009). According to BIM professionals, BIM can provide a number of benefits for construction projects such as: accurate representation of the building objects, effective processes, efficient design, better control on whole life data of buildings, a better understanding of life cycle costs, better access to the details designed objectives and more predictable environmental performance, increased quality in production, automated assembly, better customer service, and better Facility management (Chan et al., 2019).

Studies in the UK show that BIM led to project time reduction of 7%, contract value by clash detections decreases 10%, cost estimates accuracy increase of 3%, reduction in time used for preparing cost estimates by 80%, dismissal of unbudgeted change by 40% (CIFE, 2007).

Wide support for BIM is due to its various benefits throughout the project lifecycle. The result is anticipated to greatly support decisions and reduce the processes through reducing the information loss that occurs when a new team takes "ownership" of the project as well as in delivering extensive information to owners of complex (Leite et al., 2011).

BIM helps in identifying design conflicts before construction, enabling the prefabrication of components prior to construction, and accurate geometric representation of all parts of a facility (Becerik-Gerber & Rice, 2010).

During construction, BIM helps to reduce rework, reduce Requests for Information (RFIs) and change orders, increase customer satisfaction through visualization, improve productivity in phasing and scheduling (Leite et al., 2011). The benefits of the BIM technologies span the entire construction lifecycle starting from the conceptual design/feasibility stage to the handover and facility maintenance stage or even up to the decommissioning or demolition of the building (Enshassi et al., 2018). To sum up, the most common benefits of BIM can be identified as follow:

Reduce project cost: companies adopting BIM have reported a positive return on their investments. Close collaboration with contractors can lead to a reduction in tender risks, lower insurance costs, and fewer opportunities for claims and variation (Lu et al., 2017).

Improve scheduling: BIM helps in reducing the time of project cycles and eliminating schedule setbacks. It allows documentation to be done at the same time as the design allowing Schedule can be planned more accurately (Stanley & Thurnell, 2014)

Improve the quality of work: the tool automatically checks models against spatial requirements. By automating such tasks, the quality and speed of design improve greatly (Zhou, et al., 2017).

Increase visualization and simulation. BIM allows receiving early feedback from downstream players through program simulations. By linking a high-level project plan during the feasibility study/concept development stage and developing a 4D model, a significant amount of variability can be reduced through a constructability review (Stanley & Thurnell, 2014).

Accurate representation of the building: with earlier 3D (non-BIM) technologies where geometric models were created with non-parametric technology, significant time and effort were required to generate such visualizations which were not accurate at many times. With the advent of BIM technologies, visualization of the design at any stage is allowed to accurately reflect the design (Stanley & Thurnell, 2014) (Linderoth, 2010).

Reduce reworks: drawing generation from the majority of BIM systems is an automatic process that allows drawings to corresponding to the current model ensuring accuracy and reducing reworks and RFIs (Love et al., 2015). Design is an iterative process where changes are made constantly. BIM allows to control and link the object properties in a parametric way and hence changes made to one element ensure that all connected objects change their properties in a parametric way (Saieg et al., 2018).

Improve collaboration and communication: BIM allows collaborating and sharing of information. With cloud-based tools, BIM collaboration can occur among all disciplines. The model allows practitioners to share models, coordinate planning. BIM ensures that all stakeholders have input and insights into the project and have access to up-to-date information at any time (Lu et al., 2017) (Zhou, et al., 2017).

Accurate estimates: introducing estimators in the planning stage allows for more effective cost estimation. BIM automates the time-consuming task of quantifying and applying cost.

The possibility to generate automatic cost estimates based on the BIM model at any stage during design enables the client to make a better-informed decision. During the bidding/tendering stage BIM provides an accurate bill of quantities to all bidders (Zhou, et al., 2017).

Improve productivity: BIM enables carrying out sophisticated simulations such as acoustics, energy, and lighting during the design stage to make sure the facility performs to the requirements (Eastman et al., 2011).

Allows early clash detection: BIM helps in synchronizing design models from all disciplines before construction begins to identify any hard (physical) or soft (tolerance) clashes between elements. This ensures not delaying the construction process and minimizes rework (GhaffarianHoseini et al., 2017). BIM gives the opportunity to plan it right from the first time, where one can avoid last minutes changes and unforeseen issues.

Better facility management: An accurate as built model that carries up-to-date information about a facility's assets and its operational data can be extremely useful. When the facilities management system is integrated with the BIM, the operatives can bring up relevant information to reduce the time taken to respond to a call.

Table 2.1 presents a summary of the benefits earned from the implementation of BIM in the construction industry according to the literature.

Table 2.1: Citation frequencies of BIM benefits in the construction industry

Number	Benefits of Implementing BIM Practices in the Construction Industry
B1	Reduction of the project time and schedule
B2	Reduce the final project cost
B3	Improve quality of the work
B4	Increase the efficiency of the process
B5	Allows clash detections at early stages
B6	Reduce errors, rework, RFI and Change orders
B7	Increase visualization and simulation
B8	Better control on whole life data of buildings
B9	Ensure an accurate estimate and plan
B10	Improve productivity and performance of the Facility
B11	Improve stakeholder collaboration and communication
B12	Accurate representation of the building objects
B13	Better Facility management
B14	Increase owner’s satisfaction.
B15	Make the scope and the information clearer
B16	Facilitate the implementation of green building
B17	Increase standardization
B18	Support decision making
B19	Facilitate resource planning and allocation
B20	Enhance sustainability
B21	Reduce risks
B22	Decrease energy usage
B23	Efficient design
B24	Dismissal of unbudgeted change
B25	Reduce construction waste
B26	Ensure retention of staff
B27	Enhance creativity and innovation
B28	Enhance The reputation of the company
B29	Helps the growth of the business
B30	Improving program through a spatial analysis
B31	Integrating supporting systems with BIM
B32	Easy Code reviews

2.1.4 BIM Adoption Barriers

How BIM is being used in the construction industry is revealing difficulties that have to be addressed. Limitations are encountered because historical data is not readily available due to the lack of recordkeeping. This software is still in its infancy, and although most experts consider BIM to be the future of the construction industry, the change over by architects and engineers is very slow. In the construction industry, BIM is more widely accepted because of the ways that it links with currently used scheduling and estimating software.

Negative aspects of BIM have to be addressed for the technology to be successfully integrated into the construction industry. There are a lot of specific requirements with structure, inspections, etc. that relate to the International Building Code. A BIM model must be capable of recognizing project locations to meet regional building codes, especially for overseas projects. All the input from users accessing the drawings may become problematic. Sealing of drawings may prove to be difficult if different people have input to the drawings, how will professionals be able to verify that they witnessed what work had been done on the BIM model. This also applies to the actual program; BIM is supposed to make changes for the user. How will the engineers be able to identify all the changes that the program itself can make to the model and would they be willing to sign and seal the drawings not knowing what changes may have taken place from their original intent or design,

Factors affecting BIM adoption in the construction industry can be grouped into two different categories: technical tool function requirements and needs, and non-technical strategic issues (Gu & London, 2010). Technical barriers can include interoperability issues, lack of BIM standards, errors, and accuracy issues. Interoperability is the smooth sharing of information among stakeholders across platforms to share data (Bryde et al., 2013). While BIM standards such as IFC and gbXML schema do exit, no information infrastructure has been unanimously adopted across the entire AEC industry. Non-technical strategic issues include cost, lack of management buy-in, stakeholder reluctance, time constraints, lack of skilled personnel, organizational issues, contractual and legal concerns. Employees at the bottom of the learning curve using BIM will inevitably take more time to to perform a task than an employee that is well versed in the same software program. Another major non-technical barrier to implementing BIM is the process-related risks, such as, ownership of design/ data, model protection, and standardizing a processor updating the model (Azhar, Khalfan, & Maqsood, 2012). Table 2.2 shows a list of 39 barriers found in the literature.

Table 2.2: Barriers to the implementation of BIM in the construction industry

Number	Barriers
1	Commercial issues and investment cost
2	Cost of training
3	The complexity of the program
4	Lack of skills, qualified staff to carry out the BIM
5	Current technology is enough
6	People refuse to learn
7	Absence of Standard BIM Contract Documents
8	Legal impact and copyright
9	Lack of BIM specialist
10	Lack of client demand
11	Cultural resistance
12	Lack of additional project finance to support BIM
13	Resistance at the operational level
14	No need to change the conventional method
15	Difficulties in assigning responsibilities and liabilities
16	Collaborative nature of the design process
17	Interoperability
18	difficulty in assigning intellectual property allocation
19	Lack of legal backing from Authority
20	Lack of awareness and knowledge of BIM concept
21	Risk allocation,
22	Traceability
23	Legal issues around IP & PI insurance
24	Process implementation of a new software
25	Waste time and human resource
26	Unsuitable for the projects
27	Confidentiality
28	Lack of government’s lead/direction
29	Lack of incentive to have stakeholders using BIM
30	The reluctance of team members to share info
31	Lack of immediate benefits /ROI
32	takes a long time to develop a schedule
33	Lack of software compatibility
34	distributed design decisions by third parties
35	software agents,
36	Lack of expertise of BIM within the project team
37	requested in the limited phase of the project
38	Absence of contractual requirement to implement BIM
39	Comparison between BIM and CAD

Researchers mentioned the financial challenge as a main hinder to the implementation. The initial expenses associated with education and acquiring the hardware and software necessary for transitioning from traditional projects to a work method where BIM can be employed in construction projects is high (Okeil, 2014; Louis, 2014; Chan, 2014; Enshasse et al.,2016; Ghaffarianhoseini, 2017; Turk & Klinc, 2017).

2.1.5 Status of BIM Adoption

The integration of BIM is on the rise due to figuring out its potentials in creating a procedural evolution in the construction industry (Borrmann et al., 2015). The European Union has mandated the use of BIM in construction projects (Eadie et al., 2013). Finland, Norway, UK, and Sweden are considered leading countries in developing and implementing BIM (Group, 2015) within Europe. BIM in the US is required in all governmental projects and the US Army Corps of Engineers (USACE) have worked with BIM models since 2003 (Ghaffarianhoseini et al., 2017). Singapore is one of many countries leading to develop BIM standards and introduce the tools into practice. The Building Construction Authority (BCA) developed the "Singapore BIM Guide" which is used as a reference for BIM implementation (Rogers et al., 2015). In Australia, 70% of stakeholders have been involved in BIM-related projects (Aibinu & Venkatesh, 2013). Yet, despite the excitement towards BIM adoption, its integration is not straightforward and differs from one region to the other. Authors agree that the above promising pictures are not present in developing countries where BIM is still in its infant stage (Chan 2014). In Africa, the implementation of both the process and the technology is relatively low (Jung & Lee, 2015). In Columbia, 60% of construction practitioners are non-BIM users (Aibinu & Venkatesh, 2013). In the Middle East (ME), BIM diffusion is in its early stage (Gerges et al., 2017), having Dubai as the leader in terms of mandating the use of BIM in the region. BIM in Qatar has not yet been requested as an obligation; however, its implementation has increased during the last years especially in stadium projects for FIFA 2022. Some countries in the MENA have shown a shy level of BIM integration in construction projects namely Lebanon and Jordan where the penetration rate does not exceed 12% (Ahmed, 2018) (Jawad et al., 2019). As it can be seen, the perception of BIM, as well as its penetration rate, differs from one region to the other. Several factors affect the decision toward BIM adoption as it is complex and requires a lot of resources.

2.2 Middle East and North Africa (MENA) Region

2.2.1 MENA Geographical Presentation

The MENA region refers to the Middle East and North Africa and covers the vast area from Southwest Asia to Northwest Africa. The area accounts for six percent of the entire world's population (El Masry et al. 2016) and includes the following countries: Algeria, Bahrain, Egypt, Iraq, Jordan, Kuwait, Lebanon, Libya, Mauritania, Morocco, Oman, Israel, Palestine, Qatar, Saudi Arabia, Syria, Tunisia, United Arab Emirates, and Yemen (UNHCR 2010 and UNICEF 2021). This region contains 60% of the worldwide oil reserves and 45% of the global natural gas reserves, therefore it is considered a substantial source of stability for the global economy (El Masry et al. 2016). In most MENA societies, there are great differences between rich and poor, and from many countries, great emigration is taking place.

The majority of the MENA region is characterized by a warm desert climate. Weather in this climate is very high during the summer and can reach dangerous levels, with parts of Iraq and Iran having recorded feel-like temperatures of over 160 degrees Fahrenheit (71 degrees Celsius). Average temperatures during the summer usually rest at around 120 degrees Fahrenheit (49 degrees Celsius), while the winters are somewhat milder. This climate also has very little rainfall, resulting in large desert regions. Areas of the MENA surrounding the Mediterranean, such as Israel and Lebanon, instead boast a warm Mediterranean climate like parts of Greece and Italy.

Many factors motivate considering the MENA as a whole entity to be studied. The first factor is the unified language (Arabic), which is used by most of these developing countries. The second is that the MENA has some resemblances in societal values, norms, and practices and shares many cultural, religious, and environmental similarities across its countries (Umar, 2021). The third factor is that MENA developing nations have some broad common characteristics, for example, the dependence on oil in most countries is heavy, the economic base of these nations is weak, the population growth is high, the unemployment rate is elevated, the dominance of the state in the economic sector is considerable, the level of integration with other world regions is low, the majority of the institutions are underdeveloped, and the rate of return on human and physical capital are low (Sabah et al. 2012; Makdisi, Louca and Kamsaris 2013). All of the above, pushed previous scholars to consider the MENA as one entity when examining various research topics (Louca and Kamsaris, 2013).

Considering the construction sector, it is known to have a leading role in the MENA economic growth. The key drivers for the development of the construction sector are increasing housing starts and rising infrastructure (Jawad et al. 2019). Previous scholars agreed that for the construction industry to continue to play its role in developing the region, it has to adjust to contemporary construction frameworks and promote innovative technologies such as BIM (Umar, 2021). BIM has evolved as a strategic resource for construction organizations in the MENA, allowing them to improve their business procedures, and re-organize their operational activities (El Hajj et al. 2021, Enshassi and AbuHamra 2017, and Hamada et al. 2016). However, BIM is documented to be a complex, problematic, hard to implement, and costly technology (Chen and Lu 2019).

2.2.2 BIM in the MENA region

The construction industry in the Middle East is growing rapidly due to the growing population and the greater demand for infrastructure projects. The UK government has mandated the use of fully collaborative BIM for government projects (minimum of 5m capital cost) by 2016 to reduce project delays and cost overruns (Constructing Excellence, 2008). This decision by the UK Government has put a lot of pressure on contractors as they currently making a rapid transition into BIM to meet the specified project demands (Withers, 2012). This mandate has resulted in the widespread of adoption of BIM especially in the Middle East, with the close economic relationship between the UK and the Middle East, which is reflected in the local dominance of British architects, project managers, engineers, and contractors. In addition, many multi-national firms have multiple offices across the Middle East region, which impose a wider adoption of BIM in construction processes across the Middle East.

BIM advancement in the Middle East is on the rise. The Dubai Municipality was the first public authority in the Middle East to mandate the use of BIM for most large-scale projects in the Emirate (Guideline for BIM Implementation 196, 2013). In Kuwait, (Gerges, n.d.) reports that BIM implementation improved communication, mitigated project risks by encouraging collaboration, and facilitated stakeholders in transparently monitoring the status of their project throughout the project phases (Gerges, n.d.). Building Smart reported on the adaptation of BIM in the entire Middle East region (BuildingSmart, 2011). The report concluded that the use of BIM in the Middle East region is not mandatory. The report surveyed the usage of BIM across the Gulf Cooperation Council (GCC) and Jordan and recommended how the use of BIM can be increased in the future. Although the survey showed that only 25% of people are using BIM, it was stated that the use of BIM has improved quality control, productivity, and reduction in design errors. In addition, the report stated that the lack of BIM specialists was a concern since 64% of people who received training are self-taught. With consultants and contractors accounting for the highest number of BIM users, 40% of respondents have stated that they have used BIM on more than 5 projects, but there were a large number of companies who have only implemented BIM for one project. 62% of respondents stated that the main reason why BIM has not been implemented is “that client has not asked for the use of BIM”. Also, there were 43% who did not know how to use BIM, and 41% were interested in using BIM but do not know how to start, and finally, 19% of respondents stated that BIM is too expensive to be implemented. In addition, (Awwad, 2013) explained that the Middle East has the lowest take up of BIM, with the public sector not taking any steps to implement it. Professionals in the Middle East look at BIM as just a tool that presents a 3D model of the building (Awwad, 2013). In addition, (Jung, 2015) researched across six continents stated that the Middle East employed BIM service overall for 3D coordination, design authoring, and clash detection. Recent research by (Mehran, 2016) showed that the nonexistence of standards along with related implementation costs and uncertain profitability are the main challenges when investigating the use of BIM in the UAE. Although other countries (apart from the Middle East) have highlighted similar reasons for the lack of adopting and implementation of BIM to those mentioned by current research in the Middle East, some factors motivate considering the Middle East as a whole entity when comparing it to the rest of the world. The first factor is the unified language (Arabic), which is used by all Arab countries. The second factor is the similarity of Arab cultures whereas most countries around the world have differentiated and distinguished cultures. The final factor is that most (if not all) construction practices within the Middle East use similar standards (mostly American or British) and protocols, which motivate the need for a holistic investigation of current BIM practices from different Middle Eastern countries.

2.3 Chapter's Summary

This chapter has provided a deeper understanding of BIM-related concepts and terminologies and the impacts of BIM on construction productivity. Firstly, this chapter has presented BIM definitions as a technology; process, and methodology from several literature sources including software vendors, the industry, and professional institutes and academics. The chapter has discussed the nature of BIM as a technology and collaborative processes in which BIM advantages over traditional CAD practices. Secondly, the chapter presents an understanding of BIM dimensions and various uses of 80 BIM, focusing on BIM uses in design, construction, and facility management. BIM tools and software applications are presented for an overview of the available BIM technologies. The barriers to the adoption of BIM at an organizational, process, and product (technology) level are explored. Following that, productivity in the construction industry is explored in detail. This chapter has reviewed the literature exploring the efforts to increase the productivity of the construction industry.

Part III

RESULTS

Chapter 3

BIM Benefits Knowledge Domain

3.1 Introduction

With today's public scrutiny and stringent financial resources, construction firms can no longer afford to rely on traditional methods to conduct their business. The need to change their approaches and manage their operation more efficiently is critical to meet the industry demands (Chang & Shih 2013). Yet, the complexity of the construction sector makes it harder to implement innovative working methods (Hardin & McCool 2015) unless they are widely proved and accepted (Van Eck & Waltman 2014).

Building Information Modeling (BIM) is one of the significant tools that is changing the dynamics of the construction industry and promoting the use of collaborative-based information methodologies. BIM is perceived as a platform of information that assists in synchronizing and visualizing production (Tezel et al. 2015) and serves as a storing tool of all the data needed to coordinate the exchange of information between practitioners (Di Giuda et al. 2015). Currently, BIM is referred to as a "model of information that comprises sufficient information to support all lifecycle processes" (Chang et al. 2018; El Hajj, 2021). However, BIM is not only a tool that promotes coordinating among practitioners, but it also allows the attachment of the facility components to parametric data that describes its attributes and virtually builds the project (Stanley & Thurnell 2014).

As BIM establishes an interdisciplinary research area at the interface between several disciplines, such as information systems, construction informatics, and construction management, the application of BIM in multi-disciplinary research domains can be reflected in scientific literature. Previous scholars aimed to uncover the unseen relationships of different knowledge domains, which are vitally important to the evolution of BIM, by filling literature gaps and recommending new research areas to contribute to the body of knowledge. For example, Zhou et al. (2017) applied the underlying semantic analysis to rearrange the unstructured data objects and explore the trends in BIM by retrieving several thematic words from the literature. However, their study did not highlight the temporal evolution of BIM topics. Likewise, Van Eck and Waltman (2014) employed scientometric analysis to construct knowledge maps of managerial aspects of BIM using Cite-Space and proposed an integrated conceptual framework to summarize the current status and structure future directions, thereby allowing bibliometric data to provide an accurate perspective in the field. However, this study focused only on the managerial research of BIM topic and included a small number of studies.

Li et al. (2017) in their bibliometric study have mapped the knowledge domains of BIM and identified 60 key research areas and ten research clusters for the development of BIM community knowledge. Olawumi Chan and (2019) studied the evolution in the intellectual structure of BIM studies and identified three patterns of BIM research namely the funding structure, BIM research categories, and project sectors affected by BIM. Although this research highlighted BIM benefits as one of the main categories that were researched by previous authors, details on this topic were not examined. Santos et al. (2015) presented a bibliometric analysis that reviewed BIM publications between 2005 and 2015 and identified four emerging themes (Collaborative Environments and Interoperability, Sustainable Construction, BIM Adoption & Standardisation, and BIM Programming) that have the most significant research growth on BIM topics.

As shown above, since the initiation of BIM, most academics tended to focus on specific topics under a BIM sub-area that contribute to the body of knowledge. Many previous state-of-the-literature studies have concentrated on the themes of BIM-related policies, feasibility, and education. For example, Cheng and Lu (2015) reviewed publicly available international guidelines and found that standards are commonly supported although not applied thoroughly. Howard and Björk reviewed studies related to the feasibility of BIM (files to be retrieved, extracted, shared to support decision-making regarding a facility. Sacks and Pikas (2013) presented a review of the efforts of globally active educationalists to teach BIM in the context of advanced engineering education with communication and visualization.

Moreover, many previous authors have examined the benefits emerging from BIM adoption, yet most of the studies were based on case studies and empirical observations (Solnosky, 2013; Newton and Chileshe, 2012; Khudhair et al. 2021; Wong 2018; Yin et al. 2019), and none have examined the network community, visualization density and temporal evolution of BIM-Benefits-related research.

To sum up, while there is a sum of literature works on BIM already published, these studies either focused on surveys and case studies that are specific to certain geographical regions or provided a holistic picture of BIM as a whole. Moreover, studies that targeted detailed topics of BIM have focused on specific features of the technology (education, management, policy). Despite the valuable contribution of previous studies, they did not deliver knowledge on the chronological evolution of BIM benefits body of knowledge. Moreover, previous studies that employed bibliometric studies on BIM, made subjective classification and were based on databases other than those applied in this study.

To bridge the gap in BIM literature, this study attempts to uniquely present a bibliometric analysis of the evolvement of BIM benefits in various construction stages. Divergent from other published state-of-the-literature on BIM, this study presents a conceptual and relational analysis of BIM benefits to the construction sector and offers a dedicated systematic analysis through examining the published research analyzing these benefits in the construction industry. In contrast to other published bibliometrics on BIM that provide a general view of BIM research, this study contributes with a more specific aspect of BIM (benefits) and highlights the main delays in the literature.

3.2 Objectives and Methodology

This study seeks to identify the network of BIM benefits articles and classify them according to construction stages, and time of burst where their impact is mostly observed. The study is exploratory and follows a methodical approach in generating the results. To analyze the research on BIM benefits until 2020, the study employs the quantitative methods of bibliometric analysis.

To begin, Scopus was used as a search engine on the keywords: BIM, BIM Benefits, BIM advantages, and Construction Industry, which results in a total of 417 papers. Scopus is useful for bibliometric studies as it enables the download of massive information for numerous bibliometric analyses.

To refine the search, articles that (1) do not have an abstract, (2) are not written in English, (3) are not from the engineering and computers research domain, (4) does not have BIM benefits as their core topic, (5) have less than 10 citations, (6) and published in journals having an impact factor less than 0.5 were excluded. After eliminating the papers that did not meet the mentioned criteria, only 226 were found to be relevant for this study as illustrated in figure 3.1. It is important to note that the articles selected for review are all published in well-reputed journals that have a quartile and a journal rank on Scimago.

To have a holistic view of BIM-benefits papers, the search was not limited to a period, yet it analyzed all the papers that were found during the search. The results show that the first paper focusing on the advantages of BIM for construction goes back to 2004 where Fu et al. focused on the use of BIM and IFC to enhance the project costing (Fu et al. 2004, Zhu et al. 2020). So, the whole period that presented BIM benefits reviews and articles was taken into consideration starting from the first article in 2004 till the last article in 2020 to cover all the benefits of BIM and evaluate their evolvement.

Bibliographic records such as the list of authors, title, abstract, year of publication, type of publications, set of keywords, and set of references cited by the article were retrieved at first. Vos-Viewer validates the formation of various types of networks from bibliographic sources. In this study, Vos Viewers was employed to create a keywords co-occurrence network and a document co-citation network.

Vos-viewer was also employed to distinguish highly cited articles, publications with solid and citation bursts. The examination of the precedents helps in determining whether the entity has boosted steeply when contrasted with its peers or not.

Moreover, a relational analysis of these benefits that compile and combine isolated studies in chronological order was then performed, followed by an in-depth discussion of the results, and their perceived explanations. Lastly, this research contributed to highlighting the delay of BIM impact research topics and points out the gaps in the literature to recommend future areas for investigation. This research can be of significant value for academic researches of advancement in the construction industry as well as BIM industry business developers who are interested in global markets.

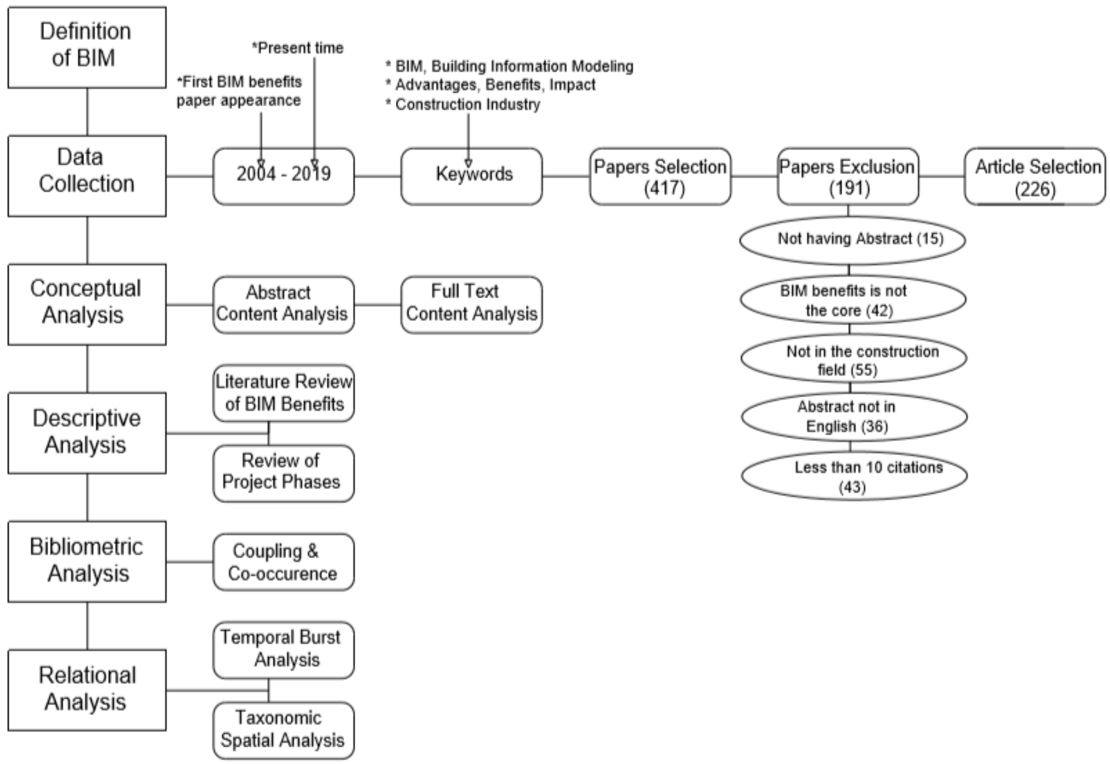


Figure 3.3: Outline of research design

3.3. Results

3.3.1 Evolution of the Number of BIM Benefits Publication

The results demonstrate the positive impact of BIM on the construction industry since 2004. Although a couple of papers were published between 2004 and 2007, only since 2008 has the literature started to be more assertive about BIM benefits in construction. The volume of BIM published articles has rapidly increased in the last decade as shown in the publication's timeline of the selected published Journal papers in figure 3.2. The graph shows that the number of publications has increased with time and reached its peak of 47 published articles in 2018. More so, in the last five years, more than 70% of BIM benefits papers were published.

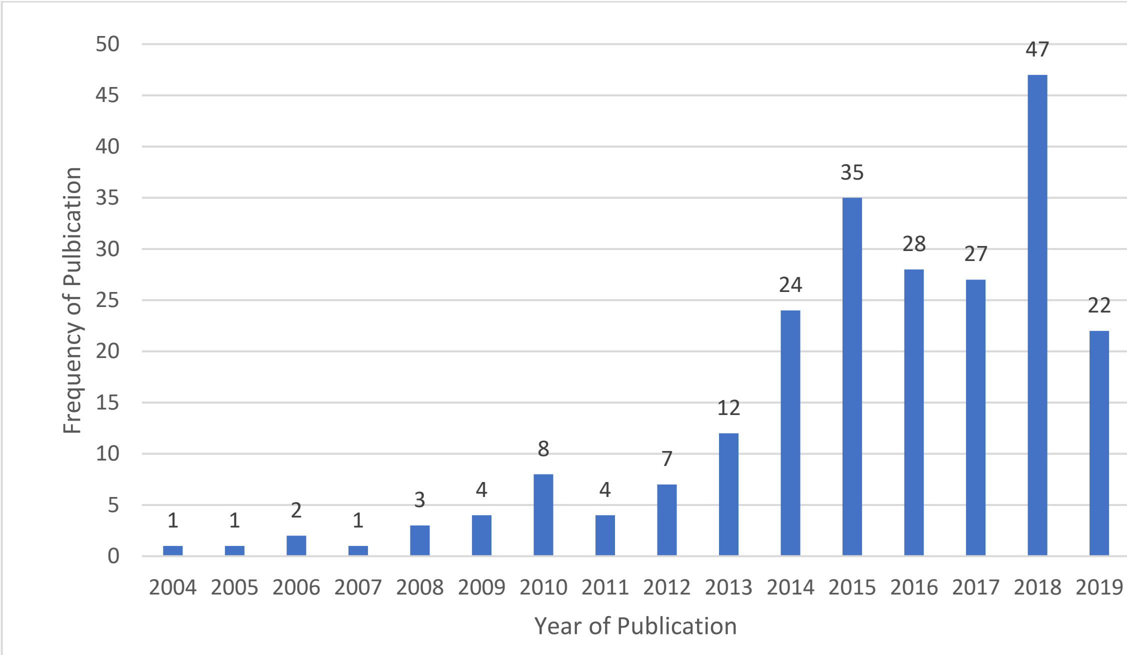


Figure 3.4: Frequency of publications versus year of publication

3.3.2 Research Design Description

It is interesting to recognize the set of methods and procedures (experimental design and collection method) used in published research when analyzing the impact of BIM. Figure 3.3 illustrates the scientific research method used in the reviewed papers. As it can be seen, 102 papers used a case study method, whereas 99 used a survey method (interviews or questionnaires), and 25 papers used a mixed approach. This chapter will use the conceptual method to analyze the above studies.

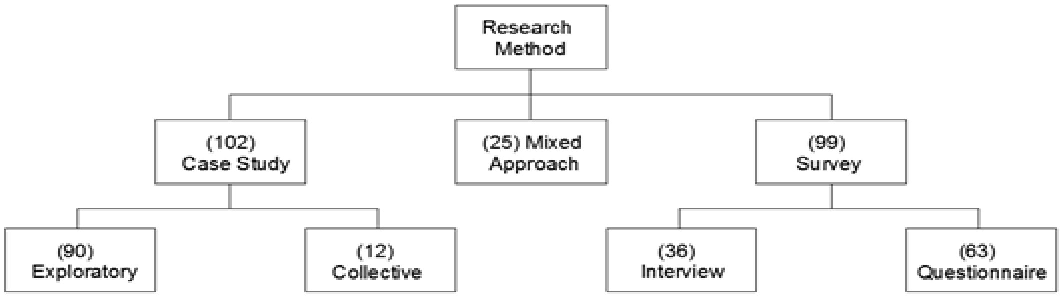


Figure 3.5: Research design method in the reviewed papers

3.3.3 Journals Profile

The analysis of the journal's list reveals that the 226 articles used in this study were published in 76 different journals with the largest percentage published in: Automation in Construction (17.3 %), Journal of Information Technology in Construction (7.1%), Engineering Construction and Architectural Management, and Journal of Construction Engineering and Management (6.2%). These four journals account for 36.7% of the total number of articles. The journals of the selected research papers are shown in table 3.1.

Table 3.1: Journals list of the selected articles on BIM benefits

Journal	Number of Articles
Automation in Construction	39
Journal of Information Technology in Construction	16
Engineering Construction and Architectural Management	14
Journal of Construction Engineering and Management	14
Electronic Journal of Information Technology in Construction	8
Practice Periodical on Structural Design and Construction	6
Built Environment Project and Asset Management	6
Construction Innovation	6
Journal of Civil Engineering and Management	6
Journal of Management in Engineering	5
Journal of Cleaner Production	4
Computers in Industry	4
Construction Management and Economics	4
Journal of Building Engineering	4
Journal of Computing in Civil Engineering	3
Building Simulation	3
Proceedings of Institution of Civil Engineers Management Procurement	3
Safety Science	3
Sustainable Cities and Society	3
Advances in Computational Design	2
Architectural Engineering and Design Management	2
Building and Environment	2
Canadian Journal of Civil Engineering	2
Construction Economics and Building	2
Energy and Buildings	2
International Journal of Civil Engineering and Technology	2
International Journal of Construction Education and Research	2
International Journal of Product Lifecycle Management	2
Journal of Asian Architecture and Building Engineering	2
Journal of Professional Issues in Engineering Education and Practice	2
KSCE Journal of Civil Engineering	2
ASHRAE Journal	2
Architectural Science Review	2
Asian Journal of Civil Engineering	2
Australasian Journal of Engineering Education	2
Building Engineer	2
Building Research and Information	2
Buildings	2
Others with single publications	37

3.3.4 Geographical Dispersion

The geographical region means articles with originating data or case studies based in that country. The country where each study has been conducted was based on the information provided in the paper. A total of 38 countries where BIM benefits studies have been conducted were identified, and seven geographical regions: Africa, Asia, Europe, Middle East, North America, Oceania, and South America. The leading area with BIM benefits research is Europe where 63 studies were found, Asia is the following with 58 studies, 57 from North America, 22 in Oceana, 11 in Africa, 10 in the Middle East (ME), and five from South America. The details of the distribution are presented in table 3.2 showing the positive impacts of BIM in construction around the globe. The highest volume of papers in Europe comes from the UK (44.4%), and 87.7% of the papers found in north America are originated in the United States. China and Honk-Kong count for 56.8% of the total papers found in Asia. In Africa, 45.5% of the papers engage in Egypt, and in the MENA 40.0% of the papers are originated in Iraq and Palestine. The outcomes demonstrate the technological advancements of the UK and the US in capturing the benefits of BIM in construction. The high figure of the UK and the US are not implausible because their governments are leaders in encouraging and mandating the implementation of BIM in public construction works via regulations and policies (Wong 2018; Chen et al. 2019).

Table 3.2: Geographical distribution of BIM literature

Europe (63)		**Asia (58)**		**South America (5)**	
UK	28	China	21	Brazil	3
Germany	7	Hong-Kong	12	Chile	2
Finland	5	South Korea	10	**Middle East (10)**	
Ireland	4	Singapore	7	Iraq	2
Portugal	3	Malaysia	5	Palestine	2
Sweden	3	India	3	Iran	1
Netherlands	3	**Africa (11)**		Jordan	1
Slovenia	3	Egypt	5	Saudi Arabia	1
Austria	2	Nigeria	2	UAE	1
Belgium	1	Morocco	2	Lebanon	1
Denmark	1	South Africa	2	Syria	1
Turkey	1	**Oceana (22)**		**North America (57)**	
Bosnia	1	Australia	20	US	50
Poland	1	New Zealand	2	Canada	7

3.3.5 Project Lifecycle Stages Affected by BIM

The subsequent step of this analysis is to identify the construction stages where BIM has shown potentials. Five main stages of construction were considered where BIM showed benefits namely the pre-design phase, engineering (design), procurement, construction, and operation & maintenance phase (Eadie et al. in 2013).

It can be concluded from figure 3.4 that the stages having a high number of published papers are associated with a high number of citations, indicating that these stages were appealing to investigations. To provide a more qualitative examination of the literature, a differentiation between the stages based on content analysis was anticipated. After the loading of the research themes into the different construction stages, some research themes were shown to be heavily present in each stage of the project development.

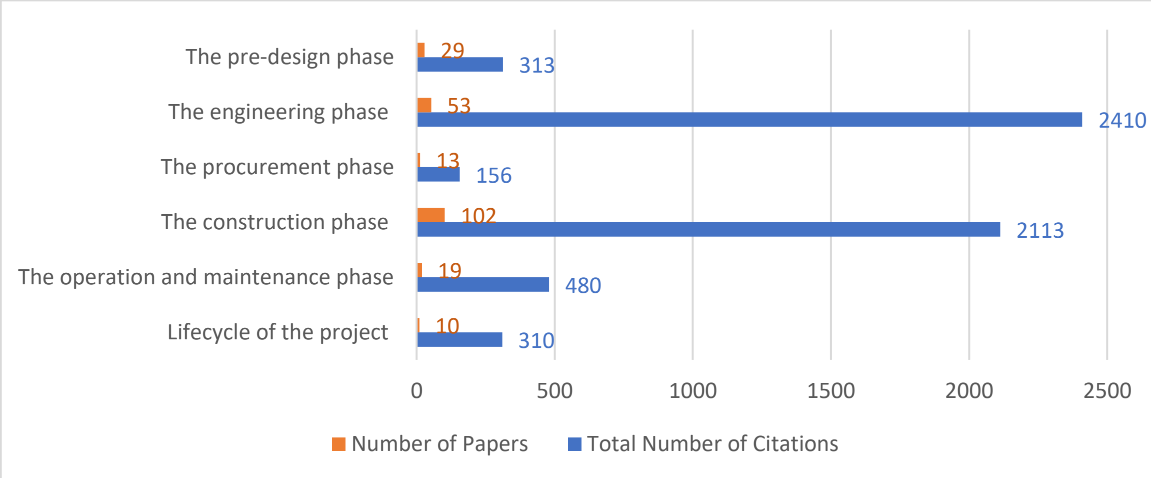


Figure 3.6: Number of articles and citations of BIM research in different construction stages

Further analysis allowed the classification of the research themes under one of the stages as shown in figure 3.5. In the *Pre-Design* phase, most papers focused on the improvement of BIM-based tools offered to conceptual designs (41.3%), estimation (24.1%), feasibility studies, or risk assessment (13.7% each), and permitting (6.8%). In the *Engineering (Design)* phase, BIM shows potentials in cost planning and estimation (23.5 % of the papers, and 41.7% of the total citations). BIM-benefits-related papers have signaled a remarkable number of papers in topics related to planning, scheduling, and cost control. Sustainability is the prime topic with a high growth rate in the BIM recent studies in this phase (Doumbouya et al. 2016, Hong et al. 2018). However, the use of BIM in the p*rocurement* stage has the lowest number of papers and citations (13 and 156 respectively). Only 34 authors addressed the need for BIM in procurements despite its ability in generating automated quantity take-off lists (Abanda et al. 2017). In this stage, previous authors have proposed the use of a BIM-based framework in procurement, to squeeze the impact of fragmentation through the integration of data in purchasing (Arunkumar et al. 2018; Monteiro et al. 2014), and credited BIM for developing accurate 3D parametric models generating significant data to support procurement tasks (Fakhimi et al. 2017; Matarneh et al. 2019). Nevertheless, few studies focused on the gains of BIM in quantity and material cost estimation affirming the immaturity of BIM in the procurement stage.

On the other hand, the *Construction/Execution* stage is the phase with the most published papers and citations since 2004 (Hatem et al. 2018; Nawari 2012). This high percentage might be due to the need of reducing reworks, wastes, and RFIs in the construction process. Another finding is the shy number of papers that tackle the benefits of BIM in quality control, while a high volume of articles (28 out of 102) addressing the usage of BIM in prefabrication or off-site construction, indicating it as one of the best features of BIM that speed the construction process. Moreover, BIM benefits for the *Operation and Maintenance* (O&M) stage is a rising subject as practitioners apply information from the model for maintenance, emergency management, and energy control (Wang et al. 2014). The low number of papers indicates the need for more research and investigations in the future.

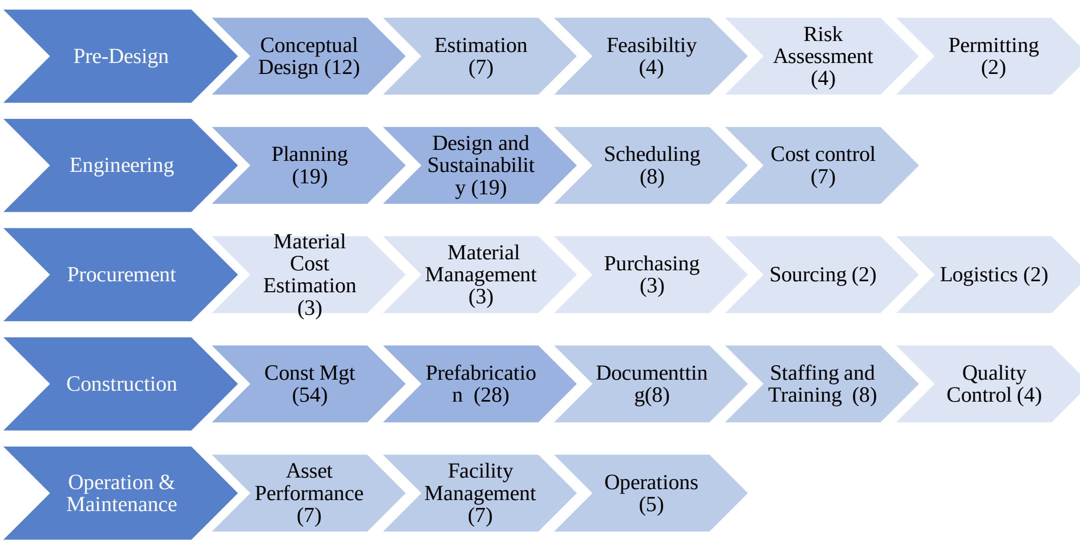


Figure 3.7: Research themes and number of BIM benefits papers by project stages

3.3.6 Published Benefits of BIM

The construction sector has extensively sought to increase its productivity and overcome the challenges faced during the construction process (Azhar & Brown 2009), thus, BIM is claimed to be a key to attaining these long-standing aims. Based on the content analysis of the selected papers, BIM can provide various benefits for construction projects such as an accurate representation and 3D visualization of the building objects, accurate cost estimation and quantity takeoff, improved facility and space planning and logistics, better constructability, structural and energy analysis among others. Table 3.3 presents a summary of the benefits earned from the implementation of BIM in the construction industry found in the 226 analyzed articles.

The results show that the topmost experienced BIM benefit is ensuring 3D visualization of the facility that organizes information by building as-designed and/or as-built models, which was mentioned in 78% of the reviewed papers. Ensuring 3D coordination of various project systems to locate their interferences before the beginning of the execution was found as the second most frequently cited benefit of BIM research with a citation frequency of 74%. However, as table 3.3 implies, other BIM benefits are not effectively reaped by practitioners such as the use of BIM for safety analysis and code validation which were found to be recorded in only 7 and 8% of the reviewed papers respectively. This implies that only a minority of the practitioners are using BIM to design a complete safety plan that enables better communication of safety obligations on-site and to check the compliance of the buildings with regulatory requirements.

Table 3.3: Citation frequencies of BIM benefits in the retrieved papers

Number	Benefits of BIM in the Construction Industry	% Citation
B1	Better 3D visualization	78%
B2	Enhanced 3D coordination - clash detection	74%
B3	Enables constructability analysis	69%
B4	Accurate Cost estimation and quantity takeoff	63%
B5	Detailed Shop Drawing	58%
B6	Better Stakeholders' Engagement	52%
B7	Enables facility and Space planning and logistics	49%
B8	Enhanced Scheduling (4D animation)	40%
B9	Enables Structural analysis	37%
B10	Project Closeout and Documentation	30%
B11	Energy analysis	21%
B12	Sustainable Design	20%
B13	Better Facility management	12%
B14	Allow material tracking, delivery, and management	10%
B15	Safety analysis	8%
B16	Ensure code validation	7%

3.4 Discussion

3.4.1 Bibliometric Analysis of the Results

The number of citations ranking is an indication of the author's prominence, and it is a critical parameter in bibliometric statistics, table 3.4 presents the most cited authors in the reviewed articles. Azhar is the leading author who has explored the benefits of BIM in different construction stages and agreed that BIM helps in recognizing potential design and construction issues (Azhar 2011). Bryde is the subsequent author who has clustered the benefits of BIM according to BIM uses (Bryde et al. 2013). Sullivan comes third and conducted a qualitative case study concluding the potentials of BIM. Sacks et al. is the fourth most cited author and has explored a matrix of 56 positive interactions between BIM and Lean management (Sacks et al. 2010). Eadie et al. is next and is mainly known for presenting the key performance indicators for BIM.

Table 3.4: Most cited studies on BIM benefits

Author	Year	Title	Citations
Azhar	2011	Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry	1389
Bryde et al.	2013	The project benefits of building information modeling (BIM)	828
Barlish & Sullivan	2012	How to measure the benefits of BIM - A case study approach	482
Sacks et al.	2010	Interaction of lean and building information modeling in construction	449
Eadie et al.	2013	BIM implementation throughout the UK construction project lifecycle: An analysis	381

To provide an insightful view, VOS Viewer was used to create a *co-occurrence network* of keywords that identifies popular areas and directions of research and monitors developments in scientific areas as presented in figure 3.6. Analysis was conducted on keywords presented in the abstract and in the titles to examine the emerging and the fading themes. Out of the 1580 terms identified; 47 terms besides BIM and Building Information Modeling met the threshold number of co-occurrences above 15, resulting in a visual keyword co-occurrence network with a chronological order of items.

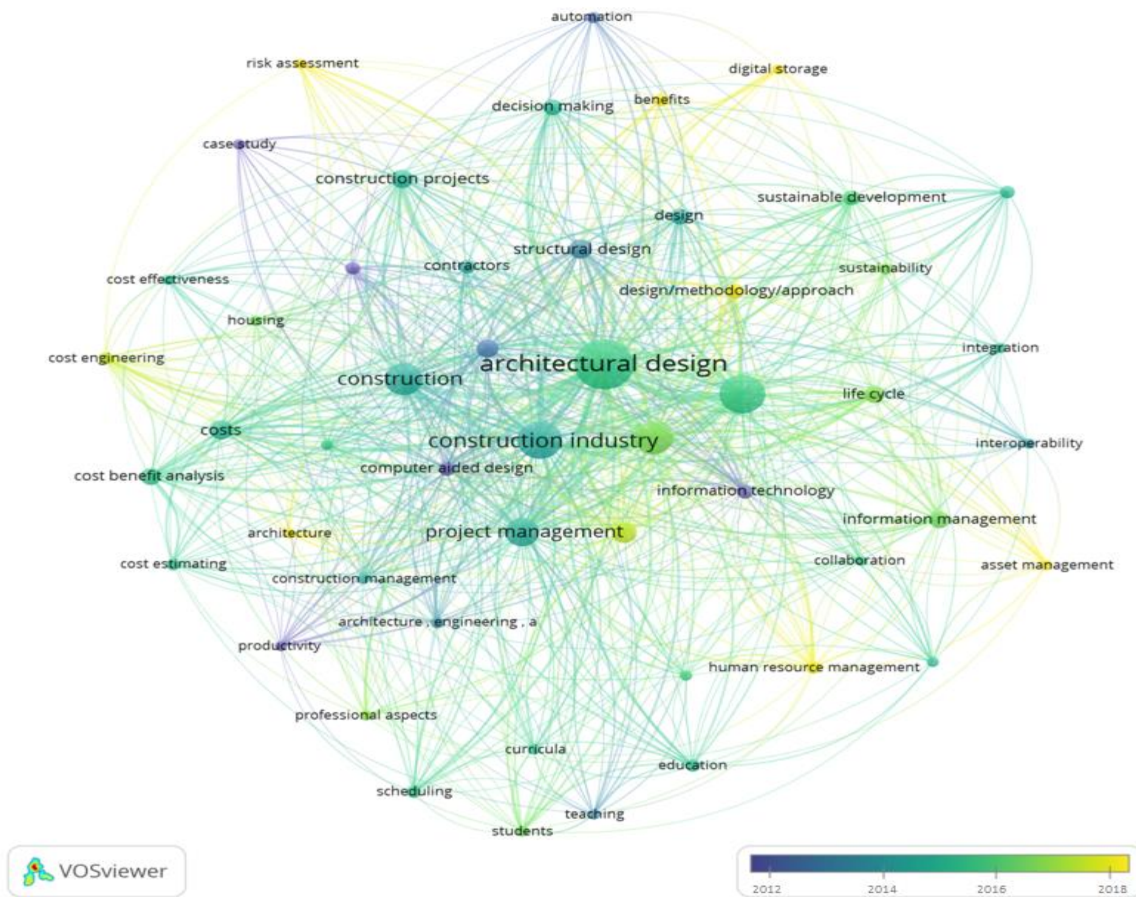


Figure 3.8: Co-occurrence map of keywords

Several terms devoted to BIM benefits have experienced rapid growth in citation activity shown in figure 3.6. The results show that BIM benefits evolution benefits began in the period 2004–2012 (colored in dark blue) with fundamental concepts like “information technology,” “computer-aided design,” “three dimensional,” “productivity,” “automation” and “construction process”. The results show that throughout all this period the same keywords were detected, which might be due to the small number of papers and the deliberate investigations on BIM benefits before 2010. The burst of these keywords originates from influential BIM studies that concentrated on introducing BIM's fundamental benefits, such as those by Sacks et al. (2010), Azhar (2011), and Wong and Fan (2013).

Information management and sustainability grasped researchers’ attention in the period from 2013 to 2016 (colored in green) with the focus on keywords such as are “information theory,” “information management,” “architectural design,” sustainability,” “sustainable development,” and “construction industry”. The high frequency of these keywords presents them as a hot topic in BIM research. In this period a burst of citations occurs across the project lifecycle. Zhou et al. (2016) pointed out that the benefits of BIM were studied in different stages of the construction process and researches focused on whole lifecycle approaches.

Integrating BIM in different stages has begun to gain assets in 2015, so the terms such as "design," "structural design," "teaching," "facility management" and "life cycle" start to show up. The presence of these keywords confirms a coherent vision for the integration of BIM in the construction industry. This period was the core for evaluating the benefits of BIM in specific areas and for specific usage which enlightened keywords such as "decision making," "scheduling" "visualization" and "collaboration" which confirms that practitioners are noticing the potential to redesign their practices to align with BIM. Moreover, the keywords co-occurrence indicated the focus of research that attempted to support introducing BIM in curricular programs of engineers, as terms such as curricula, teaching, education, and students appeared in the period between 2014 and 2016.

The period after 2018 has shifted towards recent ideas tackling the importance of BIM for project management and terms such as "asset management," information management," and "human resource management" appeared. The interesting finding at this point is enlightening the belated attention of the construction industry to BIM benefits related to optimizing the management of resources. Digital storage is another keyword that has a high co-occurrence after 2018, which indicates that there has been a high penetration rate of BIM in the market that reached a maturity level to touched on digital storage. The co-occurrence of keywords related to the methodology used in the literature confirms that "case study" co-occurred largely before 2012; however, "surveys" appeared as a keyword in recent literature from 2015, indicating that the study on BIM started with a case study approach that produces rich descriptive data, and then shifted to surveys. The flow is logical since case studies are usually used to validate a theory or hypothesis, whereas the data gathered from surveys are not very descriptive, instead, they are statistically significant and can be generalized.

3.4.2 Temporal Evolution of BIM Benefits

Driven by the interest in identifying the underlying foundations and trends in the BIM benefits body of knowledge, table 3.5 illustrates the period in which each of the 15 BIM benefits has appeared. The below discussion will go deeply with explaining the benefits captured in each period. The examination of the evolution of the benefits allows the identifications of the *trending, emerging,* and *early reaped* benefits.

Table 3.5: Evolution of benefits with time

Nb	2004-2006	2007-2009	2010-2012	2013-2015	2016-2018	2019-2020
B1: 3D visualization	**3**	4	8	65	66	22
B2: 3D coordination	**2**	**2**	19	57	59	22
B3: Constructability analysis	0	**4**	18	49	62	18
B4: Cost estimation	0	**3**	7	58	49	21
B5: Shop Drawing	**4**	4	18	48	39	18
B6: Stakeholders' Engagement	0	**5**	15	42	36	20
B7: Facility and Space planning	0	**3**	12	46	27	21
B8: Scheduling	0	0	0	**11**	61	18
B9: Structural analysis	**4**	3	20	16	22	19
B10: Project Closeout	0	0	**6**	13	32	17
B11: Energy analysis	0	0	0	0	**37**	10
B12: Sustainable Design- Green	0	0	0	**7**	10	7
B13: Facility management	0	0	0	**4**	9	14
B14: Material tracking	0	0	0	0	**14**	10
B15: Safety analysis	0	0	0	0	**7**	11
B16: Code validation	0	0	0	0	**9**	7
Number of Papers per Period	**4**	**8**	**19**	**71**	**102**	**22**

In bold is the time range in which the benefit first appeared in the literature

Trending benefits

*S*tarting with the trends of BIM benefits, the analysis in the latest years from 2016 to 2020 indicates that some BIM benefits have started to be reaped for the first time in this period. In other words, before 2016 these benefits were not mentioned in the literature as added value or potentials achieved from BIM adoption. These benefits are energy analysis, material tracking, safety analysis, and code validation as presented in table 3.5.

Practitioners after 2016, have started to feel the benefits of using BIM to simulate the energy performance of the facility. According to Eguaras-Martínez et al. (2017), the use of *energy simulation* with BIM to reduce emissions and energy waste is an ongoing practice with a high growth rate and has the possibility of saving one-third of the total consumption. This is consistent with Abanda et al. (2017) results that the concern of venturing BIM tools with energy simulation was a foreseen result, especially with the global race to reduce energy consumption and GHG emissions.

Similarly, using BIM for *safety planning* is a theme with low frequency yet has a high growth rate in the last years. BIM lately showed to have a great impact on the safety performance of the company. A virtual safety tour through BIM facilitates virtual navigation around the site make easy to detect and prevent hazardous conditions and predict risks. The findings reveal that safety is an area that has caught the attention of an increasing number of researchers in latest years. Scholars have investigated the use of automatic processes to avoid occupational accidents by proposing a framework to incorporate 4D BIM and safety planning (Malekitabar et al. 2016). This allows a dynamic approach to avoid falls, collisions, and safety risks. While this topic remained unnoticed until recently emerged in the past few years, investigators started to focus on the need and urge of using BIM for safety analysis.

Concerning the *material tracking* benefit, Tsilimantou et al. (2020) confirmed that professionals with extensive experience with BIM are applying its tools along with other information systems, such as geographical information systems (GIS), to visualize the material-management process with accurate information regarding material flow on job sites. Similary, Getuli et al. (2017) showed that *code validation* is a difficult tool to be used in BIM, and only BIM professionals with adequate skills were to ensure automated code validation through BIM applications to deliver permanent accurate feedback on code compliance while saving time and money.

To understand the late appearance of the above benefits, I will refer to Gholizadeh et al. (2018) study that concluded that some BIM functions mainly safety planning and energy analysis are to be used only by well-skilled BIM professionals to deliver the needed benefits. This means that for users to adopt these two functions correctly they need to have passed through the utilization of many other BIM functions. This indicates that only mature users who are familiar and professional with the usage of a variety of BIM functions can start operating BIM for safety planning and energy analysis. Figure 3.4 shows that users have used all other BIM functions, before being able to use BIM for safety and energy practices.

Moreover, Bhoir et al. (2015) have reported using BIM for code validation and energy analysis, and safety planning as the most difficult functions to be adopted. All of the above explains the rationale behind having energy analysis, code validation, and safety planning as the latest functions adopted among participants and explains the late realization of their benefits. To conclude, the trending benefits can only be achieved if the users have already practiced and mastered many other BIM functions. In other words, users have to pass through the utilization of many BIM functions before being able to successfully use BIM for the trending functions. Thus, the trending benefits are the ultimate level of BIM adoption, as only mature users who are familiar and professional with the usage of a variety of BIM functions can start benefit from these advantages as shown in table 3.5.

Emerging (Realized) benefits

The examination of the benefits indicates the realization of some BIM benefits between 2010 and 2015. The realized benefits are those not reaped in the very early stages of BIM adoption and are not the latest benefits to be captured. The analysis of table 3.5 provides evidence that several benefits have experienced rapid growth in the number of publications and appeared frequently between 2010 to 2015. The results imply fast-growing areas of research on topics under the umbrella of ensuring closeout documentation, better facility management, sustainable design, and enhanced scheduling.

Increasing project sustainability is a prime topic with a high growth rate after 2013. This theme progressively got pivotal focuses with the categories of sustainable development at the cutting edge of this pattern (Wong & Fan 2013; Ran & Singh 2016). There are three principal associations between BIM and sustainability: transparency of the design, efficiency of the design, and control (Carvalho et al. 2020). BIM boosts the ability to analyze and evaluate green buildings and allows access to information to make sustainable decisions (Ran & Singh 2016). BIM benefits show to have reached maturity in the design phase. This is supported by the noticeable number of publications in this phase.

Better Facility Management (FM) is another critical topic that has first emerged between 2010 and 2015. BIM simulates the performance of a structure using the operation imitation tool that gives the option to apply information from the model for maintenance, and emergency management (Wang et al. 2014) and therefore ensure the functionality of the built environment. Focusing on this topic, Shalabi & Turkan (2015) have proposed a framework for the use of Radio Frequency Identification (RFID) technology sensors to observe building deformations featuring in the BIM model. Naghshbandi (2017) portrayed the benefits of BIM to FM in investigating broken equipment and improving ergonomic and comfort conditions

(Naghshbandi 2017). The wealth of BIM in FM stems from the improvement of the now-available manual procedures of data handover; enhancement of the accuracy of FM information, enhancement of the efficiency and speed of work orders execution (Becerik-Gerber & Rice 2010). Incorporating facility management knowledge into the initial phases of a building through BIM can reduce the take for major modifications during the operation phase.

Adding to the above, enhanced 4D scheduling is another topic that emerged after 2010. An interesting outcome is the significant volume of studies that report the benefits of BIM in improving project schedule, planning, and sequencing which was referred as to as one of the finest potentials of BIM mainly after 2013 as shown in table 3.5. BIM is a remarkable assistant for increasing the logical sequencing of onsite tasks (by updating the start and finish dates of tasks) which can catalyze the way construction projects are designed, managed, and developed (Luth et al. 2013). 4D BIM Scheduling allows designers, estimators, and schedulers to link 3D models to timetables. It leverages the opportunities of real-time scheduling in terms of duties and allocation of each discipline/trade during each construction stage and helps in detecting flaws. Complete 4D schedules allow practitioners to mitigate the risk of delays through re-sequencing and coordination optimization. Four types of construction schedules techniques are delivered by BIM: Gantt Charts, Critical Path Method, Line of Balance Sequencing, and Q-Qantitive scheduling (Hergunsel, 2011).

Moreover, between 2010 and 2015, practitioners have started to feel and report the benefits of BIM in providing accurate project documentation. Table 3.5 shows that considerable attention was given to having all project's detailed documents in a single model (BIM) which eases information exchange and enhances associated cost-effectiveness. BIM allows design and documentation to be done at the same time, and for documentation to be easily changed to adapt to new updated information (Mayo and Issa, 2014). This benefit was never reported as an added value of BIM in the literature before 2010, however, its impact gradually increased after this date. The emerging benefits might be explained grounding on Roger's statements that any technology comprises hardware, that is usually more visible to users, and software that needs to be effective and accessible for users (Rogers, 1983). Even with the provision of manuals that might assist in communicating considerable understanding about the software, practitioners' interaction and sharing of information is a highly efficient approach to realize the accessibility and effectiveness of any information technology. Therefore, while the architecture, engineering, and construction industry can obtain the desirable hardware through upgrading the system to increase the adoption of BIM, the lack of effective and accessible add-ons for BIM functions might blind current users about the potentials of BIM, and thus they are unlikely to encourage their peers to adopt the specific functionalities which lead to specific values such as these emerging benefits.

Early Benefits

Tables 3.6 identified 3D visualization, shop drawing, 3D coordination\clash detection, and improved structural analysis as the earliest reported benefits of BIM, which have appeared from 2004 to 2006 when the first papers tackling the BIM benefit topic have been published. The examination of table 3.5 shows a gradual increase in the frequency of reporting these four benefits over years. These benefits have gained high shares and diffused since the first inception of BIM in the construction industry in comparison to other functions such as code validation that was found to be diffusing the latest among practitioners. These BIM benefits showed to have a considerable realization in the US and Europe where 60 to 63% of practitioners reported their benefits (Kim and Yu, 2016).

To examine the possible relationship between the realization of the benefits and their ease of use, I will refer to the conclusions reported by Bhoir et al. (2015) that the easiest BIM features to be implemented are 3D visualization, developing detailed drawing, clash detection, and developing structural models. This conclusion might help in explaining the rationale behind having these usages as the first adopted functions among participants and their implied benefits as the earliest to be captured and reported. The examination of the above indicates that these early realized benefits can be achieved by most BIM users. In other words, users with acceptable (not very high) BIM skills can generate these benefits to the project, as using these functions is easy. This indicates that even beginners BIM users can lead the project to achieve the above benefits from BIM adoption.

Diverged topics such as sustainability, energy analysis, operations, maintenance, estimation, procurement, and safety were all not reported between 2004 and 2009.

To conclude, the evolution of BIM practices and benefits is tightly linked to the reason stakeholders are integrating BIM for. Before 2010, the implementation of BIM was in an early infant stage, where the industry was partially satisfied with the advantages accompanied by the new system. The early benefits are mainly related to sharing an accurate 3D model, developing structural models, and detecting conflicts. It is remarkable that despite the early appearance of these benefits, they were referred to in most BIM benefits articles regardless of the period of the study, indicating that these benefits did not fade with time. The rationale behind this is that these benefits are maintaining their significance to the construction industry. Other benefits were first perceived in studies conducted between 2010 and 2015 and are found to be related to the use of BIM to squeeze the schedule and improve the quality of work through designing sustainable projects and ensuring better facility management.

The last four years represent the trending topics of BIM and reveal the delay of appearance of BIM usage for safety analysis, energy simulation, code validation, and material tracking. As these benefits did not report before 2016, these new BIM benefits are rising and becoming hot topics in BIM adoption literature.

3.5 Conclusions

This chapter has ~~This paper aimed to~~ analyzed the literature on BIM benefits, identify its impact on the lifecycle of a construction project, and perceive the deployment of BIM through its recorded benefits. The level and depth of the bibliometric analysis and literature review are considered as the prime distinction of this study.

The results demonstrate that BIM benefits in construction have been a hot topic for research that experienced significant growth in recent years. The study confirms that BIM benefits are mostly gained in the execution and the engineering phases of the project. Further, the outcome showed interest in the benefits of BIM to off-site construction studies which pointed out prefabrication as an important topic on the agenda.

One more contribution of this study lies in combing and compiling isolated studies in chronological order to be used as a reference frame for investigators. In this category, another finding is the classification of benefits between Early, Realized, and Trending benefits. The novelty of this research lies in describing the evolution of BIM benefits that started with simple and general concepts and then shifted the focus towards more specific BIM applications such as information theories. The spatial comparison proved the establishment of the realized benefits in most of the regions, however, it reinforced the different status of BIM benefits in the studied regions with South America and Africa lagging, Australia gradually advancing, Asia are promptly advancing, whilst Europe and North America leading. The former was being attributed to the digital divide between the studied regions. Research gaps and areas for future research were identified showing that the now-available literature on BIM benefits is concerned with the execution phase. Fragmented efforts confirm the benefits of BIM in checking building permits and safety planning, and sourcing which urges for further research on these areas. These fields of research are recommended to be considered for future investigation. Evidence from this research identified the delay of articles for BIM benefits in probing BIM in construction engineering education, which calls for further research on these areas. Conclusively, this research would assist researchers to recognize the pattern of BIM benefits research and help them to point out the lifecycle stages and themes in their future work.

Chapter 4

BIM Adoption Limitations

4.1 Introduction

The complex nature of the Architecture, Engineering, and Construction (AEC) industry is mainly triggered by the multidisciplinary network of participants that compose the construction value chain (Ahmed, 2018). This fragmented nature results in time and cost overruns, and quality problems (Liu & Van Nederveen, 2017). BIM is suggested to be the gateway to resolve these issues, as it is a tool for generating and managing building data (Alhumayn et al., 2017). BIM proved to enhance the design, collaboration, and communication among parties (Alhumayn et al., 2017). Many countries such as the US, UK, Singapore, and Australia have taken the lead in developing BIM (Cheng, 2015). As part of the development, the architecture, engineering, and construction industry (AEC) from each country have created standards to define the requirements needed for BIM implementation and give practitioners proper guidance of the implementation (Borrmann et al., 2015). Yet, the full integration becomes significant only when stakeholders recognize the limitations that prevent BIM from offering full potentials to the industry and endorse strategies to overcome them. In the past years, several BIM research attempted to identify the limitations that hamper the embracement of BIM in construction such as the studies presented by Olawumi and Chan (2018) and Ahmed (2018) who identified a plethora of technological, and social barriers using qualitative approaches (Olawumi & Chan, 2018) (Hamid et al., 2018). Most of the previous BIM barriers literature are case studies that employ interviews as a data collection tool (Ahmed, 2018).

In investigating BIM adoption limitations based on a quantitative assessment, previous studies have provided outcomes from a single country such as the research of Onungwa and Uduma-Olugu in Nigeria (Onungwa & Uduma-Olugu, 2017), Siddiqui et al. in Pakistan (Siddiqui et al., 2019), Monozam et al. in Australia (Monozam et al., 2016) and Bosch-Sijtsema et al. in Sweden (Bosch-Sijtsema et al., 2017). These studies assessed a single country and were performed in different time periods which makes it difficult to compare their similarities. Although, NBS report in 2013 investigated a sum of countries including the UK, Canada, Finland, and New Zealand, yet the results are missing data from developing countries (NBS, 2013). Thus, an investigation of the global perception towards BIM barriers that are based on theoretical explanations and quantitative results that bridges for the development of overcoming strategies is still missing. Driven by the above, this study aims to present a comprehensive view of BIM adoption barriers retrieved from quantitative BIM literature at an international level to explain their theoretical and practical implications.

The novelty of ~~the paper~~ the research is in examining BIM published papers amongst Asia, Africa, Europe, the Middle East, and Australia using a quantitative procedure to track the evolution of the challenges facing the proliferation of BIM between 2015 and 2019 at large. ~~The authors narrowed their~~ The search was narrowed to these five years to examine the current situation of BIM, and to involve the most recent adoption barriers. To do so, a conceptual analysis was performed to identify the major BIM limitations, which were then grouped using cluster analysis. The research used the meta-analysis procedure to evaluate the relative importance index (RII) of each barrier and presented an in-depth discussion of the results and their perceived explanations based on theoretical backgrounds.

4.2 Theoretical Background: BIM Status and Barriers

The integration of BIM is on the rise due to figuring out its potentials in creating a procedural evolution in the construction industry (Borrmann et al., 2015). The European Union has mandated the use of BIM in construction projects (Eadie et al., 2013). Finland, Norway, UK, and Sweden are considered leading countries in developing and implementing BIM (Group, 2015) within Europe. BIM in the US is required in all governmental projects and the US Army Corps of Engineers (USACE) have worked with BIM models since 2003 (Ghaffarianhoseini et al., 2017). Singapore is one of many countries leading to develop BIM standards and introduce the tools into practice. The Building Construction Authority (BCA) developed the "Singapore BIM Guide” which is used as a reference for BIM implementation (Rogers et al., 2015). In Australia, 70% of stakeholders are involved in BIM-related projects (Aibinu & Venkatesh, 2013). Yet, despite the excitement towards BIM adoption, its integration is not straightforward and differs from one region to the other. Past scholars agree that the above promising pictures are not present in developing countries where BIM is still in its infant stage (Chan , 2014). In Africa, the implementation of both the process and the technology is relatively low (Jung & Lee, 2015). In Columbia, 60% of construction practitioners are non-BIM users (Aibinu & Venkatesh, 2013). In the Middle East (ME), BIM diffusion is in its early stage (Gerges et al., 2017), having Dubai as the leader in terms of mandating the use of BIM in the region (Gerges et al., 2017). BIM in Qatar has not yet been requested as an obligation; however, its implementation has increased during the last years especially in stadium projects for FIFA 2022. Some countries in the MENA have shown a shy level of BIM integration in construction projects namely Lebanon and Jordan where the penetration rate does not exceed 12% (Ahmed, 2018).

As it can be seen, the perception of BIM, as well as its penetration rate, differs from one region to the other. Several factors affect the decision toward BIM adoption as it is complex and requires a lot of resources. Recognizing the adoption limitations is deemed to be a prelude to its successful penetration (Aibinu & Venkatesh, 2013). Considering this, researchers have made efforts to identify these limitations. The first paper that studied the barriers to BIM adoption in the construction sector goes back to 2009 when Mutai presented a qualitative analysis of the limitations encountered during the early diffusion of BIM in the US. His results revealed rare BIM adoption in existing constructions because of high modeling/conversion effort from captured building data into semantic BIM objects. In 2009, Aryaci et al. performed a qualitative scientometric review of BIM barriers in the UK and pointed out the importance of the social and legal enablers to adopting BIM. Lately, Santos et al. (2017), took it one step further and used a mixed methodology to examine BIM barriers in refereed journals have an impact factor greater than 1.0 between 2005 and 2015 and highlighted the lack of awareness, initiatives, and training as the main barriers (Santos et al., 2017). Chan (2014) confirmed that the fragmented nature of the construction industry and the reluctance to change the traditional working methods, in addition to the lack of government support are the main hinderers of BIM in Hong Kong (Chan, 2014). Gerges et al pointed out the shortage of expertise in the Middle East as a generic barrier to the implementation of the technology (Gerges et al., 2017). Dainty et al confirmed that the varied market readiness across organizations is a serious limitation for small construction firms (Dainty et al., 2017). The results of Bin Zakaria et al. prioritized the lack of knowledge and unavailability of standards among the impediments to a higher penetration rate of BIM in Malaysia (Bin Zakaria et al., 2013). Liu and Van Nederveen investigated the status quo of BIM in China and deduced that the financial expenses are the foremost hindrances to BIM adoption (Liu & Van Nederveen, 2017). The absence of universal adoption of BIM is an inhibiting factor to the widespread of BIM levels since the maximum benefits are reaped when BIM is used by most stakeholders (Bataw, Kirkham, & Lou, 2016). Ezeokoli et al. in their case study have identified a set of BIM limitations that form an interdependent circle namely: lack of awareness of BIM added value; lack of skills and expertise; cultural resistance; and contract type delivery method (Ezeokoli et al., 2016).

All the above studies have summarized the adoption barriers either by using a qualitative approach that is based on case studies or through surveys that are based in one country. This confirms that the investigation of BIM barriers at an international level that is based on recent quantitative results is still missing. This chapter will focus on the quantitative ranking of BIM barriers that were published lately to have an updated idea about the latest BIM adoption barriers grounded on the results emanating from 17 countries. It is noteworthy to mention that the study focused on the period from 2015 to 2019 because it does not aim to investigate the barriers during the diffusion of BIM but rather during the implementation of the new technology. The next section will present the methodology used to analyze the barriers facing BIM adoption in the construction sector.

4.3 Objectives and Methodology

This theoretical research aims to study the relative importance of the limitations facing BIM adoption in the AEC industry at an international level. The study aims to summarize the empirical findings from previous publications addressing BIM barriers, synthesize their findings, and provide a holistic vision of BIM barriers across geographical borders. Decisively, the study seeks to examine the convergences and the divergences of the impacts of BIM barriers through presenting a comparative analysis among the regions. For the literature search, Scopus was used as the search engine. A focus on keywords and abstracts was performed when searching for relevant papers, the keywords applied for the database search incorporate the particular search string ("information modeling "OR" information modelling "OR "BIM ") AND ("barrier" OR "challenge" OR "limitations") AND ("construction") AND ("survey" OR "questionnaire"). The initial search resulted in 365 published studies. To refine the results, several criteria were used to decide on the final set of papers. The English language was set as an inclusion criterion which shrank the results to 301 publications. Then a content analysis was performed on the selected papers to refine them. First, the scope of the study was narrowed to the barriers of BIM adoption in the construction industry between 2015 and 2019 which squeezed the outcomes to 116 papers. To conduct a quantitative meta-analysis of the results, studies that used a survey as their methodology was selected. As the Likert scale allows to measure perceptions of participants towards certain topics, questionnaires based on the Likert scale set as a contribution to the inclusion criteria. Moreover, the availability of information such as sample size, response rate, and empirical data (Relative importance factor RII/ Mean Score MIS) is another decisive criterion for the selection, which ended up with a sum of 33 papers to be included in this study. Content analysis of the included papers allowed the identification of BIM adoption barriers which were grouped later in clusters to grasp the holistic nature of BIM. Subsequently, the study used the meta-analysis procedure to outline the empirical results of previous examinations addressing BIM limitations. The significance of the barriers was analyzed using the Relative Importance Index (RII) and the Mean Item Score (MIS) which are widely used statistical analyses in evaluating the significance of a set of variables (Johnson & LeBreton, 2004), and are used according to the below formulas 4.1 and 4.2:

$$\text{Relative Importance Index } I = \sum W/(A \times N)\ ,\ (0 \leq \text{RII} \leq 1)\ [4.1]$$

$$\text{Mean Item Score } MIS = \sum W/N \quad (1 \leq \text{MIS} \leq \text{A})\ [4.2]$$

Where: W = weight given to each factor by the respondents and ranging from 1 to 5, A = highest weight, and N = sample size.

It is worth noting that where researchers used the original rating score to rank the barriers in their surveys, we calculated the RII/MIS to their studies data according to the above formulas. I prepared an excel sheet to document the parameters needed for each of the 33 reviewed studies, such as N, W, A, and RII and assumed that the ratings based on the Likert scale form an interval scale. This assumption allowed the use of parametric statistical tests to come up with objective interpretations (Brown, 2011). This chapter does not aim to examine the correlation between variables, but rather to summarize the weighted ratings of the barriers in the reviewed papers. The last step was to calculate the sum of the documented data (N, W, A), and aggregate them (ΣW, AN, and N) for each barrier to be able to analyze the RII. Following the meta-analysis, a spatial comparison of the barriers was presented and academic discussions that examine the results based on established theories from the literature were provided as figure 4.1 shows.

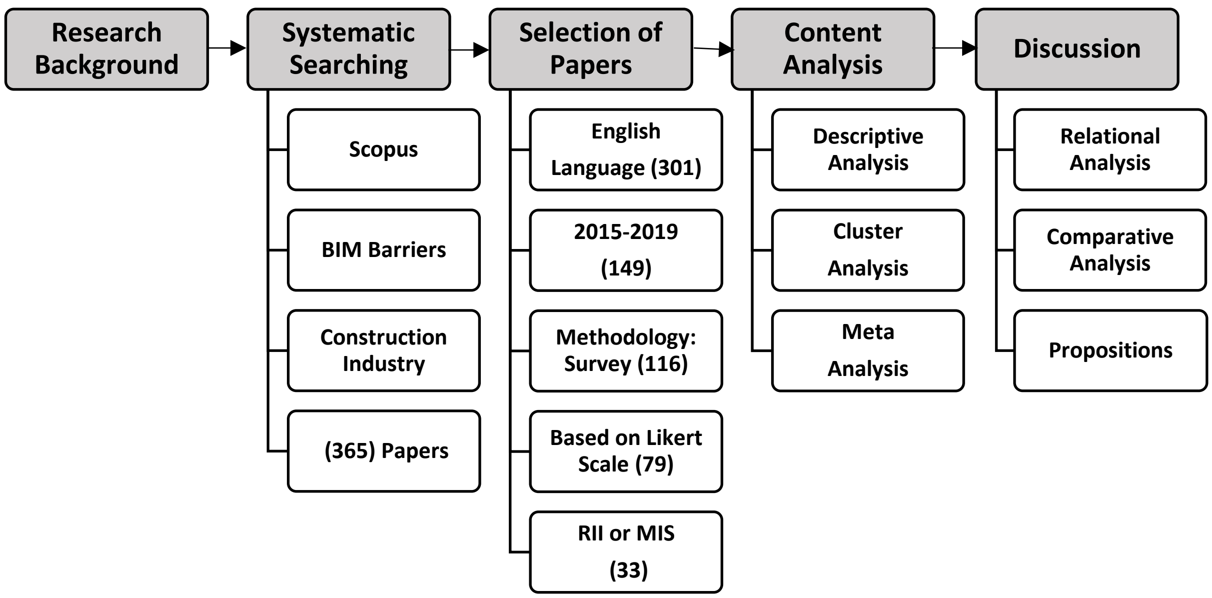


Figure 4.1: Selection criteria of the final Set of papers

4.4 Results

4.4.1 Descriptive Analysis of the Selected Papers

Among the 33 included studies, nine studies were published in 2015, six studies in 2016, nine studies in 2017, five studies in 2018, and four studies in 2019. Starting with a descriptive presentation of the selected papers, it is evident that they have a wide geographical reach originating from 17 countries, and five geographical regions (Asia, Middle East (ME), Australia, Europe, and Africa). The studies' sample sizes range from 16 to 548 participants, while the population sizes vary from 18 to 1365 respondents, which results in a total sample size (∑N) of 3362 respondents and a population size of 7082 participants, and an average response rate of 57% which is satisfactory compared to the scientifically recommended minimum threshold of 30% (Baruch, 1999). Table 4.1 presents the geographical dispersion of the selected papers, considering the number of papers in each region, the total sample size, and the response rate.

Table 4.1: Geographical dispersion of the literature

Region	***Number of Papers***	***Total Sample***	***Response Rate***
Asia	9	656	59.50%
Middle East (ME)	6	833	59.70%
Australia	4	429	30.00%
Europe	6	879	62.90%
Africa	8	565	73.20%
Total	**33**	**3362**	**57%**

It is validated by the above studies that the adoption of BIM is a complex process being confronted by numerous barriers, which confirms that this meta-analysis study has a sound basis on which the limitations of BIM can be examined with accuracy. In this chapter section, detailed descriptive statistics of the reviewed papers based on their originations are presented as elicited in table 4.2. The author’s name, country of study, population, sample size, response rate, number of barrier items, and the data analysis method used in each of the 33 reviewed papers will be presented for each region.

In Asia: the nine studies selected from this region originate from a sum of four countries (China, Malaysia, Korea, and Pakistan), yet emanate mostly (78%) from China and Malaysia. It is important to note that according to the strict inclusion criteria used in this study, the retrieved research papers in Asia emanates mostly from developing countries. None of the included studies was originated in Singapore, Japan, or South Korea. Thus, for the consistency of the results, the region will be named “Developing Asia”. Further, the results highlight the interest in BIM research in South Asia compared to the North and the Central regions. Remarkably, about one-third of these papers were published recently in 2019 confirming the ongoing interest of this region in exploring the barriers of BIM. The total sample size ($\sum N$) is 656 respondents, the total population is 1526, and the average response rate is 59.5%. It is shown in tables 4.2 and 4.3, that there has been a developing interest in the subject “BIM barriers” since 2015 that led to the identification of 94 barrier items.

In the Middle East: the six selected papers in the MENA stem from five countries. The total population is 1607, and the total sample size is 833 which are the highest among the studied regions, indicating the importance of this geographical area for the study. The average response rate is 59.7% and referred up to 92 barriers items. The results show that some of the studies in this region come from advancing countries such as UAE, while others originate from lagging countries such as Palestine in terms of BIM adoption.

In Australia: **w**hat is interesting in this region is that all the four Journal papers included in this study originate in Australia as a country, not as Australasia. The total sample size is (∑N) of 429 respondents, the population is 1823 participants, and the average response rate is 30%.

In Europe: around 80% of all the journal papers found in Europe originate in the UK. The studies’ sample sizes range from 32 to 548 respondents, which results in a total sample size (∑N) of 879 respondents and an average response rate of 62.9 %.

In Africa: the selected papers emanate from five countries and lean towards Nigeria that constitutes 50% of the reviewed papers. The total population is 837, and the total sample size is 565 leading to an average response rate of 73.2% which is the highest among the studied regions. There has been a developing interest in the subject “BIM barriers” since 2015 and referred up to 119 barriers items in this region.

Table 4.2: Studies included in the meta-analysis (N=33)

	Year	Authors		Country	Populatio	Sampl	Resp	N	Analysi
Asia (N=9)	2019	Wong et al.	Conferenc	Malaysia	175	43	24.60	8	Mean
	2019	Siddiqui et al.	Journal	Pakistan	120	89	74.20	21	Rank
	2019	Zhou et al.	Journal	China	140	138	98.60	18	Mean
	2018	Hamid et al	Conferenc	Hongkon	18	16	88.90	10	Mean
	2017	Jin t al.	Journal	China	297	94	31.60	9	RII
	2017	Li et al.	Conferenc	China	555	136	24.50	12	Mean
	2016	Vasudevan	Journal	Malaysia	100	55	55.00	6	Origina
	2015	Liu et al.	Journal	China	64	37	57.80	5	Mean
	2015	Anuar	Journal	Malaysia	60	48	80.00	5	Origina
MENA (N=6)	2018	Hatem et al.	Journal	Iraq	300	273	91.00	23	Mean
	2017	Alhumayn et	Journal	Saudi	342	224	65.00	9	Origina
	2017	Venkatachla	Conferenc	UAE	100	60	60.00	20	RII
	2017	Banawi	Conferenc	Saudi	230	195	84.80	10	Origina
	2016	Enshassi et al.	Journal	Palestine	75	37	49.30	17	RII
	2015	Hosseini et al.	Conferenc	Iran	560	44	7.90%	13	Origina
Australia (N=4)	2016	Hosseini et al.	Journal	Australia	1365	335	24.50	13	RII
	2016	Monozam et	Journal	Australia	326	41	12.60	10	RII
	2016	Kim et al.	Journal	Australia	68	26	38.20	7	Score
	2015	Liu et al.	Journal	Australia	64	27	42.20	5	Score
Europe (N=6)	2019	Georgiadou	Journal	UK	100	71	71.00	8	Mean
	2018	Alrashidi et al	Journal	UK	118	97	82.20	26	RII
	2017	Bosch-	Journal	Sweden	104	32	30.80	15	Mean
	2017	Oduyemi et	Journal	UK	120	66	55.00	10	RII
	2017	Andre et al.	Journal	Spain	744	548	73.70	9	Mean
	2015	Eadie et al.	Journal	UK	100	65	65.00	32	RII
Africa (N=8)	2018	Nasila and	Journal	Kenya	310	147	47.10	15	MIS
	2018	Ogunde et al	Conferenc	Nigeria	105	74	70.50	25	MIS
	2017	Onungwa and	Journal	Nigeria	30	16	53.30	9	Origina
	2016	Ezeokoli et	Journal	Nigeria	84	56	66.70	8	RII
	2015	Akwaah	Conferenc	Ghana	35	30	85.70	20	MIS
	2015	Ugochukwu	Journal	Nigeria	155	135	87.10	7	Mean
	2015	Saleh	PhD	Libya	77	75	97.40	27	MIS
	2015	Chimhundu	PhD	South	41	32	78.10	8	MIS

In the US

The remarkable result about the US is the null number of recent articles found when searching for BIM adoption barriers according to the inclusion criteria since 2015. However, if refreshing the search for the last 15 years, several studies would show to be originated in the US. This might indicate that the US is the leader in investigating the limitations of BIM, and the absence of studies in recent years indicates that the US already revealed the barriers of BIM and ventured the overcoming strategies. In other words, exploring BIM barriers is no more a hot topic or a trend in the US.

In the next part of this analysis, I will dissect the barrier items found in the reviewed empirical data.

4.4.2 Identification and Clustering of BIM Barriers

The deep content analysis of the 33 papers allowed the condensation of 440 items barriers that were found in the literature into a total set of 25 barriers that explains all the above.

For example, if the barrier found is “shortage of experts who can perform the design on BIM”, or “no one knows how to run BIM tools” or “practitioners are not BIM professionals”, we assign it under the barrier of “Lack of BIM specialists”. The analysis of the 25 barriers found, suggests that some of these barriers are interconnected and can be grouped together. For example, people refuse to learn, resistance to change, and cultural resistance are all related to the behavior of personnel when introducing a new system of work. I thought of clustering these barriers to reduce the number of variables into a smaller number of significant components. The clustering aimed to provide easier interpretation of results based on the examination of the fundamental relationships among the variables under each component. Five barrier clusters were identified and are presented in table 4.3.

Cluster 1: “Human Resources” barriers, links five pitfalls together related to the skills and knowledge required from personnel to adopt the new technology. Resistance to change as well falls under this cluster as it is related to the people's attitude towards BIM. Therefore, this cluster tackles the attitude, behavior, and skills of BIM practitioners.

Cluster 2: “Financial” barriers, conceptually links four hindering factors related to the cost of acquiring the technology whether the implementation costs, the training expenses, or even the doubts of BIM financial returns.

Cluster 3: “Process and incentive” barriers, links five hindering barriers related to the increasing demand of 3D modeling to have levels of support.

Cluster 4: “Legal” links six barriers together that are related to the contractual and legal implications of adopting BIM such as difficulty in assigning intellectual property, responsibilities, and liabilities. In addition to the government initiatives to adopt BIM such as government support and initiation of standards.

Cluster 5: “Technology” barriers, links five barriers that are related to developing complex vendor-orientated solutions.

Table 4.3: Clustering of BIM barriers

Frequency of Barriers Cluster *citations*	**Citations**
Human Resources Barriers	**74**
Lack of skills, and BIM specialist	23
Resistance to change	20
Lack of knowledge and awareness of BIM	12
Lack of management support	16
Lack of training on BIM	3
Financial Barriers	**63**
Commercial issues and investment cost	20
Cost of training	18
Lack of project finance to support BIM	14
Lack of immediate benefits /ROI	11
Process and Incentives Barriers	**55**
Current technology is enough	28
Lack of client demand	9
Absence of BIM standards and guidelines	8
Lack of incentive to have stakeholders using BIM	5
Waste time and human resource	5
Legal Barriers	**50**
Liabilities	16
Legal impact and copyright	9
Difficulty in assigning intellectual property	8
Lack of government support and legal backing	8
Absence of Standard BIM Contract Documents	6
Confidentiality	3
Technology Barriers	**39**
Interoperability	13
Complexity of the program	13
Insufficient Infrastructure	8
Lack of software compatibility	3
Takes a longer time to develop a schedule	2

The survey of the literature showed that stakeholders identified the unavailability of the needed human resources as the most common challenging cluster with a variance of (74/281) = 26.3%. Financial barriers form the second most common cluster with a frequency of 63/281= 22.4 % due to the presence of monetary expenses related to acquiring the software and training the practitioners to make the step from traditional working methods to BIM. Lack of incentives and processes is the third most common cluster of barriers with a frequency of 55/281= 19.5%, as one needs first to understand what the change is good for, to be able to get rid of the doubts concerning the usefulness of the technology. The legal status is the fourth common barriers group with a frequency of 50/281= 17.7% and emphasizes the doubts of parties' responsibilities, liabilities, and ownership of the data (Turk & Klinc, 2017). Another issue brought up in the review of the literature was the technological barrier with a frequency of 39/281= 13.8% that is caused by the complexity of BIM tools. The application of BIM is not straightforward because one needs different file formats to function properly through one combined model, especially when it comes to material volume computation (Aibinu & Venkatesh, 2013) (Stanley & Thurnell, 2014). In summary, this study shows that the implementation of BIM practices is associated with many potential barriers, and their examination by means of cluster analysis was based on a close examination of variables under the five components derived.

4.4.3 Meta-analysis Results

Meta-analysis can quantify the findings to qualitatively compare a large number of studies. It is a synthetization of previous analyses that creates a complete understanding of the complete picture (Borenstein et al., 2011). The goal behind adopting this procedure is to consolidate the findings through synthetization. In this section, I will dissect the reviewed empirical data, drawing on the cluster analysis presented in section 4.2.

Developing Asia: the results demonstrate that all the barriers cluster in Asia are considered as substantial hinderers to BIM adoption as they scored an overall RII of 0.790 > 0.7. The significance of the barriers clusters is analogical indicating that Asia has various types of impediments to overcome before successfully venturing BIM. This infers that this region might have a long way to undergo (compared to other regions) before realizing the full benefits of BIM adoption. A closer assessment of the results implies that the financial, human, and legal-related barriers are rated as the topmost critical BIMs limitations in Developing Asia having a high RIIs of 0.836, 0.831, and 0.811 respectively. The financial aspects prevent Asian firms from adopting BIM for strategic and economic reasons. The results demonstrate that the construction sector in this region is confronting challenges in affording BIM, in terms of software and hardware costs and training expenses. The barrier with the highest impact in this cluster is the high investment cost associated with BIM adoption (0.885). At large, all costs-related barriers are crucial limitations for BIM in Asian countries. Another critical cluster that should be brought to attention in Developing Asia is related to participants themselves. The results indicate that practitioners in Asia have a negative attitude and a low desire to shift from the traditional working methods and accept the adoption of the new technology. This can be induced from the high load assigned to the resistance of the Asian respondents in changing their working method (0.854). According to Oesterreich and Teuteberg (2019), it is the vicious cycle of fear of the unknown, mistrust of the system, and the lack of knowledge (0.880) that is accountable for this unanticipated resistance to change. Another implication of the results is related to the high weights scored by Legal barriers such as legal impact and copyright barrier 0.890, lack of government support 0.889, and absence of BIM Standards 0.888 in Asia. This supports the findings of Park and Kim (2017) that the model ownership and the legal difficulties are the core glitches to be solved before venturing BIM, and that the existing guidelines are not enough to meet the legal requirements.

Table 4.4: RII of BIM adoption cluster barriers in Asia developing countries

Barriers	∑W	AN	N	RII
Human Resources Barriers	**13293**	**15985**	**3197**	**0.831**
Lack of skills, and BIM	2709	3040	608	0.891
Resistance to change	2438	2855	571	0.854
Lack of management support	1970	2620	524	0.752
Lack training on BIM	2015	2580	516	0.781
Lack of awareness and	1258	1430	286	0.880
Process and Incentives	**12897**	**17100**	**3420**	**0.754**
Current technology is enough	1393	1930	386	0.722
Lack of client demand	1092	1240	248	0.881
Absence of contractual	2467	3280	656	0.752
Lack of incentives to using BIM	1195	1690	338	0.707
Waste time and human resource	2173	3065	613	0.709
Legal Barriers	**10559**	**13020**	**2604**	**0.811**
Confidentiality	941	1230	246	0.765
Absence of BIM standards and	1079	1215	243	0.888
Legal impact and copyright	2541	2855	571	0.890
Difficulty in intellectual	1892	2620	524	0.722
Liabilities	1353	1900	380	0.712
Lack of government support and	1200	1350	270	0.889
Financial Barriers	**9165**	**10970**	**2194**	**0.836**
Commercial issues and	3320	3760	752	0.885
Cost of training	2458	2855	571	0.861
Lack of project finance to	984	1215	243	0.810
Lack of immediate benefits /ROI	1493	1900	380	0.786
Technology Barriers	**8145**	**11265**	**2253**	**0.723**
Complexity of the program	2312	3280	656	0.705
Takes longer time to develop	1668	2380	476	0.701
Interoperability	2186	3040	608	0.719
Insufficient Infrastructure	1112	1425	285	0.780
Lack of software compatibility	809	1140	228	0.710

Middle East: the results of table 4.5 illustrate that the process and incentives cluster was perceived to be the least impending yet significant in the MENA with RII 0.744, however, the financial cluster is the most hampering cluster with an RII of 0.829. The examination of the results shows the homogeneity and convergence of the RII values delegated to the clusters, indicating they are somehow equally hindering BIM adoption. The financial barrier items were all aggregated with a high RII> 0.801. The commercial and investment cost coupled with the cost of training and the lack of project finance has led to perceiving BIM as a costly investment in the ME. Their high significance in the MENA might be due to the predominance of SMEs, in this region, that are characterized by having limited resources (Ibrahim M. , 2015) (Park & Kim, 2017).

Likewise, BIM in the MENA seems to pose risk, in light of the fact that there are doubts among MENA practitioners regarding the positive returns of BIM (RII= 0.861), as deduced from the empirical findings. Moreover, technological barriers were assigned high weights in the MENA having interoperability as the leading limitation. The top positioning of interoperability confirms the findings of Eadie et al. that the heteronomous applications and the interference of different players to the BIM model, together with dynamics needed to operate in the construction sector are generic problems of BIM (Eadie et al., 2013). Compatibility is the subsequent limitation in this cluster, signaling that the successful adoption of BIM is not always guaranteed, as it is problematic to make diverse documents and file formats function appropriately together. Human resources are the ensuing BIM limitations in the ME, pointing out the lack of awareness (0.901) and the lack of skills (0.853) as the most hampering factors. The precedents prove that a huge proportion of MENA respondents have no understanding of BIM concepts, and therefore lack the needed expertise to run BIM. This is consistent with the outcomes of Ibrahim (2015) who confirmed the deficiency of BIM awareness among experts in the Middle East (ME) region (Ibrahim M. , 2015).The above might be due to the lack of local standards and guidelines that explains how to align BIM with constructions in the ME. Therefore, it is inferred that the MENA might have a long road to undertake in order to fade the adoption barriers and reach a successful penetration of BIM.

Table 4.5: RII of BIM adoption cluster barriers in ME

Barriers	∑W	AN	N	RII
Human Resources Barriers	**11858**	**14890**	**2978**	**0.755**
Lack of skills, and BIM	2376	2785	557	0.853
Resistance to change	1806	2580	516	0.700
Lack of management support	1703	2395	479	0.711
Lack of training on BIM	3403	4165	833	0.817
Lack of awareness and	3388	3760	752	0.901
Process and Incentives Barriers	**17858**	**24015**	**4803**	**0.744**
Current technology is enough	2760	3760	752	0.734
Lack of client demand	3707	4165	833	0.890
Absence of BIM standards and	2882	4165	833	0.692
Lack of incentive to use BIM	1977	2800	560	0.706
Waste time and human resource	1796	2580	516	0.696
Legal Barriers	**20784**	**29685**	**5937**	**0.700**
Confidentiality	1438	1995	399	0.721
Absence of Standard BIM	450	660	132	0.682
Legal impact and copyright	4778	6825	1365	0.700
Difficulty in intellectual property	5109	7145	1429	0.715
Liabilities	6336	8775	1755	0.722
Lack of government support and	1319	1995	399	0.661
Financial Barriers	**13637**	**16440**	**3288**	**0.829**
Commercial issues and	3012	3760	752	0.801
Cost of training	1976	2395	479	0.825
Lack of project finance to support	1990	2395	479	0.831
Lack of immediate benefits /ROI	3397	3945	789	0.861
Technology Barriers	**7832**	**9775**	**1955**	**0.801**
Complexity of the program	1977	2785	557	0.71
Takes a longer time to develop	1174	1460	292	0.804
Interoperability	3275	3760	752	0.871
Insufficient Infrastructure	328	405	81	0.810
Lack of software compatibility	1107	1365	273	0.811

Australia: Comparing the overall significance of the clusters between Australia, the MENA, and Asia, indicates that the clusters have received lower impacts in Australia ranging from 0.674 for the technological barriers (lowest) to 0.788 for the financial barriers (highest). The financial limitations were proven to be the most challenging by stakeholders in the Australian sample. The reviewed surveys reflecting Australians practitioners' perceptions towards BIM challenges confirm that lack of project finance gained more attention compared to other financial barriers. This validates the findings of Eadie et al., that the tasks and the monetary barriers are the first to overwhelm in Australia (Eadie et al., 2013). When reviewing the barrier items in the subsequent significant cluster, subgroup differences were noticed in the people related dimension indicating that in Australia the lack of skills and expertise (0.802) is more significant than the cultural resistance of people (RII =0.692), and the lack of BIM knowledge and awareness (RII =0.678), which denotes an attitude of acceptance among Australian practitioners towards the new technology. In line with the above, Australian respondents held a more positive view of BIM technological barriers, ranking it as the least significant cluster with a RII=0.674, signifying that Australia is on the right track and was successful in implementing overcoming strategies to fade the technology-related barriers such as updating the IT infrastructure, dedicating high-speed internet connection, along with the implementation of the tools that suits best the organization needs. Yet, it needs to employ other strategies to handle the financial barriers.

Table 4.6: RII of BIM adoption cluster barriers in Australia

Barriers	∑W	AN	N	RII
Human Resources Barriers	**32421**	**44595**	**8919**	**0.727**
Lack of skills, and BIM	5474	6825	1365	0.802
Resistance to change	6086	8795	1759	0.692
Lack of management support	4784	6825	1365	0.701
Lack of training of BIM	1745	2290	458	0.762
Lack of awareness and	6180	9115	1823	0.678
Process and Incentives	**22899**	**31585**	**6317**	**0.737**
Current technology is enough	4778	6825	1365	0.700
Lack of client demand	5057	6825	1365	0.741
Absence of contractual	6572	9115	1823	0.721
Lack of incentive to use BIM	1770	2290	458	0.773
Waste time and human	1346	1950	390	0.690
Legal Barriers	**21462**	**29685**	**5937**	**0.723**
Confidentiality	1438	1995	399	0.721
Absence of BIM standards and	450	660	132	0.682
Legal impact and copyright	4778	6825	1365	0.700
Difficulty in intellectual	5109	7145	1429	0.715
Liabilities	7538	8775	1755	0.859
Lack of government support	1319	1995	399	0.661
Financial Barriers	**20538**	**26390**	**5278**	**0.778**
Commercial issues and	515	695	139	0.741
Cost of training	7028	9115	1823	0.771
Lack of project finance to	6280	7145	1429	0.879
Lack of immediate benefits	1653	2290	458	0.722
Technology Barriers	**23708**	**35165**	**7033**	**0.674**
Complexity of the program	6055	8775	1755	0.690
Takes longer time to develop	1359	1995	399	0.681
Interoperability	5697	9115	1823	0.625
Insufficient Infrastructure	4655	6825	1365	0.682
Lack of software compatibility	5859	8455	1691	0.693

Europe: the perception towards the legal barriers in Europe shows a remarkable optimistic view that was translated by the lowest RII (0.598) of this cluster among the studied regions. The above illustrates the gap between the initiatives taken by European governments to overcome the legal barriers and guarantee a successful adoption of BIM and those reluctant governments initiatives employed in other areas. The results revealed the positive perception of the European participants to legislation and policies that helped in receding the solidity of the legal barriers. The findings praise the measures brought by the European governments in terms of launching standards and mandating BIM usage in the construction sector. Looking at how Europe is dealing with BIM, one can detect the ongoing movements towards enchasing BIM full integration. Another implication of the study is demonstrating a noticeable chasm between the weights assigned to the legal clusters, and those assigned to the financial ones (RII=0.849) in Europe, urging the need for other types of initiatives that might help in reducing the financial charges and the burdens associated with BIM implementation. on the other hand, when examining the human resource barriers in Europe, one can notice that this chapter has produced a ranking of the lack of skills, lack of training, lack of management support, resistance to change, and lack of awareness in the European context. Further, evaluating the presence of BIM specialists to run BIM models is observed to be surprisingly low in Europe. This was concluded from the high ranking of lack of skills that received an important index of 0.858, demonstrating the need for professionals, and BIM experts in this region. However, the results highlighted the understanding of European practitioners to BIM processes (RII=0.637), which might be due to the penetration of BIM courses in the education curricula of some European universities such as in the UK, and Finland (Panuwatwanich et al., 2013).

Similarly, the process and inventive barriers are ranked low in Europe (RII=0.623) in comparison with other regions, designating the consciousness of practitioners in Europe of the need for BIM to enhance the triple constraints of a project, which incorporates their attentiveness about the need for changing the conventional working methods. Similarly, the technological barriers have shown low impact, and interoperability is ranked among the bottommost significant barriers in Europe. Another anticipated finding in Europe is the low significance of the barrier related to having insufficient technological infrastructures (0.541) which is considered the lowest in the compared regions.

Table 4.7: RII of BIM adoption cluster barriers in Europe

Barriers	∑**W**	AN	N	RII
Human Resources Barriers	**21798**	**29560**	**5912**	**0.737**
Lack of skills, and BIM	1896	2210	442	0.858
Resistance to change	3949	5930	1186	0.666
Lack of management support	4011	5320	1064	0.754
Lack of training on BIM	3258	4220	844	0.772
Lack of awareness and	3459	5430	1086	0.637
Process and Incentives	**16743**	**26840**	**5368**	**0.623**
Current technology is enough	1507	2210	442	0.682
Lack of client demand	1653	2710	542	0.610
Absence of contractual	2971	5930	1186	0.501
Lack of incentive to use BIM	3524	5340	1068	0.66
Waste time and human resource	3210	4820	964	0.666
Legal Barriers	**18831**	**31490**	**6298**	**0.598**
Confidentiality	4048	5910	1182	0.685
Absence of BIM standards and	957	1590	318	0.602
Legal impact and copyright	3309	5320	1064	0.622
Difficulty in intellectual	2584	4820	964	0.536
Liabilities	957	1590	318	0.602
Lack of government support and	3154	5830	1166	0.541
Financial Barriers	**13839**	**16300**	**3260**	**0.849**
Commercial issues and	4833	5430	1086	0.890
Cost of training	4910	5930	1186	0.828
Lack of project finance to	982	1120	224	0.877
Lack of immediate benefits /ROI	1770	2210	442	0.801
Technology Barriers	**14842**	**24110**	**4822**	**0.615**
Complexity of the program	3234	4820	964	0.671
Takes longer time to develop	1452	2110	422	0.688
Interoperability	3018	5930	1186	0.509
Insufficient Infrastructure	2608	4820	964	0.541
Lack of software compatibility	4302	6430	1286	0.669

*Africa***:** All the clusters in Africa were perceived to be crucial hurdles to the successful adoption of BIM, as their RIIs fluctuate in a narrow range from 0.746 for the process and incentive barrier to 0.828 for the legal ones. BIM is an innovation that requires legislation to be productive (Abor & Quartey, 2010), challenges such as the absence of contractual requirements, and government's incentives are serious in this developing region.

In line with the above, human-related barriers appeared to have a high RII (0.812), pointing to the lack of knowledge and awareness as the most significant barriers in Africa with an RII of 0.871. Therefore, it is worth noting that BIM knowledge and expertise in the fragmented construction sector is essential to collaborate between parties that have different objectives and requirements. These results are consistent with the examination of Ezeokoli et al., (2016) and Hamma-adama and Kouider (2019) who stated that Africa has a low BIM-advantage and readiness to emerge the new technology (Ezeokoli et al., 2016). This is consistent with the results of Ogunde et al. (2017) who featured the absence of an expanded degree of BIM knowledge and confirmed that most of the SMEs in Africa are highly acquainted with the paper-based formats and 2D CAD indicating that just a minority of African practitioners are familiar with 3D models and none of them use 4D BIM (Ogunde et al., 2017) (Hamma-adama & Kouider, 2019). This opposes with the results of Saka and Chan (2019) who demonstrated that although there is a low degree of BIM awareness in North Africa, there is a form of BIM knowledge among participants (Saka & Chan, 2019). Shifting our focus to the financial barriers, monetary issues were retrieved to be major impediments of BIM adoption in Africa like in other regions. These results were anticipated, as most construction companies in Africa are SMEs who are typified by the poverty of resources (Hamma-adama & Kouider, 2019). Therefore, construction companies operating in Africa need to create a solid business case, unique to the needs and objectives of their firms.

Table 4.8: RII of BIM adoption cluster barriers in Africa

Barriers	∑W	AN	N	RII
Human Resources Barriers	**10268**	**12525**	**2505**	**0.819**
Lack of skills, and BIM	414	510	102	0.812
Resistance to change	1546	1930	386	0.801
Lack of management support	1315	1640	328	0.802
Lack of expertise and training of	2167	2665	533	0.813
Lack of awareness and	1407	1615	323	0.871
Process and Incentives Barriers	**5744**	**7695**	**1539**	**0.746**
Current technology is enough	392	535	107	0.732
Lack of client demand	1332	1640	328	0.812
Absence of contractual	388	510	102	0.761
Lack of incentive to use BIM	987	1360	272	0.726
Waste time and human resource	252	360	72	0.701
Legal Barriers	**8975**	**10835**	**2167**	**0.828**
Confidentiality	1294	1615	323	0.801
Absence of BIM standards and	1424	1615	323	0.882
Legal impact and copyright	1289	1640	328	0.786
Difficulty in intellectual property	1320	1625	325	0.812
Liabilities	962	1210	242	0.795
Lack government support and	322	360	72	0.894
Financial Barriers	**3237**	**4030**	**806**	**0.803**
Commercial issues and	945	1210	242	0.781
Cost of training	832	1050	210	0.792
Lack of project finance to	605	730	146	0.829
Lack of immediate benefits /ROI	714	880	176	0.811
Technology Barriers	**5251**	**6970**	**1394**	**0.753**
Complexity of the program	1935	2665	533	0.726
Takes longer time to develop	1464	1720	344	0.851
Interoperability	1270	1930	386	0.658
Insufficient Infrastructure	303	375	75	0.809
Lack of software compatibility	202	280	56	0.723

Overall, the prioritizing of the barriers among geographical regions was not alike in every approach. A comparison to assess similarities and differences between developed and developing regions is not applicable since every region shows to have its own ranking of the barrier clusters, and a combination of both types of countries. The below discussion will build on established theories from the literature to explain the results of the meta-analysis, this will be accompanied by propositions for managers, decision-makers, and owners to diminish the effect of the impediments.

4.5 Discussion of BIM Adoption Barriers

To the best of our knowledge, the meta-analysis conducted in this study is among the first research efforts to investigate BIM limitations based on mathematical formulas to evaluate the type of barriers across geographical regions and to present a global view of BIM limitations at an international level. The below discussion will be grounded on theoretical research streams from the literature to justify the convergences as well as the divergences of the barrier's significance across the boards.

Human resources barriers: the meta-analysis results imply that as the implementation of BIM is new, a shortage of qualified BIM specialists is present at an international level and is predominantly hampering BIM adoption. The outcomes illustrate the high significance of this barrier among the studied regions with minimal differences in its impact across the territories (lowest RII in Australia 0.802, and highest RII in Asia 0.891). To understand the rationale behind this minor fluctuation, we will base our examination on the *framework of resource constraints* that explains the unique features and the structural nature of the AEC sector. The framework refers to the *Resource-Based View* of organizations postulating scarcity of resources as a main characteristic of SMEs. It must be mentioned here that according to published reports, the percent of construction firms that are categorized as small and medium businesses is: 99.6% in Europe, 97.8 % in Australia, 95% in Africa, and 90% of the AEC industry at a global level (EBC's, 2017) (Australia, 2008) (Abor & Quartey, 2010). Thong et al employed the Knowledge barrier theory in their SMEs assessment study and confirmed that the lack of skills and expertise is caused by the tendency of small firms to employ generalists and not specialists which make the above results reasonable. Another finding in this cluster is positioning the lack of training as an imperative barrier across geographical areas with adjacent weights of 0.762 in Australia (the lowest) and 0.817 in the MENA (highest). This is consistent with the conclusions of Hosseini et al (2017) that construction companies tend to train practitioners on BIM without educating them on its processes, and that most BIM experts are self-trained. The deficiency of BIM specialists is being a concern for the industry calling for urgently training people on BIM as a prerequisite for its expansion. To solve this problem, professional education about BIM in universities is encouraged to graduate skilled employees familiar with the new technology. Yet, the content of these courses should be carefully examined to ensure they are aligned with the industry's practical needs. Furthermore, resistance to change was found to be a significant barrier in this cluster, however, it impacts remarkably varies from one region to the other. The *organization culture theory* explains this resisting behavior by proposing a four elements framework that focuses on users, organizational hierarchy, political power and environment. The political power presented in the framework presumes that the deviations caused by the shift toward information technology affect the normal distribution of power in the organization and increase the uncertainty toward the integrated system. Pliskin et al. confirmed the validity of the above framework and expanded it by adding the cultural element confirming that practitioner’s resistance is affected by the coherence between the actual and the presumed distribution of power within the firm (Pliskin, Romm, Lee, & Weber, 1993). Examining the results of our empirical study, the findings demonstrate the high significance of resistance in Asia (RII=0.854), and Africa (RII=0.801) compared to Europe (0.666) and Australia (0.692). These disparities might be explained by grounding on *Rogers technology adopters’ model* that classifies adopters into groups according to their time of adoption. The model states that early adopters are those who first support and accept the innovation, the majority adopters (early majority, and late majority) are those who adopt the technology after the revelation of its benefits, and the laggards are those who adopt it only after making sure that the associated uncertainties were removed (Rogers E., 1983).

Further, the model confirms that the laggards are the last to be convinced of the reaped benefits, thus, tend to resist the adoption aggressively. In this sense, the study of El hajj et al (2019) categorized the geographical regions according to BIM diffusion rate and uses to came up with the conclusion that Europe and US are the leaders, Australia is an early adopter, and Africa is a laggard. Combing the two studies, one can justify the high resistance to change in Africa and developing Asia from the laggard’s standpoint owing to their limited resources making them cautious of innovative technologies until they are certain that the new concept will not fail if they adopt it. To explain the lower significance of the resistance barrier in the

Middle East (Africa <RII of ME=0.701< Europe), the examination of the included studies was useful in pointing out that the published articles emanate from a mix of developed countries in the MENA such UAE (Dubai) which is advancing in BIM and leader to its adoption in the MENA region, and other developing countries namely Palestine and Iraq that were confirmed to be laggards and have very high resistance to BIM (Jawad et al., 2019).

Besides, the study of Rizzuto and Reeves (2007) confirms that the lack of management support increases users' resistance to adopting the technology because the way managers involve workforces in the new system affects their attitude toward it. The precedent confirms the high interdependencies between the two barriers. Grounding on the *organizational influencing theory* the use of upward influencing processes such as intermediaries with formal authority is recommended to increase top management commitment to the new technology. Thus, management ought to develop a strategic vision around BIM to effectively clarify the rationale behind its adoption through appropriately promoting cost-benefit analyses that help practitioners to feel the need for the adoption. Another reason for resisting the change is not being convinced of the benefits of the technology. Therefore, awareness programs that deliver evidence of the costs and benefits of BIM are proposed to help organizations in weighing the risks versus the opportunities. The supply chain collaborators might be propelled to utilize BIM for data sharing, collaboration, and cost optimization by showing the saving and gains of BIM, through presenting quantitative examinations of the financial values that are attainable through coordination and collaboration (Cheng, 2015). Convincingly, it is the vicious cycle of lack of knowledge, lack of management support, and delay in the adoption that is accountable for this high resistance at an international level. To resolve this problem, construction firms need to take the correct actions to deliberately change their norms to a degree that might evade resistance and bolster innovation (Alhumayn et al., 2017). This incorporates the development of an organizational culture that fosters continuous development, tolerates risks and provides a substantial degree of collaboration between parties (Alreshidi et al., 2017). A culture of power-sharing and participative decisions assists in improving practitioner's acceptance and contribution towards BIM. Therefore, the technology should be accustomed to suit the firm's culture or the firms' culture need to be changed to enable the adoption of BIM (Ezeokoli et al., 2016).

Another finding from the meta-analysis of the human resource cluster positions lack of awareness as a foremost limitation to widespread adoption of BIM. To understand the mechanism behind the intention of an organization to decisively adopt a complex technology, the *push-pull theory* presented by Zmud in 1984 might be of value. The technology-push aspect of the theory enlightens that companies ought to adopt a new system if they have enough knowledge about it, or if they have the needed skills to adopt the technology (Zmud, 1984). In other words, the higher the knowledge about BIM, the higher the penetration rate. In line with the above, researchers have proposed numerous approaches to increase BIM application and BIM knowledge, where introducing BIM education in engineering schools is one of them (Jin et al., 2017).

To increase the knowledge about BIM, scholars advocated the effort of incorporating BIM in higher education curricula. Several studies identified the need to offer courses or programs that emphasize BIM to provide engineering graduates with a sufficient understanding of BIM concepts. Based on the above and examining the penetration rate of BIM in education, the study of Jin et al indicated that Singapore and the US have a high integration of BIM in their university curricula (Jin et al., 2017). UK was first in identifying BIM education as a key strategy to the roadmap of BIM implementation. Similarly, in Denmark and Norway, and UK, universities are leading the charge by educating engineering students about BIM processes.

Likewise, Jin et al., confirmed the use of BIM courses at the program level in Australian universities has increased the awareness of Australian practitioners about BIM. In contrast, developing countries such as Pakistan, Ghana, South Africa, Libya, and Iraq have been very low in BIM application and have done little if none to support the integration of industry BIM practices into the university curriculum. Based on the above discussions, one can understand the low perception of European practitioners to the lack of awareness barrier RII= 0.637 compared to higher values in Africa 0.871 and developing Asia 0.88. The results confirm the correlation between the awareness level on BIM and the integration of BIM in university courses. One More tactic to overcome the lack of knowledge, is driving organizations to form core groups comprising of carefully chosen motivated and empowered representatives to effectively improve learning and encourage knowledge transfer. The provision of research grants is also recommended to promote efforts towards BIM research and developments (Bataw et al., 2016).

The financial barriers seem to be crucial limitations to all regions with an average international RII of 0.819. Barriers attached to this cluster are related to the lack of financial resources to adopt a costly investment such as BIM. The *Resource-Based View* and the *framework of resource constraints* pose the availability of resources as a key factor for firms to achieve competitive advantages. Combined with what was mentioned before that most AEC companies are SMEs that are typified by constrained assets, the high significance of the fiscal limitations across the studied regions can be justified. To overcome this barrier, studies on BIM rate of return and financial benefits to firms areare necessity. Because based on the *loss-aversion behavior* if one needs to compare two options both leading to equal results, but for option 1 the benefits are emphasized and for option 2 the potential losses are presented, the decision-maker tends to favor option 1 (Boettcher III, 2004). Therefore, the deficiency of empirical investigations on BIM benefits and potentials (Gerges et al., 2017), increases practitioners' doubts of BIM positive paybacks and direct them to consider the investment as an additional risk on the project (Gerges et al., 2017). Participants should be aware of the financial benefits of BIM in reducing the project duration and saving of contract value (Georgiadou et al., 2019). It is confirmed that the move to BIM involves a significant financial investment in software, training, and time, however, the costs need to be weighed against the benefits (Bataw et al., 2016) because BIM is an investment that pays off in the long run.

Process and incentive barriers: according to the meta-analysis results, the prominent barriers in this cluster are related to the lack of necessity for BIM. The findings prove remarkable divergences between the regions in evaluating the significance of the client demand. The outcomes rank the lack of demand as a frontrunner barrier in the ME, Developing Asia, and Africa with RIIs of 0.89, 0.881, and 0.812 respectively, however they position it at a lower level in Europe as the RII is 0.602. Further, the empirical results illustrate the same divergences when observing practitioners' satisfaction with the traditional working methods. As discussed earlier, participants from Asia and the Middle East lack a good understanding of BIM processes making it harder to convince them to ditch their conventional procedures and penetrate BIM. Yet, European practitioners seem to be more positive in perceiving the limitations resulting from the lack of demand and the unnecessary shift. To validate these disparities, it is worth mentioning that some European Ministries of Public Works announces that the BIM methodology will be mandatory for building tenders in December 2018 and for civil works at the end of 2019, which demoted the lack of incentives barriers. As governments are the clients in many cases, the lack of client demand and necessity of BIM was not perceived as a significant barrier in Europe. The findings validate the *theory of network effects* in confirming that the availability of any good or service is dependent on clients' demand to adopt it. In other words, the handiness of BIM software expands, when the adoption rate increases. Aside from these hypothetical clarifications, it is imperative to mention that there is a notable number of suppliers providing BIM software around the globe, and Europe entails more than 280 suppliers who deliver High-quality BIM software. The combination of the three explanations presented above justifies the low importance assigned to the lack of clients in demand in Europe when juxtaposed with other regions. Another barrier in this cluster is the satisfaction with the current technology that shows to be extremely significant in Africa and the Middle East. To explain the results, I will refer to the *need-pull aspect* of the push-pull theory in confirming that the decision toward adopting BIM is induced by the firm’s dissatisfaction with its current systems. The dissatisfaction is a result of both, a clear performance gap and a conviction that a more effective tool that was tested and proved exists. As discussed before these regions are: (1) late majority and laggards who are very conservative (2) not convinced with BIM benefits, (3) and have low awareness about BIM, which increases their attachment to the existing working methods.

Legal related barriers: the results prioritize lack of standards and legal backing from the authority as substantial limitations to widespread adoption of BIM in Africa (RII=0.894) and Asia (RII=0.889) compared to inferior significance in Australia (RII=0.661) and Europe (RII=0.541). Thus, it is important to have an idea about the standards and initiatives imposed by different governments to foster BIM adoption. To start, the EU governments have promoted a set of regulations, and standards to enhance the integration of BIM in the construction industry. The UK Government's Construction Strategy declared a set of mandated requirements to fully integrate BIM level 2 on centrally procured public projects by 2016 (Eadie et al., 2013).

Similarly, public guidelines are currently in practice in Scandinavian countries. Finland declared that any design software must pass Industry Foundation Class (IFC) Certification before being used (Eadie et al., 2013). BIM acceptance in Sweden is high, and several "best practice" manuals have already been circulated in the sector (Eadie et al., 2013).

Likewise, the Australian Government has become a promoter of BIM and released a report with several recommendations to adopt the transformational technology. Standards Australia recently published, *IFC* for collaboration, communication, and data sharing in the AEC sector. But, despite the passion for BIM employment, the Australian Government is gradually approaching BIM but has not mandated it yet (Eadieet al., 2013). However, the Australian Department of Defense has emerged at the forefront of efforts to incorporate BIM at the Federal procurement level. In the Middle East, despite mandating the use of BIM for large projects in Dubai (Gerges et al., 2017), the UAE does not have a national BIM standard put in place to abide by, thus, everyone tends to follow ad hoc standards. Some UK BIM standards became a guide for practice in UAE, due to the absence of own national BIM standards (Bosch-Sijtsema et al., 2017). MENA countries such as Syria, Lebanon, Jordan, and Palestine are having much poorer initiations from their governments to support BIM (Gerges et al.,2017). In Africa, governments have taken no position on driving BIM practices, and consequently, there is no single African government that has mandated BIM standards. As Well, no trade or professional associations have stepped into this gap to standardize local BIM practice, which implies that companies grapple with implementation in isolation. In Asia, to allow the public sector to take the lead, Building and Construction Authorities (BCA) in Singapore requested the usage of BIM since 2012, and published the Singapore BIM Guide that is currently used to clarify the requirements of BIM usage.

Despite the promising results from Asia, it is important to note that the included papers from Asia emanate from developing countries in this region. The above explanations were important to reasonably accept the empirical results and justify their significance. The results demonstrate that the government's support through promoting regulations and rules is a more significant factor in developing regions than in developed ones. To conclude, the outcomes confirm the vital role of government support in adopting complex technologies such as BIM. Thus, governments should boost the dissemination of BIM by playing an effective role through providing guidelines, and regulations related to solving legal and contractual issues and provide motivations and incentives for the diffusion of BIM such as endorsing and financing the invasion of BIM (Bodea & Purnus, 2018). The development of BIM standards that fit the whole industry necessitates the contributions of participants from different groups to satisfy all practitioners (Ahmed, 2018). Their venture is guaranteed by engaging members having high influence in the penetration process.

Another set of barriers in the legal cluster is related to the difficulty in assigning intellectual properties and distributing the liabilities among practitioners which have gained high significance at the global level with an RII of 0.713 and 0.741 respectively. The results show that the open-access of the model in terms of allowing different parties to make contributions to the model raises the problem of ownership issues and intellectual property rights (Yan & Demian, 2008) (Chan, 2014) .

The ownership of the intellectual property in the shared design philosophy of BIM has been addressed in the included studies, confirming that the ability to share project's information and building's data in a way that one can modify or add details to the virtual design platform, might blur the copyright bright line.

The technology barriers: the *technology acceptance model* states that the ease of use and the usefulness of a technology affect its adoption. Complexity and incompatibility of the software were found to be slightly significant yet indifferent between the regions with an average RII of 0.699 and 0.697 respectively. The results prove the criticality of these factors; although confirm that they can be easily overcome. Moreover, the results focus on the lack of technological infrastructure as a frontrunner barrier to BIM adoption in developing regions. The findings point out its high significance in MENA (RII=0.810) and Africa (RII=0.809), followed by Asia (RII=0.780), then Australia (RII=0.682), and finally Europe (RII=0.541). The results might be justified based on the *geography of innovation model* presented by Feldman and Florida (1994), who argued that innovation's capabilities depend on the technological infrastructures of the geographical region it is implemented in, as the infrastructures are able to provide input resources like knowledge, and technical inputs. The precedents were validated by the results of Chan (2014) that innovations such as BIM tend to emerge in regions having developed technical infrastructures which reveal the need for an environment that encourages experimentation and exploration of the technology. In line with the above, the barriers related to the complexity of the software can be overwhelmed when participants support each other (Bataw et al., 2016).

To end, studies on the limitations facing BIM adoption in the AEC industry are becoming common in the last years, raising the flag for the urgent need for effective solutions. I am strongly persuaded that a deeper understanding of the barrier's clusters is the key to eliminating the problem.

4.6 Conclusion

Drawing on the quantitative body of knowledge on BIM, ~~the authors analyze~~ the barriers to BIM adoption according to their impact level in different geographical areas have been analyzed. The empirical results reveal that BIM limitations can be categorized in five clusters according to their impact dimension namely: legal, human, financial, process, and technological. The spatial comparison discloses that the significance of the barriers differs from one region to the other. However, at an international level, the financial clusters are the most substantial factors hampering BIM adoption, yet the technological barriers are the easiest to overcome. The hindering factors presented in this study can be perceived as the basepoint or reference list when searching for BIM challenges. Moreover, the research educates about the required concerted efforts from various practitioners, scholars, governments, and industry groups to guarantee the successful adoption of the technology. Finally, this study contributes to serving organizations who are considering the implementation of BIM, by presenting a set of recommendations that might help when making decisions about BIM adoption.

Limitations: like any study, this research has limitations that must be considered to guide future research. The analyzed empirical data are grounded on a final sample of 33 designated studies that were included in the selection procedure. In any case, I cannot ensure that they have caught every single relevant research, since there may exist research that I have not noticed or disregarded. According to the selection criteria, commercially driven research that are based on interviews or even multiple choice were excluded, because their results are not expressed in RII or WIS. Further future investigations could focus on qualitative outcomes such as interviews. The meta-analysis perceived in this chapter has used clustering to condense the number of barrier items. Nevertheless, in a couple of cases, overlapping might exist and one barrier might be assigned to more than one cluster.

Practical Implications: the analysis presented in this chapter is relied upon to be of worth to the construction sector stakeholders as it generates a deeper understanding of the significance of the barriers, and the types of BIM adoption challenges. Mapping the outcomes according to the geographical region where they are mostly skeptical provided a more logical, transparent, and defined view of the barriers. Moreover, BIM comprises an interdisciplinary and inter-organizational data framework that necessitates purposeful efforts from stakeholders. For organizations that have settled on the choice towards BIM implementation, the results of this study serve as a guide for setting up the implementation process by understanding the types of barriers present in their area to take the preventive actions before venturing BIM.

Research Implications: by examining the empirical findings, ~~the authors of this paper~~ the research have found out interrelations between various BIM adoption limitations. For instance, current technology is enough, lack of incentives and lack of client demand are considered to be significant reason for keeping the CAD or traditional working tools and are all related to delaying the diffusion of BIM and thus are interrelated. As indicated by the push-pull theory presented by Kirkwood (2009), the embracement of new technology is triggered by the company's willingness to change because of hierarchical requirements and the performance gaps between participants (Kirkwood, 2009). Consequently, the absence of need is expected to be a result of the lack of demand which ends up in a low penetration rate. Given the above, it may be valuable to analyze which limiting barriers are interrelating and to what degree a certain barrier can influence another. It would be also interesting for future researchers and companies to know which barrier is significant in each geographical area to design their future questionnaires and surveys accordingly. Another promising road for future research is to deeply investigate and compare the venture of BIM in construction compared to the venture of other systems such as Six Sigma, Lean, and Agile to comment on common approaches, since the aforementioned concepts have a common goal of reducing construction costs and wastes and increasing the efficiency of the construction process (Setijono & Al-

Aomar, 2012) (Sertyesilisik, 2014). Convinced with the potentials of BIM in the construction industry, the research confirms that there is a need for more research to move the topic on.

Chapter 5

BIM Adoption from the lens of the Socio-Technical Theory

5.1 Introduction

The traditional construction project delivery practices along with the multidisciplinary, complex, and fragmented nature of the construction value chain often result in quality problems as well as time and cost overruns (Bygballe and Ingemansson 2014; Foster 2008). As such, many researchers have been developing innovative approaches that can contribute to reducing these complexities while supporting the process in achieving the most desirable value (Gerges et al. 2017; Jawad et al. 2019). Among these recognized approaches, Building Information Modeling (BIM), a major technological advance, has been attributed to its ability to enhance the collaboration among stakeholders, increase the efficiency of the procedures, and reduce the project's costs and mitigation risks (Aibinu and Venkatesh 2013; Andrés et al. 2017). Likewise, arguments about other innovative solutions to positively influence the project performance metrics have been ongoing in the Architecture Engineering and Construction (AEC) industry. These solutions use an operative technological perspective such as the Integrated Project Delivery (IPD), or a managerial perspective such as Lean Construction (LC) and Six Sigma to assure higher customer satisfaction and lower reworks that result in sustainable and resilient products (Banawi & Bilec, 2014). Notwithstanding the established benefits of these innovations (Aibinu and Venkatesh 2013; Gerges et al. 2017; Ghassemi and Becerik-Gerber 2011; Taner 2013), construction firms are still reluctant in their implementation (Dainty et al. 2017).

In the past years, numerous scholars have addressed this issue and identified a plethora of adoption barriers related to various internal and external organizational aspects (Gerges et al. 2017; Hosseini et al. 2016; Koskela et al. 2002). In examining the limitations to the widespread adoption of innovative approaches, most of the available research focuses on analyzing implementation results of one particular methodology (Gerges et al. 2017; Hosseini al. 2016; Jawad et al. 2019). There are few attempts to analyze the adoption barriers of BIM in comparison to other highly value-adding and forward-thinking construction concepts. Previous literature focused on either assessing the bilateral and trilateral effects of integrating BIM, Lean, IPD, and Six Sigma (Terreno et al. 2019) or evaluating the cooperative relationship, synergies, and efficiency of different combinations in boosting the performance of the sector (Banawi & Bilec, 2014). Surprisingly, none of the past studies have examined mechanisms of BIM diffusion in comparison to other newly introduced innovative concepts, which implies that the analogies of their adoption limitations were never explored (Hosseini et al. 2015). In filling this gap, this research presents a comparative analysis that pinpoints the similarities and differences of the barriers to the adoption of BIM, Lean, IPD, and Six Sigma. The rationale behind this comparison is to investigate any similarities in the existence of a set of limitations that hinder the penetration of any innovation in the construction sector.

Apart from this gap, the review of the literature reveals that although BIM is an interdisciplinary research area at the interface between construction management (CM) and information systems (IS) (Murphy, 2014), it has been widely ignored in IS disciplines research and is rather allocated in the engineering disciplines with an extremely technological focus (Cao and Wang 2014; Murphy 2014). But as BIM is conceptualized as technological innovation (Cao and Wang 2014; Poirier et al. 2015), looking at BIM through the lens of IS is recommended as an effective approach for analyzing these barriers (Murphy, 2014). Given the high significance of BIM as one of the most encouraging technological advancements (Eastman et al. 2011), and given that the challenges faced during BIM adoption in construction are similar to those experienced during technology’s adoption in other sectors (Cheng, 2015), the current literature in the IS domain can give considerable insights about to the root causes of BIM barriers (Cao et al., 2015). One approach, that has been uncommonly considered regarding IS uptake in the construction body of knowledge, is looking at the analysis from a socio-technical systems lenses (Bostrom & Heinen , 1977). Therefore, this chapter will exemplify the suitability of a sociotechnical approach to BIM uptake in the AEC field. This will be done through developing and validating a BIM socio-technical explanatory model based on IS-related theories. As such, the basic principles of the sociotechnical analysis approaches and the IS-related theories will be critically reviewed to assess whether the foundations of the manifold limitations can easily be found in their impact dimensions.

To sum up, two gaps were identified in the literature:

- Studies that assess the similarities and differences between the adoption barriers of BIM and other innovative solutions in the construction sector are dearth.
- Studies that investigate the roots of BIM barriers based on theoretically founded explanations in the IS domain have received little academic attention.

Based on the above, this study aims at answering these three research questions:

- RQ1: What are the common barriers in hindering the adoption of BIM and any innovative solution in the construction sector?
- RQ2: How the roots of BIM adoption barriers can be explained using established theoretical foundations from the IS body of knowledge?

Answering these questions from an academic standpoint and across disciplinary borders can be of significant value for academic research and BIM industry business developers who are interested in emerging markets.

To answer these questions, the approach follows two paths:

I. The first studies the mechanisms of BIM diffusion in comparison to other newly introduced innovative concepts in the construction industry (Lean Construction, Six Sigma, and Integrated Project Delivery), and
II. The second analyses BIM barriers according to the premises of Socio-Technical Theory.

5.2 Literature Review

Several recent publications have discussed the diffusion approaches of each of LC, Six Sigma, IPD, and recently BIM (Akwaah 2015; Desale et al. 2013; Sarhan and Fox 2013) in the construction industry, whereas few investigations are focusing on examining parallels in their adoption. In this section, the definition of each innovative solution as defined in the construction literature is presented and then the current studies focused on their adoption barriers are discussed. In addition, a review of the Socio-Technical theory is displayed.

5.2.1 Innovative construction Trends

5.2.1.1 Lean Construction (LC)

LC is a way of thinking that focuses on improving construction processes to deliver value for customers, it is a combination of operational research and practical development in design and construction (Smits et al. 2017). LC is used to decrease wastes in time, efforts, and materials through the construction project lifecycle and focus on setting up anticipated objectives to streamline the master plan (Smits et al. 2017). Three unique LC concepts are evolved by professionals: The last Planner system, Target Value Design, and Lean Project Delivery System (Koskela et al. 2002). In addition to a variety of means and techniques such as Just-In-Time , off-site fabrication, value stream mapping, 5S principle, huddle meeting, and plan-do-check-adjust procedure (Koskela et al. 2002; Salem et al. 2006), that are used to increase the efficiency of the process (Ballard & Howell, 2006). Koskela et al. stated that lean concepts aim to eliminate variability and pursue perfection (Koskela et al. 2002). Lean Construction focuses on process and people but does not use specific tools for its implementation (Ballard & Howell, 2006).

Lean Construction (LC) adoption barriers: previous authors assessed several processes and people-related barriers that prevent the successful implementation of Lean concepts. They summarized the main process barriers to be related to the lack of awareness and understanding of Lean principles, financial problems, and traditional direction of the organizational management (Bashir et al. 2015; Omran and Abdulrahim 2015). Moreover, people related barriers that are associated with the lack of management support, lack of government support, cultural resistance, the attitude of personnel in not accepting the new working methods, and lack of skills, expertise, and training were perceived as primary LC limitations (Olamilokun 2015; Omran and Abdulrahim 2015; Sarhan and Fox 2013).

5.2.1.2 Six Sigma

Six Sigma has various definitions for various applications. For the AEC sector, Six Sigma is designed to be at the near elimination of wastes in the process. It is a strategic initiative to boost productivity and improve customer satisfaction through measurable statistical tools (Harry, 1998). Six Sigma application involves a top-down instead of a bottom-up approach. It is a disciplined method that commonly incorporates five phases: Define-Measure-Analyze-

Improve-Control (DMAIC). The application of such a structured and organized approach assures an increased performance accompanied by lower complexities of construction activities (Banawi & Bilec, 2014). The DMAIC system streamlines the procedure and acts as a guide for the improvement group. Six Sigma offers methods for performing tasks the right way from the first time and thus solves quality problems. The deployment of Six-Sigma in the construction sector has been predominately focused on micro-opportunities, which implies that its tasks would be smaller in scope and likely related to a sub-task within a macro-opportunity.

Six Sigma adoption barriers: since its inception, Six Sigma has been associated with big companies that were the first in reaping its benefits and achieving considerable savings and growths. Misconceptions about Six Sigma has made SMEs wary about its appropriateness for their organizations. Aside from these, there are some technology and cost-related impediments that act as barriers for Six Sigma adoption by SMEs. Companies essentially need experienced and trained personnel to run Six Sigma projects. Yadav and Desai have stressed the excessive financial capacity needed to adopt the innovation (Yadav & Desai, 2017) since the implementation is associated with high expenses to cover the agent and the training costs. Extensive preparation and training for competent individuals are important to deliver any imperative Six Sigma result (Banawi & Bilec, 2014). Apart from the needed financial resources, Six-Sigma calls for a lot of expertise and knowledge about how to implement the new process. Both, the lack of awareness and resistance to change are limiting the diffusion of Six Sigma because the innovation requires employees to change their accustomed working methods (Banawi & Bilec, 2014). The shift to new techniques is always encountered with skepticism. Employees normally tend to criticize new tools and ignore the new technique. The main reason for this resistance is that people are not convinced of the benefits of the new tool and perceive it as a waste of time and resources (Setijono and Al-Aomar 2012). Thus, communicating positive results is the key to encouraging people for accepting the shift. This must be followed by a change in the organizational culture to motivate people to integrate a new tool as a component of an overall quality management system. The absence of client demand and the low competition are core challenges of Six Sigma implementation in the construction industry (Antony et al. 2005; Desale et al. 2013; Taner 2013; Yadav and Desai 2017).

5.2.1.3 Integrated Project Delivery (IPD)

IPD is a project delivery technique that integrates individuals, frameworks, business structures, and practices into a process that cooperatively harnesses the knowledge of all practitioners to reduce the process wastes and optimize its efficiency (Li & Ma, 2017). IPD like BIM brings all contributors together early with collaborative incentives to maximize the project value. IPD is a formal coordinated effort that occurs throughout the lifecycle of a project (Ghassemi and Becerik-Gerber 2011; Kent and Becerik-Gerber 2010) and gives two contractual conceptions: multiparty agreements (MPA) and single-purpose entity (SPE), which refer to the identical distribution of risks and rewards between associates. The primary motivation behind IPD adoption is to determine extensive shortcomings of common project delivery methods such as unassured profitability levels, uncertainties in managing time and cost, insufficient data in details and drawings, and elevated level of materials' wastage (Poirier et al. 2017).

(IPD) adoption barriers: despite the rise of IPD as a successful project delivery approach, the literature presents various limitations. As a new delivery method, IPD comes with additional challenges to its stakeholders including legal, financial, cultural, and technological impediments. Li and Ma stated that legal, and process barriers are the main hindrances (Li & Ma, 2017). The biggest fear of professionals concerning adopting IPD is liability allocation. Legal risks are major obstacles for firms to move hostilely into IPD (Ghassemi and Becerik-Gerber 2011; Kent and Becerik-Gerber 2010). Contracts developed for Integrated Project Delivery are not commonly used by industry professionals. Concerns about risk and reward sharing and liability insurance are arising. Other authors such as Arensman and Ozbek ranked technological barriers (Arensman & Ozbek, 2012) including interoperability and compatibility as the main barrier items. Organizations require a skilled and trained workforce for conceiving IPD projects, which are associated with a high expense. The training towards IPD requires trust-building activities, collaboration, coordination, and communication between group members to share information (Ghassemi and Becerik-Gerber 2011; Kent and Becerik-Gerber 2010).

5.2.1.4 Building Information Modeling

Building Information Modeling is defined as a digital representation of the physical and functional parameters of a project (Dainty et al. 2017) enabling the virtual design and management of the buildings (Kuehmeier, 2008). Through the provision of appropriate data such as rates, materials, and geometry, the resulting model can be extracted, updated, and exchanged among multiple stakeholders and AEC professionals at any time during the project lifecycle (Azhar et al. 2012; Lee et al. 2006). The notion of 'BIM Levels' is usually used to explain what criteria are needed to be considered BIM-compliant (Arensman & Ozbek, 2012). BIM-level 1 involves using a 3D parametric software tool for the conceptual work, but a close collaboration among participants is not present (Oesterreich & Teuteberg, 2019). This is rather the case of level 2 where an information exchange process that is specific to that construction is required to be communicated to all practitioners. BIM level 3 is achieved when organizations share object-based models in a central repository allowing full interoperability and coordination among participants, which causes the rise of social challenges (Ahmed 2018; Oesterreich and Teuteberg 2019).

In BIM levels 4 and 5, sequence planning and cost management are enabled. The main benefits BIM offers to the industry are: reducing the project's time and cost, improving quality, and enhancing sustainability (Aibinu and Venkatesh 2013; Andrés et al. 2017; Dainty et al. 2017). Besides, BIM facilitates communication and collaboration among stakeholders and helps in the early detection of clashes.

Building Information Modeling barriers: The examination of BIM barriers in developed countries revealed that the main limitations to BIM adoption are the insufficiency of capital, reluctance to begin new work processes, resistance to change, and perceiving to BIM as a risky investment. While in developing countries, researchers pointed out the lack of client demand, lack of BIM specialists, absence of standardized protocols, and data ownership among the most hindering factors (Anuar & Abidin, 2015). Although the awareness about BIM is noticeable in many construction firms, the diffusion rates are evolving slowly and vary from one country to another. Consequently, context research mostly focuses on a single country to assess BIM limitations. For example, in Saudi Arabia, resistance to change along with satisfaction with the existing procedures was considered the frontrunner limitations to

BIM adoption (Al Reshidi et al. 2017). Whereas in Ghana, for instance, where small and medium enterprises govern the market, costs associated with hiring experts and training the workforce were identified as the main subject (Akwaah, 2015).

To give a more holistic understanding of BIM, many authors attempted to categorize these barriers according to several aspects. El Reshidi et al. confirmed that there are two main classifications to define the BIM barriers: the technical and the non-technical factors (Al Reshidi et al. 2017). The technical barriers consist of factors such as interoperability problems, and lack of standards (Mohammad et al. 2018), and the non-technical barriers consist of financial burdens, lack of skilled personnel, organizational issues, process risks, and legal issues (Mohammad et al. 2018). Rogers et al. prioritized the technical, process, financial, legal, and people dimensions as the main barrier groups (Rogers et al. 2015). Sun et al. identified twenty-two barrier items and classified them into five clusters: technology, cost, management, personnel, and legal-related barriers (Sun et al. 2017). Lately, Ahuja et al. analyzed the mechanisms of BIM penetration based on the technological, organizational, and environmental factors which broadly categorize the influencing factors (Ahuja et al. 2016).

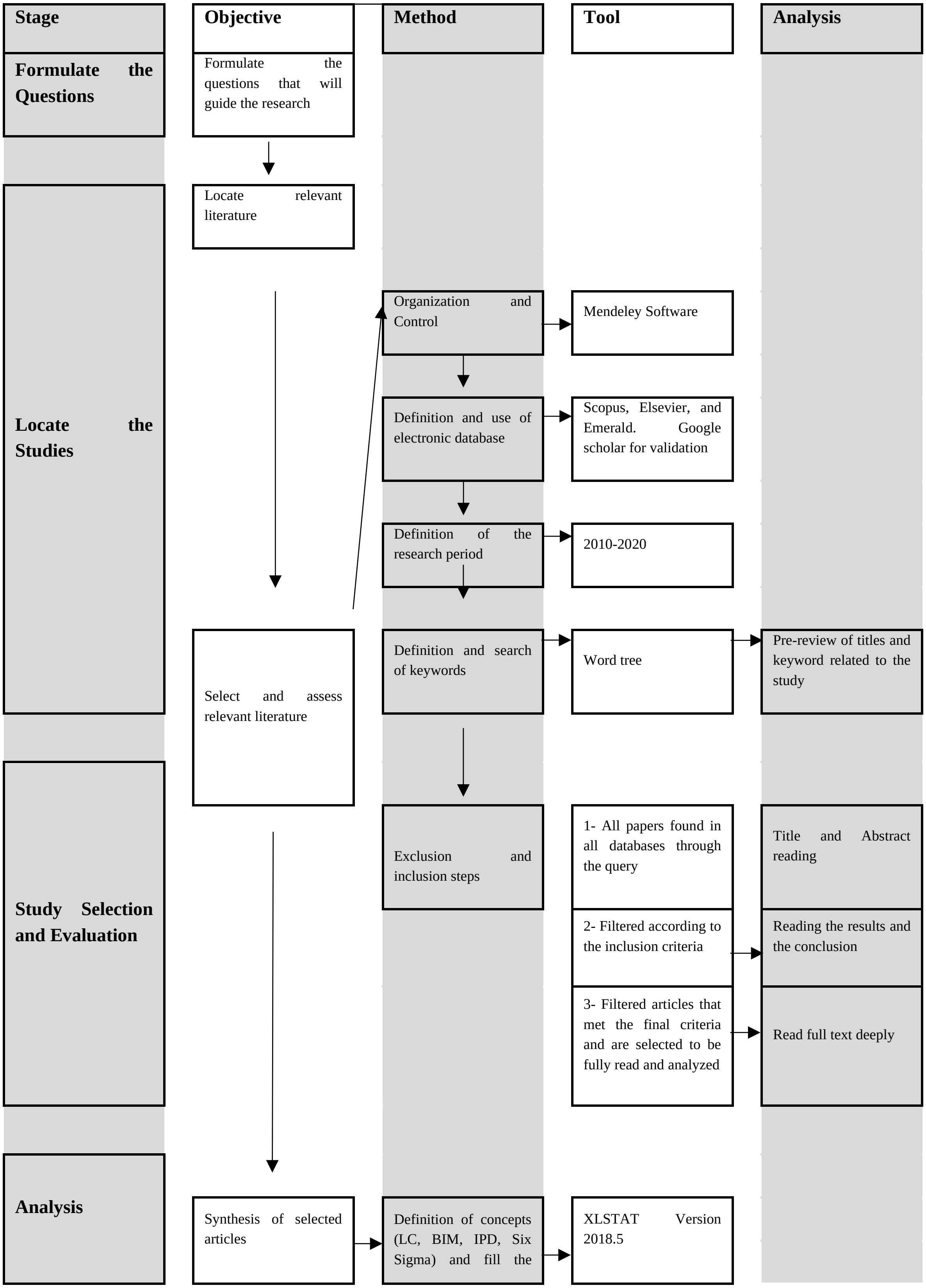
5.2.2 Socio-Technical Theory (STT)

The review of the IS theories implies that they can deliver a comprehensive theoretical base for investigating aspects affecting the usage of BIM for construction companies. Research fields of IT have continually seen many successful applications of STT (Mumford, 2006). The theory can be traced back to the 20th century where it was developed by the Travistock Institute in London (Bostrom & Heinen, 1977). It suggests that any company entails two interdependent Subsystems: the social and the technical subsystems. The social subsystem is concerned with the People (P) and the Structures (S) components, while the technical subsystem is composed of the Tasks (TA) and the Technology (TE) components (Bostrom and Heinen 1977; Sharma and Mishra 2014). The people construct of the social system pertains to the employees and the knowledge, skills, and needs they bring to the workplace, while the structure construct investigates border organizational issues such as rewards systems and authority structures. The task component of the technical subsystem involves the goals, purposes, and client requirements needed for the adoption process; while the technology component involves the technology by which organizational tools, infrastructure, and methods are set (Oesterreich and Teuteberg 2019; Saka and Chan 2019; Venkatesh et al. 2016). The ST theory posits that the social and technical systems cannot be perceived as independent of each other as their interaction and compatibility are essential in determining the efficiency of the work. In other words, when the firm makes a process change such as integrating BIM, both the social and the technical dimensions must be considered to find the optimum solution (Sharma & Mishra, 2014). In this sense, the definition presented by RICS that "BIM uses defined processes and technology to get individuals and information work together" (Eastman et al. 2011; Sharma and Mishra 2014) makes it clear that BIM is not only a software but rather a combination of social and technical factors. By emphasizing the four facets of a firm (P, S, TA, and TE), one can notice a shift away from the isolated view of BIM as a technology-centric subject to a socio-technical view of BIM as an information and communication system. Therefore, a combined focus on both subsystems is essential for theoretically examining the roots of BIM limitations and achieving an enhanced understanding of the impact level of each barrier.

5.3 Objectives and Methodology

The objective of this research is twofold. First, the study aims to examine the approaches of BIM diffusion in comparison to other innovative concepts in the AEC field in order to challenge the assumption that there is no defined set of barriers that confront the adoption of innovative solutions in the construction sector. Second, driven by the need for more attention to BIM in the IS domain, the study aims to fill the gap and examine the foundations of the encountered challenges through the lens of the ST theory.

Towards these goals, the study follows the considerations of Garza-Reyes (2015) that involve (1) formulating the research questions, (2) locating studies, (3) selecting and evaluating papers, (4) and analyzing and synthesizing the results. The below subsections will carefully explain how the review process was directed, mainly in the literature section where the search on several subjects was performed, and will clearly explain the rationale behind the use of search words and databases. Figure 5.1 illustrates the detailed research methodology followed and presents the steps followed in this study. All the methods and tools used to support each step are also illustrated in figure 5.1.


Stage
Objective
Method
Tool
Analysis
Formulate the Questions
Formulate the questions that will guide the research
Locate relevant literature
Locate the Studies
Organization and Control
Mendeley Software
Definition and use of electronic database
Scopus, Elsevier, and Emerald. Google scholar for validation
Definition of the research period
2010-2020
Select and assess relevant literature
Definition and search of keywords
Word tree
Pre-review of titles and keyword related to the study
Study Selection and Evaluation
Exclusion and inclusion steps
1- All papers found in all databases through the query
Title and Abstract reading
2- Filtered according to the inclusion criteria
Reading the results and the conclusion
3- Filtered articles that met the final criteria and are selected to be fully read and analyzed
Read full text deeply
Analysis
Synthesis of selected articles
Definition of concepts (LC, BIM, IPD, Six Sigma) and fill the
XLSTAT Version 2018.5

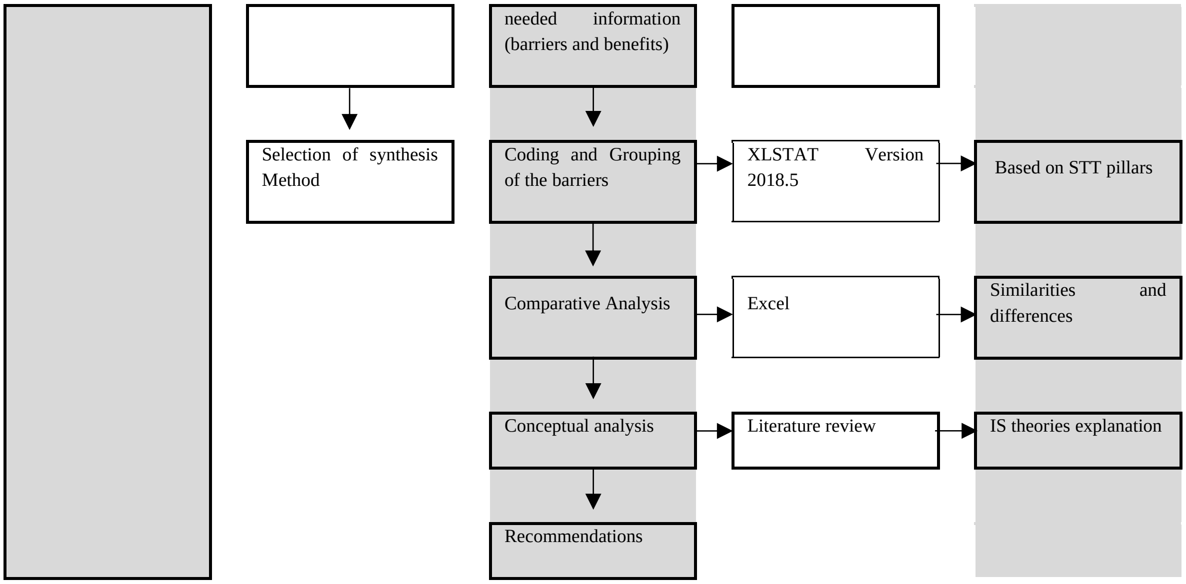


Figure 5.1: Research outline

5.3.1 Locating Studies

After setting the research questions, search strings were employed to get the most appropriate papers and to locate studies. Search strings are widely used in the literature as they operationalize research questions and assist in retrieving the highest volume of relevant documents (Olawumi and Chan 2019).

In this study, the search strings were based on the words tree (X-mind) concept recommended by Gabriele et al. (2012) that considers the use of appropriate keywords found in the literature. To increase the number of potentially relevant studies, the research string was subdivided into three, combining pairwise the main keywords as shown in figure 5.2.

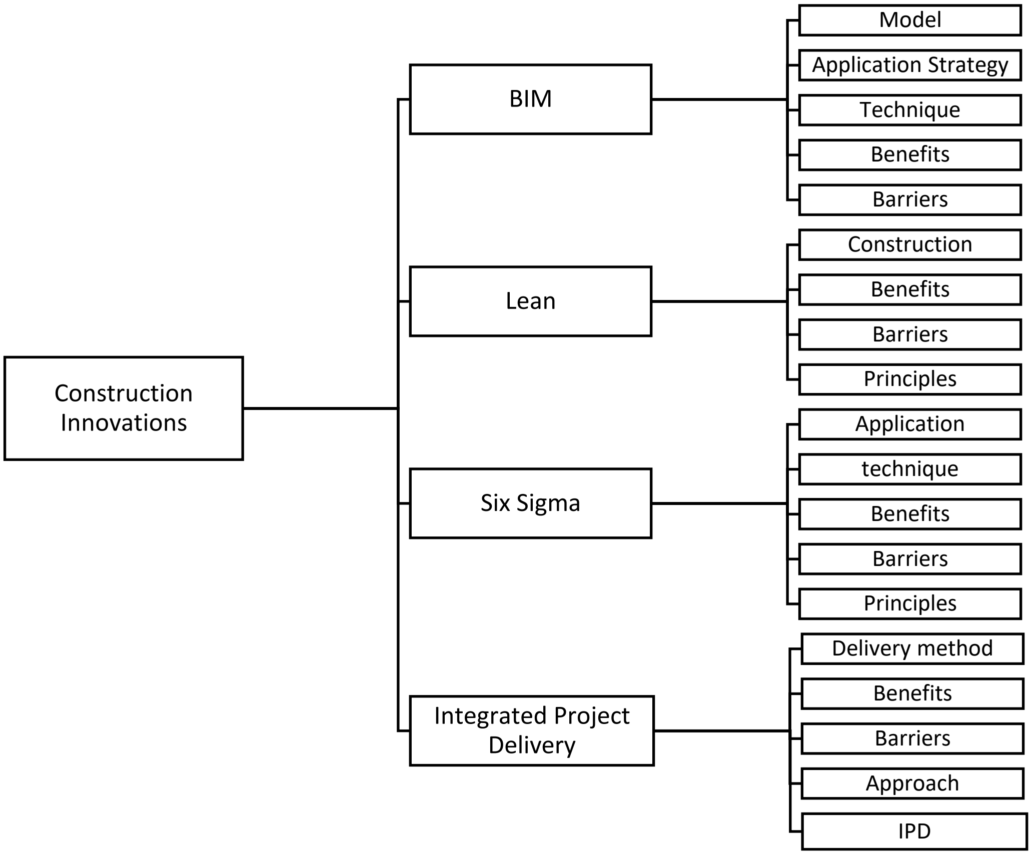


Figure 5.2: Search terms word-tree

It is worth mentioning that alternative words were considered as it is common that a variety of terms is applied to define the same area, i.e., the use of the term “model” enables broadening the search through adding different variations, such as “modeling,” and “modeling.”.

The operators “AND” and “OR” were used to define the research string and combine pairwise of the main keywords, such as (Construction Innovation) AND (BIM) AND (Application Strategy) OR (IPD) AND (Barriers OR Approach). This review considered searching for each trend individually, since it is not the aim of the study to examine the interactions or the bilateral effect of combined concepts.

Search strings in various databases were performed to retrieve the most related documents. Scopus, Elsevier, and Emerald were chosen. Google Scholar was used for validation. While using numerous databases produced a huge volume of duplicates, their use guaranteed the inclusion of almost all the needed publications since none of these databases solely can contemplate all studies of a given subject. Subsequently, reference manager, Mendeley was used to easily remove the duplicates, search within the retrieved studies, and find the most relevant papers. This step enabled the centralization and the organization of the results.

5.3.2 Selecting and Evaluating Studies

Saunders and Lewis's (2012) recommendations were followed, in considering only peer-reviewed articles since these are the most useful and reliable sources for literature review. Papers published in journals in the construction, technology, and computing domains that are known to be respectable were considered. As for the period of research, 2010 to 2020 was chosen because from the beginning of the decade, the use of construction solutions that might improve the efficiency of the sector and reduce its wastes has become a major concern of society (Smits et al. 2017) and has since then received bigger investments (Yadav & Desai, 2017).

To make critieria for inclusion or exclusion clear, journal articles that (1) do not have an abstract, (2) are not written in English, (3) are not from the engineering, technology, and computing research domain, (4) does not have BIM, Lean, Six Sigma, and IDP s as their core topic, (5) and published before 2010 were excluded.

To refine the search, three steps were followed: (1) reading titles and abstracts of the found studies to ensure that they meet the inclusion criteria; (2) reading some sections of the paper mainly the methodology, and the results and checking if they include the needed information (3) reading the full text carefully and highlighting the needed information (benefits, and barriers). This step resulted in a final set of 124 articles which were fully read to extract the needed information and perform comparative and conceptual analyses.

5.3.3 Analyzing and Synthesizing the Results

To simplify the results for the analysis, the included studies were documented and coded in Excel sheets according to their topic (BIM, LC, Six Sigma, and IPD) as well as their data, which provide information on their type, application strategy, benefits, and adoption barriers. Given the different analysis and presentation methods, some effort was needed to align the information.

The coding process was performed by using XLSTAT Version 2018.5 which also allows easy analysis of the data. To summarize the results, each barrier item was assigned to a defined adoption barrier as shown in table 5.1. For example, the item "employees are fearing the shift to a new working method" (Hosseini et al. 2016) is assigned to the barrier "resistance to change" as it is the same concept but written in different formats in the reviewed papers. This step allowed me to summarize the 217 barrier items found in the literature into a total set of 23 barriers. The same process was performed on the benefits resulting in a sum of 18 benefits. The above enabled performing the comparative analysis of the differences, and the similarities of the adoption approach of BIM, LC, Six Sigma, and IPD.

Table 5.1: Examples of the assignment process

Barrier Item found in the literature	*Adoption Barrier*	*Impact Level*
The company cannot afford the cost of BIM training	Commercial issues and high Investment costs	Tasks
The client is not asking to change the traditional working method	Lack of client demand	Structure
Employees are fearing the shift to a new working method	Resistance to change	People

Additionally, to give an enhanced understanding of BIM barriers and turn the established knowledge base from the IS field into account, the mechanisms of BIM adoption barriers were analyzed based on the Socio (Structure and People)-Technical (Task and Technology) theory. Therefore, each of the 23 barriers was assigned to one of the dimensions of the STT framework structural, people, tasks, or technological. Therefore, the barrier "resistance to change" is allotted to the "people" context of the STT, given that it is related to people behaviors, i.e., individuals are the ones who need to adopt the technology, thus managers should convince them of the benefits of the technology and provide them with the needed information to overcome the fear of change and start accepting the shift. So, to overcome these barriers, one needs to work on individuals themselves to achieve the goal (Hosseini et al. 2015). Taking another example, all barrier items that are related to the cost of the software, hardware, installation, training, and so on are summarized under "commercial issues and investment costs" and are then assigned to the task dimension.

After assigning the barriers to their impact level in the context of the Socio-Technical (ST) model, BIM barriers were then encapsulated in the form of a conceptual model that fit information systems.

Lastly, the study presented the theoretical backgrounds of the barriers based on outcomes from the IS body of knowledge, which helped in discussing the conceptual ST model and provided a ranking of the hampering barriers. To focus on the IS research domain in assessing BIM barriers, identified concepts and theories related to the IS disciplines under the ST umbrella were critically reviewed. The chapter ended with providing propositions to overcome BIM barriers and increase technology usage.

5.4 Results and Discussion

5.4.1 Comparative Analysis of Various Construction Trends

The review of the literature reveals that the development of integrated approaches positively influences the performance of construction projects [15] (Wu et al. 2014). In this sense, numerous recommendations were proposed, one of them is increasing the interest in adopting technologies and agreeing on the value of implementing new philosophies, techniques, and delivery methods to benefit from early coordination between stakeholders. Table 5.2 summarizes the type, application guidelines, and benefits of the innovative systems presented in previous sections.

The analysis in table 5.2, illustrates substantial-effectiveness regarding schedule performance, cost performance, and quality assurance resulting from the implementation of any of the four defined concepts. Not only do such methodologies guarantee a higher level of efficiency and standardization, but they also generate more sustainable outcomes and higher customer satisfaction.

Table 5.2: Innovative concepts comparison

	BIM	**Lean Construction**	**Six Sigma**	**IPD**
Type	Technology	Operational research + Practical development	Data-driven approach	Delivery method
Application Strategies	Levels of maturity (0,1,2,3)	Value-Streaming-Flow-Pull-Perfection	Define-Measure-Analyze-Improve-Control	Typical Collaboration-Enhanced Collaboration-Required Collaboration
Benefits				
Reduce the project duration	+	+	+	+
Reduce the project cost	+	+	+	+
Enhance sustainability	+	+	+	+
Improve quality of the work	+	+	+	+
Reduce RFI or change orders	+	N.I.	N.I.	+
Allows early clash detections	+	N.I.	N.I.	+
Increase standardization	+	+	+	+
Increase productivity	+	+	+	+
Increase visualization	+	N.I.	N.I.	+
Improve collaboration	+	+	N.I.	+
Reduce construction waste	+	+	N.I.	+
Support decision making	+	N.I.	N.I.	+
Better estimation	+	+	N.I.	+
Reduce rework\corrections	+	+	+	+
Increase client satisfaction	+	+	+	+
Enhance interoperability	+	N.I.	N.I.	+
Digital presentation	+	N.I.	N.I.	+
Liability waivers	+	N.I.	N.I.	+

NI: No Recorded Impact. I did not find any of the reviewed papers recording this impact as a benefit of the innovation.

Focusing on the benefits of using the BIM-based IPD approach, the results reveal exclusivity in providing a digital representation of the facility and guarantying improved visualization and enhanced interoperability. The results affirmed that the use of BIM uniquely resolves prospective conflicts through the early detection of clashes.

Apart from the benefits, the review of the literature shows that BIM, as an innovation and information method alike, falls within the adoption barriers of the two disciplines. Therefore, beyond the difficulties identified by studies that consider BIM as an innovative approach, several other barriers arise from BIM being an information technology trend. For the aim of this study, BIM diffusion barriers were viewed from the lenses of the Socio-Technical theory implying that BIM, as any IS, includes a technical subsystem that embraces all procedures/processes and assignments and a social subsystem that carries the structure of the system, workforce behavior, knowledge, and competences (Bostrom & Heinen, 1977). Therefore, as shown in table 5.3, BIM limitations were summarized under four subcategories (TE, TA, P, S), each capturing a key dimension of the ST model.

Having made the comparison between BIM, LC, IPD, and Six Sigma adoption barriers, one can detect a substantial degree of compliance among their limitations. Interestingly the results of table 5.3 demonstrated a high similarity between the barriers facing the adoption of BIM and the limitations accompanying the implementation of other construction innovative concepts mainly in the people and the task dimensions. The below discussion analyses the similarities and the differences of the adoption barriers facing each of the innovative concepts.

Similarities in the technology dimension: the results point out the complexity of the implementation (TE2) as a common hindrance indicating that the development of an adoption plan and an organizational framework is needed to optimize the implementation. This could be reached through indorsing guidelines, recommending standardizations, spreading awareness, clarifying parties' roles, and clarifying related procedures (Ahmed 2018; Oesterreich and Teuteberg 2019).

Similarities in the task dimension: the three financial barriers related to this category (TA1, TA2, and TA3) are found to be common impediments to venturing an innovation in the construction industry. The adoption requires organizations to spend time and money at the front end; however, these expenditures are for the short term. Therefore, one needs to offset the investment in these concepts with a longer-term view of the value it can bring. *Similarities in the people dimension*: all the six barrier items (P1 to P6) identified in this category are common impediments facing the implementation of any construction innovative solution. Practitioners' behavior is shown to be a shared factor affecting the diffusion of BIM and the realization of innovations. Table 5.3 emphasizes human-related factors as a focal issue. In this sense, resistance to change, for example, is related to the fear that the shift from the traditional working methods fails. Moreover, the presence of specialized personnel who have enough experience and knowledge is essential to the successful diffusion of innovations, thus lack of skilled employees is a significant limitation.

Table 5.3: Adoption barriers of innovative concepts in the construction industry

			BIM	Lean	Six	IPD
Technical		**TE: Technological Barriers**				
	TE1	Interoperability	+	NI	NI	+
	TE2	Complexity of implementation	+	+	+	+
	TE3	Waste of time	+	+	+	+
	TE4	Lack of standards and guidelines	+	+	+	+
	TE5	Lack of compatibility	+	NI	NI	+
		TA: Task Barriers				
	TA1	Commercial issues and investment cost	+	+	+	+
	TA2	Lack of project finance	+	+	+	+
	TA3	Lack of immediate benefits /ROI	+	+	+	+
Social		**P: People Barriers**				
	P1	Lack of BIM skills, qualified staff	+	+	+	+
	P2	Resistance to change	+	+	+	+
	P3	Lack of management support	+	+	+	+
	P4	Lack of specialists	+	+	+	+
	P5	Lack of training	+	+	+	+
	P6	Lack of collaboration and information sharing	+	+	+	+
		S: Structural Barrier				
	S1	Lack of client demand	+	+	+	+
	S2	Lack of awareness and knowledge	+	+	+	+
	S3	Lack of necessity	+	+	+	+
	S4	Absence of contractual requirement	+	+	+	+
	S5	Lack of incentives	+	+	+	+
	S6	Legal impact and copyright	+	NI	NI	+
	S7	Difficulty in intellectual property allocation	+	NI	NI	+
	S8	Liabilities	+	NI	NI	+
	S9	Lack of government's lead/direction	+	+	+	+

NI: No Recorded Impact. I did not find any of the reviewed papers recording this factor as a barrier to adoption.

Similarities in the structural dimension: as table 5.3 shows, the level of knowledge and awareness (S2) in every step of the implementation is an important factor before adopting any methodology. Therefore, the culture of the organization is critical in affecting the awareness of practitioners and promoting the sharing of information between participants, which might encourage the implementation of new approaches (Bygballe and Ingemansson 2014; Gurevich et al. 2017). The diffusion of any novelty relies heavily on the regulations enforced by the government as the construction field of the countries depends largely on its government support. Similarly, the effect of client demand (S1) is emphasized in the literature of all the reviewed innovations including BIM indicating that organizations should recognize and feel the demand for the new concept for practitioners to be motivated to introduce it. Despite the similarities stated above, some barriers, particularly in the technology and structure dimensions, are solely related to the adoption of virtual shared designs such as IPD and BIM.

Differences in the technology dimension: incompatibility of the program (TE5) and interoperability (TE1) are challenging the integration of shared models. Other innovative solutions such as LC and Six Sigma are not threatened by these impediments as they are not classified as technological advancements.

Differences in the structure dimension: legal-related barriers are mostly confronting the penetration of BIM-based IPD projects. The problem is that although the client has the right to possess the model for facility management purposes, designers have intellectual rights to own their designs (Arensman & Ozbek, 2012). To solve the ownership issue, Arensman and Ozbek posed the question of who will own the data at the end of the project, and came out to that the model should be owned by the ones who created it (Arensman & Ozbek, 2012). However, the collaboration of various parties to develop the model makes this suggestion difficult to be applied. From the same point of view, the liabilities of the data and the control over the model were argued (Ghassemi et al., 2011). As indicated by Ghassemi and Becerik-Gerber, it is difficult to decide on the party in question for an error as several practitioners can change the data during the construction procedure (Ghassemi & Becerik-Gerber, 2011). The loss of control over the data and the intellectual properties of the owners are exclusive BIM challenges. Design responsibility, reliability of the data, liabilities of parties, intellectual properties, and copyright have all been issues linked to the legal related barriers facing BIM and IPD.

To conclude, BIM adoption barriers show a substantial resemblance to the barriers faced during the implementation of other concepts in construction especially in the people and tasks dimensions that revealed full conformity. This induces that BIM barriers might have been predicted as these barriers are associated with the penetration of any innovation to the sector. In other words, most of the barriers that are related to human resources, process, incentive, and financial barriers that have faced BIM adoption, are not related to BIM itself, however, they are accompanying the diffusion of any innovation in the construction field. The above highlights the importance of the Innovation Adoption theory presented by Rogers et al.

(Rogers et al. 2015), who uncovered four steps accompanying the adoption of any innovation: (1) spreading the knowledge of the new methodology to confront the lack of awareness, (2) examining the participants' attitude and mindset towards it namely resistance to change and unwillingness to change their working method, (3) deciding on the adoption process by assessing if you have the financial recourses and the human skills needed to adopt the innovation, and finally (4) implementing the new concept. The precedent brings that the mentioned barriers are anticipated before the real implementation of the new concept. BIM adoption is aligned with the innovation adoption theory as BIM followed the same process and faced the stated limitations. This study confirms the results of Hoessini who concluded that BIM implementation in the construction context is well aligned with the innovation adoption process (Hosseini et al. 2015). In other words, dealing with BIM integration through the lenses of the innovation adoption theory is recommended to be an approach for investigating BIM adoption in construction.

This section uncovered the common and the uncommon themes of the adoption barriers between BIM and other construction methodology, highlighting a high degree of similarity in the people and the task dimensions, while the main difference arises from BIM being an Information Technology (IT). Thus, it is important to analyze BIM barriers in the mainstream of the IT\IS domain to have a better understanding of their nature.

5.4.2 Explanatory Model

After comparing BIM adoption limitations to other innovations in the engineering disciplines, this section will analyze BIM barriers from the mainstream of IT\IS research. Therefore, identified concepts and theories related to the IS disciplines under the STT umbrella will be critically reviewed. Based on the findings presented in table 5.3, BIM adoption barriers have impacts on both the social (P: people, and S: structure) and the technical (TE: technological and TA: task) dimensions. However, the roots of the manifold limitations cannot easily be found in the impact dimension to which they are allotted. Taking the case of the technology-related barriers such as lack of standards and interoperability (Chan 2014; Kim et al. 2016), a deeper investigation shows that they are not technologically but socially established, as the attitude of the associated contributors comes to play (Oesterreich & Teuteberg, 2019). Possible solutions to overcome the lack of BIM standards either by developing a local parametric library embedded in the BIM server (Alhumayn et al. 2017) or by establishing a BIM council have received many advocates lately (Ezeokoli et al. 2016). However, a description of the root causes of these barriers, or an explanation of the reason these solutions might be appropriate were never examined. I am firmly convinced that it is imperative to eradicate the barrier by its roots to find suitable solutions. Therefore, the authors perform a systematic literature review according to Webster and Watson (2002) to identify studies from the IS research domain that might be of high quality and help in giving explanations for BIM limitations. Three prominent research papers were recognized to become valuable for this study because they are reviews of key concepts and theories relevant to this work. The authors refer to Mumford (2006) who introduced the updated socio-technical analysis system and provided some inklings regarding the fact that implementing innovation is more than just putting together artifacts and organizational procedures. Moreover, RICS (2014) had reviewed most of the key literature that we have identified through the BIM adoption body of knowledge and presented evidence of BIM shift from an isolated technology-centric topic towards the socio-technical view. Thus, these two studies became valuable sources for synthesized knowledge to be used in our review for consistency. Additionally, Bostrom and Heinen's (1977) study for generic definitions and interpretations of the Socio-Technical theory was the base of this chapter's discussion. Bostrom and Heinen are the most cited authors in studies concerning this topic; all the papers that were reviewed in BIM barriers subject had cited their research paper, and many studies had their base in it.

Structure dimension: most of the barriers in this category are related to stakeholders concerns to various legal implications relating to the difficulty in allocating intellectual properties (S7), legal impact (S6), absence of contractual requirement (S4), and lack of government's direction (S9) which all lie in the government's responsibilities. It is the government's accountability to make available defined regulations, guidelines, and procedures related to legal and contractual measures. From a deeper economical point of view, there is a conviction that governments promote the penetration of innovations through encouraging funding programs and cooperative activities within the industry (Smith et al. 2000). Recently, Industry 4.0, and the Internet of Things are the main government initiatives introduced to support technological innovations (Oesterreich & Teuteberg, 2019). Empirical observations have proved that government support is a significant drive to the penetration of innovative solutions in the market. Such contributions can boost awareness about BIM. As per the *Technology, Organization and Environment (TOE) framework* and the *actor-network-theory*, the provision of standards and well-laid-out processes within the diffusion phase of innovation is vital as it manages the conflict of interests, generates technical knowledge, and supports the regulation of the global market (Tornatzky et al. 1990). Introducing BIM mandates, financial subsidies, and regulations that address legal impacts, liability risks, ownership, and intellectual property are commonly proposed ideas for governments to foster BIM adoption (Alreshidi et al. 2018; Ezeokoli et al. 2016; Cheng 2015; Ugochukwu et al. 2015; Zhang et al. 2016). Hosseini et al. (2015) confirmed that with the adoption of the developed standards, the involvement of highly influential contributors to standard development is desired. Moreover, the European Commission report stressed on the solid similarities between the AEC standardization effort on BIM and the IS domain standardization efforts (Poljanšek 2017), as both involve developing common conceptions for managing digital data such as properties features, libraries, and data format that empower a unified and transparent exchange of data. Similar to the standardization efforts on other IT, the development of BIM standards areare at an early stage of slow progression and are not broadly used in practice. BIM standardization effort led to the development of the IFD standard, which remains an ongoing process since 1994 (Hosseini et al. 2016). Although construction practitioners believe in standards, they are rarely adopting them due to being complex, incomplete, and do not perfectly fit the industry (Hosseini et al. 2016). This is similar to the standardization initiatives from the IT domain that was employed by only some adopters at its early diffusion.

Conclusively, despite the years of standardization efforts, the creation of BIM guidelines remains an uncompleted ongoing movement despite being decisive for BIM widespread diffusion.

As evident from the results of table 5.3, lack of BIM expertise (P4) and training (P5) influences the people dimension in the ST framework. A closer examination shows that their causes are rooted in the structural nature of the AEC sector in line with the *Resource-Based View (RBV)* of the organization, which postulates that firm’s assets, resources and abilities might support the realization of sustainable competitive advantage among organizations (Barney et al. 2001). Along the *RBV lines*, resource scarcity was distinguished as a characteristic of small firms. It must be stated here that 99% of the construction firms in Europe and 98% in Asia are SMEs, which employ less than 25 persons (Akgüç et al. 2017). Grounded in *Attewell's knowledge barrier theory*, observational outcomes revealed that the lack of expertise and training are the most remarkable hindrance to IS diffusion in SMEs. Therefore, SMEs must make use of external expertise by engaging consultants and IT vendors and providing training programs for employees to encounter the lack of expertise, which are as well common suggestions in BIM literature (Andrés et al. 2017; Borrmann et al. 2015; Chan 2014).

Other BIM adoption limitations that might be explained by the *RBV* fall in the task dimension namely commercial issues, high investment cost (TA1), and lack of project finance (TA2) which prevent small firms from extensively investing in information technologies. Nevertheless, these firms should direct their business to allocate considerable financial resources for verified and tested solutions to satisfy the industry requirements. Another limitation of BIM adoption is viewing the implementation as a waste of time (TE3). According to *RBV*, if companies dedicate the needed human resources to the implementation process, it can overcome the limited time available to adopt new concepts. Moreover, involving practitioners in the early stage of BIM adoption, and incorporating their suggestions and requirements have positive effects on the embracement of an IT in terms of reducing people’s resistance to adopting the new IS. Adding to the above constraints, small organizations suffer from being structurally centralized and having multiple bureaucratic procedures because it is solely the owner who decides on the corporate strategy.

People Dimension: previous studies confirmed that resistance to change (P2) is limiting BIM diffusion (Al Reshidi et al. 2017; Bin Zakaria et al. 2013; Borrmann et al. 2015). Resistance is a typical human behavior towards the shift to uncertain working methods and is predictable when the change is implemented without warning the affected stakeholders (Poljanšek 2017). In most cases, the change is pushed onto people without informing them what the change will include and how their work will be affected. Thus, it is the vicious cycle of fear of the unknown, mistrust of the new system, loss of job security/control, and bad timing that is accountable for aggressive resistance in the IS domain.

Pliskin et al. (1993) confirmed that the changes caused by the implementation of new IS are anticipated to affect the distribution of power in the organization. In the same study, the authors confirmed the importance of a coherent distribution of power between the presumed and the actual organizational culture for the adoption to be smooth. Innovation orientation, readiness for change, learning and development, autonomy in decision-making, support and collaboration, and power-sharing, were identified as significant elements of the organizational culture.

Similar components such as defined strategy, management support, and open communication were identified in a later stage as significant organizational culture components.

To conclude, to create an organizational culture that promotes IT adoption, organizations need to foster creativity through learning and development. Besides, companies need to increase the tolerance for conflicts and risks and promote a substantial degree of support and collaboration (Wei et al. 2011). Therefore, either the new IS must be accustomed to the organizational culture, or the organizational culture must be improved to ease the adoption (Alhumayn et al. 2017; Thong 2001; Wei et al. 2011).

Another implication of table 5.3 is that the barriers related to the necessity of BIM namely lack of client demand (S1), and lack of necessity for BIM (S3) affect the structural dimension of a firm. The results show that the construction industry is satisfied with the traditional working methods and the status-quo designating its unwillingness to shift for the use of an integrated information system such as BIM. To understand the intention of organizations to shift for new technologies, the *pull-push theory* confirms that the adoption of new technologies is induced either by noticing a performance gap in terms of competitive advantages or by the acknowledgment of technological innovations (Katz and Shapiro 1986; Kirkwood 2009; Zmud 1984). This implies that uncertainty and high employment costs are further grounds for not implementing new technology.

Other limitations that are caused by the people dimension are the financial limitations such as high investment cost (TA1) and lack of immediate benefits/ROI (TA3). While these factors influence the task dimension in the ST system, they are rooted in the social behavior of practitioners, as it is the manager's task to perform cost-benefit analysis before the IT adoption decision (Akgüç et al. 2017). Harrison et al. employed the *Theory of planned behavior* in their study to prove that the perspective of executives towards an IS adoption decision is influenced by managers' attitudes, norms, and behaviors.

The *Prospect theory* is suitable in explaining the behavior in risky decision-making as it posits that executives value the losses and the benefits according to changes in their reference point. This induces that decision-makers take risks if they realize that their current state is pessimistic, however they avoid such risky decisions if their state is optimistic. As BIM returns and benefits are not directly proven, yet the high costs are, decision-makers confronting high investment costs and uncertain benefits might choose not to adopt the new technology (Eadie et al. 2013). Therefore, adopters need to conduct a cost-benefit analysis that proves the business value of BIM before the implementation. Another important barrier caused by the people dimension is the lack of communication, collaboration, and information sharing. Even though like IS, BIM reduces information irregularities by encouraging collaboration based on a unified shared model, yet BIM alone cannot eliminate the dichotomy and the isolation work method in the industry. To promote collaboration and information sharing, it is generally advised to transparently visualize the benefits of collaboration in the relational contract that regulate the distribution of costs, risks, and benefits (Akwaah 2015; Kahneman and Tversky 2013).

Tasks Dimension: when examining the background behind the adoption limitations, none of the barriers was found to be caused by the task dimension that by definition aims to achieve the objectives and requirements of participants (Lyytinen and Newman 2008). This definition confirms that the tasks of BIM are not considered as roots of the adoption barriers.

Technology Dimension: Table 5.3 shows that BIM technology is criticized for its complexity (TE2), and incompatibility (TE5). *The Cognitive Absorption model* concentrates on understanding the user experience with the technology and highlights the importance of having an enjoyable environment that facilitates information absorption. Providing help menus and hotkeys might entice users to adopt the technology.

In summary, contrasted with table 5.3 where BIM limitations were categorized based on their impact, a different picture is revealed when the limitations are categorized based on their root causes. Along these lines, the impact dimension of a limitation is not identical to its root cause dimension. For instance, task limitations such as high investment cost and lack of immediate ROI are focused on the economic aims of the associations, yet their backgrounds are in the human dimension. Figure 5.3 demonstrates a considerable leaning towards social barriers compared to the balanced distribution portrayed in table 5.3.

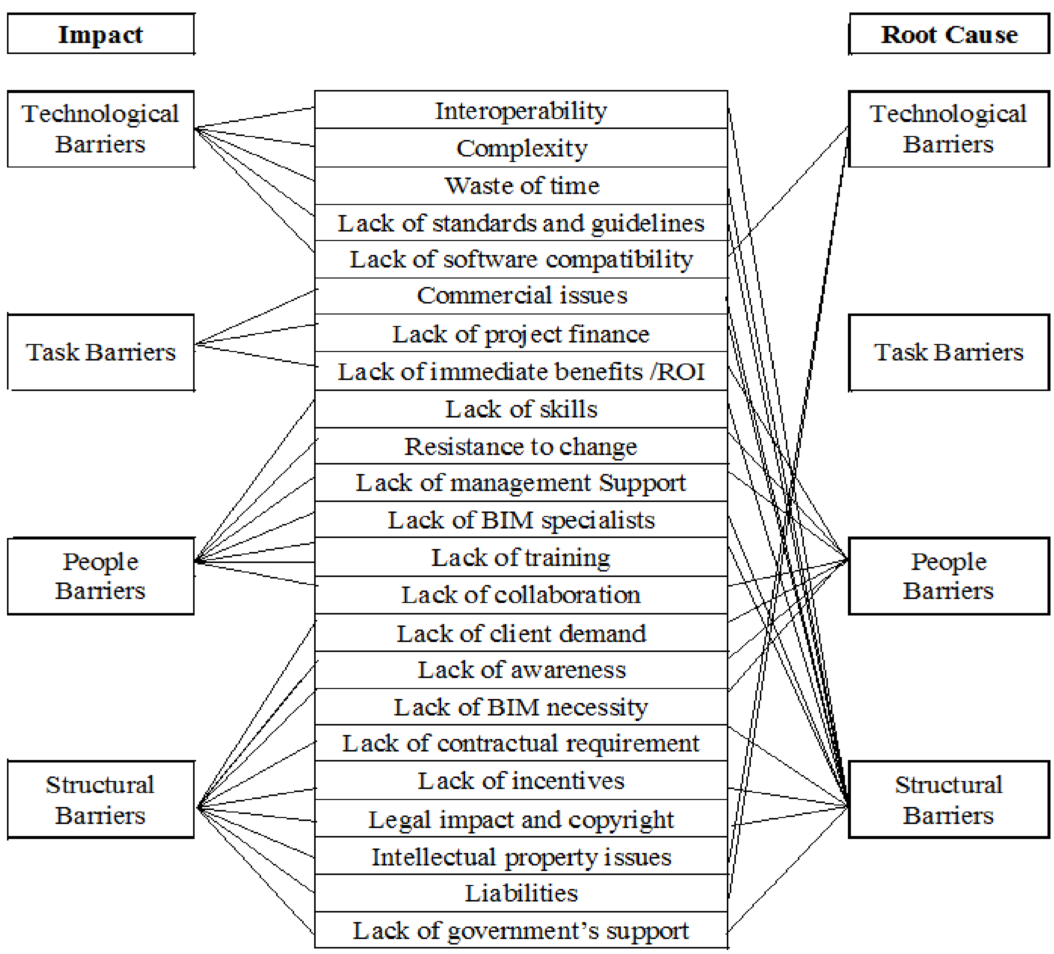


Figure 5.3: BIM adoption barriers according to STT dimensions based on impacts and root causes.

The analysis concludes that BIM implementation barriers are established by the social behavior of practitioners and the social measures of the construction sector. The conclusion of this study is similar to the empirical results introduced in the IS literature by Rizzuto and Reeves presuming that people-related barriers are responsible for the largest portion of implementation failures due to the cruciality of human decisions. Chang et al. brought out that for IT applications, social variables have the most substantial effect (Chang et al. 2018). Consistently, previous studies in the construction industry confirmed that it is necessary to focus on the soft as well as the hard-technical issues to overcome BIM barriers (Eadie et al. 2013). The analysis presented in this chapter points to many hypothetical conclusions that can be acquired from the IS research domain. The study proves that social measures involving people and structures dimensions of the BIM- IS approach can be referenced as the most significant limitations to the broad diffusion of BIM (Kassem et al. 2012; Webster and Watson 2002). Another novelty of this study is that it demonstrated that the technical rooted barriers are uncommon compared to the social barriers. Thus, researchers and practitioners should focus more firmly on the social instead of technical adoption limitations.

5.4.3 Research Implications and Future Directions

This study brings together recent BIM knowledge from the construction domain with the established knowledge base from the information system domain. This approach enables the creation of novel outcomes for both academics and practitioners in both disciplines and enhances the role of the information system discipline in the construction engineering research field.

Practical Implications: the comparative analysis used in this study allows construction companies and managers to expect the existence of a set of common limitations that hinder the penetration of any innovation. Thus, the study serves as a guideline to construction companies as it alarms them about the common blockchains that will always be met when adopting a new system. The study notifies construction companies about the need for an organizational culture that promotes trust, collaboration, and information sharing.

Moreover, the study helps in informing construction companies about the existence of common costs that are associated with the change (adoption of a new system) and induce them to develop approaches such as a cost-benefit analysis, that deliver evidence of the costs and benefits of the new system to support weighing the risks versus the opportunities and determine whether the investment pays off in the long run or not (Francom & El Asmar, 2014).

Another implication of the study that makes it of value to practitioners and construction professionals, is that it generates a deeper understanding of the root causes of BIM barriers, and thus allows practitioners to overcome them. The study implies that more effort should be put in place to overcome the socially rooted factors. Viewing the results from the lens of the ST theory provided a more logical, transparent, and defined view of the barriers, which allows to address the practical implications of the study based on 15 recommendations presented in table 5.4

Table 5.4: Recommendations for a practical adoption

	TE: Technological Barriers
1.	Employees should mutually support each other and share information.
2.	It is important that construction companies and property developers set up a specific BIM department to ease the adoption of BIM.
3.	implementation in their construction projects in the long run.
4.	Hotkeys and a help menu might make the software more enjoyable and easier.
5.	Practitioners should understand the long-term benefits of BIM and weigh the benefits versus the costs.
6.	Various stakeholders and participants should participate to develop industry standards that meet the needs of all practitioners.
7.	To overcome compatibility issues, partnership is recommended among the vendors and the firms to minimize the chance of data losses during software migration. As well a shift to cloud BIM is advised.
	TE: Technological Barriers
8.	A cost-benefit analysis is important to end the doubts about the high costs associated with the adoption as it shows the business value of the new system.
	P: People Barriers
9.	To address the lack of BIM specialists, mangers must encourage participants to attend appropriate BIM conferences and workshops to improve their BIM knowledge.
10.	Companies that lack specialists should engage external consultants to provide training for the employees and guarantee that the external expertise is correctly transferred to the company. Effective training should focus on process-oriented issues to have a better understanding of the system.
11.	Companies should create a culture of continuous development and power-sharing that enhances employee’s acceptance of change and supports creativity. Therefore, social interaction and information sharing should be supported by managers to ease the development of social relationships.

12.	**The upper management should explain the rationale behind adopting the technology and convey info about the costs and the benefits to the practitioner for them to feel the advantages and the need for the adoption.**
13.	**Tertiary institutions should involve BIM courses in their curricula to help students develop BIM and collaborative skills.**
S: Structural Barrier	
14.	**Motivated and empowered employees should help in facilitating knowledge transfer and promoting learning, among others.**
15.	**Governments should promote the penetration of BIM, by including promotional activities for increasing awareness about the new technology Moreover, governments should develop equivalent regulations related to insurances and data possession. The provision of contracts that allocate the liabilities and rewards between practitioners is essential to promote cooperation.**

BIM as an interdisciplinary and inter-organizational system necessitates intensive efforts from various stakeholders. Therefore, the recommendations presented in this study are directed towards various parties namely policymakers, managers, industry participants, owners, and universities.

This study might be of value for both BIM current adopters and BIM future adopters.

For the current adopters, the study might provide the needed guidance to prepare for the implementation process. For future adopters, the presented recommendation might serve as their guide to evaluate the effort needed to overcome the adoption blocks and develop the appropriate overcoming strategies to ensure successful adoption.

Research Implications: the study contributes to the body of literature in different ways. First, it provides academics from both the construction and the IT domain with recommendations and pathways for future research. The study shows the need for more interdisciplinary research that combines the IT body of knowledge with the outcomes from the construction industry to boost the examination of BIM.

Besides, from the deep review of the literature on the BIM topic, the interrelations among various adoption barriers were noticed. In the people dimension, the lack of management support (P3) and the lack of BIM skills (P1) are triggering human resistance to change (P2) (Katz and Shapiro, 1994). Other observed interconnected barriers are in the structural dimension and are related to the need for adoption such as the lack of incentives (S5), the lack of client demand (S1), and the lack of necessity (S3) which are all considered significant reasons for keeping traditional working tools and delaying the diffusion of BIM. Grounding on some IS theories namely the push-pull theory, the interrelations among BIM adoption barriers become evident, as organizations are triggered by the pressure for change (adopting a new technology), only when the organization feels a performance gap. Therefore, S3 might result in S1 which yields a lower adoption rate of the BIM technology, which in turn might lead to lower availability of the software. The above are a few interrelations of BIM adoption barriers among many others, therefore the examination of the extent to which BIM adoption barriers interact and interrelate as a future pathway for research was proposed.

Moreover, to have a complete picture, future scholars might focus on examining which adoption barrier should be given the most attention and should be overcome first. Additionally, it is important to know whether the internal or the external barriers are the most imperative in hindering the adoption of BIM, hence influence models might be used to simulate and assess the significance of the barriers in the future.

5.5 Conclusion

Drawing on published literature from the construction research field as well as the established body of knowledge from the IS research domain, a pool of limitations to BIM adoption was curated. BIM limitations were compared to those associated with the adoption of other innovative solutions in the construction sector as they have a common goal of enhancing the performance of construction processes. The outcomes reveal a high degree of resemblance in the people and task dimensions barriers between various innovative concepts. BIM barriers were then encapsulated in the form of a conceptual model that fit information systems. The findings reveal that the impact dimension of a barrier is not equal to its root dimension. While a minor lean towards social barriers is demonstrated when considering the impact measures of BIM limitations, a notable tendency towards the social (structural and people) barriers is noticeable when looking at their root causes. Conclusively, it can be inferred that BIM barriers are established in the social behavior of the participants and the social arrangements of the AEC sector. Given the unique nature of BIM and the unique characteristics of the construction sector, the application of IS literature finding in the construction context must be approached with care. It may be useful to assess the degree and the conditions where causalities occur. The chapter underlines that an interdisciplinary study that employs outcomes from the IS body of knowledge with the construction literature is required to promote BIM adoption. Convinced with the potentials of BIM, the need for more studies to move the topic on was acknowledged.

Chapter 6

BIM Functionalities Diffusion in the MENA Region

6.1 Introduction

While many practitioners and academics have realized the significance of adopting Information Technologies (ITs) in construction firms and identified their ability in reducing projects' cost and time, the pace of diffusion of such technologies has been slow (Kagermann, 2015). Building Information Modeling (BIM), a technology that is being implemented in the construction industry, has proved its ability in revolutionizing the work processes thru changing the planning and design activities from two-dimensional (2D) drawing to three-dimensional (3D) models.

BIM is the process of "*generating, managing and sharing building information in an interoperable way"* (NIBS, 2007). When utilized properly, BIM can help in reducing the project's cost, improving construction schedules, and detecting errors in early construction stages (Barlish and Sullivan 2012). The technology carries a unique gain to the construction industry by allowing all practitioners to share a single document to simulate the operation process (Chan et al. 2019). Previous studies show that BIM improves the quality of work by reducing the number of errors, change orders, requests for information, and corrections (Lee et al. 2015, Hajj et al., 2021). The reason behind gaining power over other ITs is that BIM has shown long-term substantial impacts that might be achieved during all stages of the construction process (Chan et al. 2019).

Construction firms' response to BIM benefits has been the subject of numerous studies conducted in the US where the diffusion rate was 69% in 2018 (Gholizadeh et al. 2018), Australia (Aibinu and Venkatesh 2015), Germany (Hill 2014), and the UK (Robertson and Samy 2015), where the diffusion rate was 71%, 72%, and 66% respectively in 2014 among many others (Kim and Yu 2016, Shi et al. 2020, Hajj et al., 2021). The findings of these studies show that BIM has promptly diffused in the construction sector of developed countries. However, the diffusion of BIM in developing countries shows fewer promising results. In the Middle East (ME) region, the adoption rate of BIM did not exceed 15% in Lebanon, Syria, and Jordan (Gerges et al. 2017, Jawad et al. 2019). In Africa, the adoption of both the process and the technology was found to be relatively low (Jung & Lee 2015). Despite the valuable contributions of the above studies (Kim and Yu 2016, Shi et al. 2020, Hajj et al., 2021), they all perceived BIM as a single product that that one diffusion rate. However, since BIM is a system that has various functionalities (Oesterreich and Teuteberg 2019), and as some functions, mainly 3D visualization, are known to gain higher shares and diffuse more broadly in the construction industry (Gholizadeh et al. 2018) than others, the use of one diffusion rate does not represent how various functionalities spread in the construction sector and does not inform on whether some functionalities are being employed more than others. Therefore, there is a need to investigate how various BIM functionalities are being used in the AEC industry. Adding to the above gap, previous studies on BIM diffusion mainly focused on examining the factors that hamper the widespread adoption. For example, Gerges et al. (2017) recognized a plethora of technological and social limitations that are hindering the widespread adoption of BIM in the Middle East through empirical observations. Jawad et al. (2019) categorized BIM barriers as technical (i.e., technology) and non-technical (i.e., individual and organizational culture) and emphasized their impact in affecting the adoption rate of BIM. Oesterreich and Teuteberg (2018) conducted a meta-synthesis study and concluded that the barriers to BIM adoption are mainly rooted in the social behavior of the participants involved in the construction network as well as the structural nature and the specific characteristics of the construction industry. However, studies that used mathematical diffusion models to examine the pattern affecting the diffusion of BIM functionalities among AEC firms are dearth.

To contribute to the body of knowledge, this research grounds on the robust innovation diffusion theory presented by Rogers (1983) to examine the diffusion of various BIM functionalities. This theory assumes that the internal and external influence factors drive the diffusion of innovation in a social setting (sector, geographical region, country). According to Rogers' definitions, the internal influence factors are those exerted by the members of the social system because of social interaction e.g., imitating others, while the external influence factors are those related to the direct influence on the innovative behavior of an individual e.g., complying with clients' requirements, changes in government regulations, demand conditions, consulting firms' suggestions, and mass media (Rogers,1983). Innovation Diffusion models are "generative models that are flexible enough to discover any randomly complex data distribution while yielding to analytically assess the distribution" (Mahajan et al. 1990). These models are credited for their ability to forecast rates and patterns of innovation adoption over time (Mahajan et al. 1990). This study attempts to employ diffusion models in the context of AEC firms located in the MENA region to value the significance of the internal and external influences on the diffusion of BIM. This will not only provide vital insights on how these functions spread in the construction industry but can also present a useful perspective on the potential number of adopters for each BIM functionality.

Despite the existence of an empirical study conducted by Gholizadeh et al. (2018) that examines the impact of such factors on the diffusion of BIM in the US construction industry, the consistency of their results, and their homogeneity across other regions such as the MENA area were never tested. Studying the construction industry in this specific region is important, as this sector is becoming a key driver for its economy, accounting for 20-25% of GDP (Dublin, 2020) and attracting investments from all over the world, which is generating more opportunities and boosting the workforce in the sector. Moreover, studying this region will provide a clear answer to the question: which of the factors (external or internal) plays a more significant role in the diffusion patterns of BIM functionalities.

Following the plea for more attention on the subject, this study aims at analyzing the patterns of BIM diffusion from an academic perspective based on their temporal realization in the studied region. Towards this goal, three innovation diffusion models were used: "internal", "external", and "mixed" which enables the merge of the strengths of various factors and their effect on BIM diffusion. Another contribution of the study is examining the effect of the project objectives (reduce cost, improve quality, increase client satisfaction, reduce schedule) on the applicability of BIM functionalities, a topic that was never examined before.

6.2 Literature Review

6.2.1 Innovation Diffusion Models

The innovation diffusion theory was originally developed by Rogers in 1983 as an attempt to understand the process by which an innovation is communicated. He agreed that the diffusion of any innovation over a given period requires specific communication channels to reach the social system (Rogers 1983). Diffusion models are largely employed to estimate the cumulative number of individuals that will accept and adopt an innovation, and to explain patterns of innovation adoption over time and space (Xu et al. 2020, Lagoe et al. 2021). The models that are mostly recognized to be effective in various social settings are the internal (Mansfield, 1961), external (Coleman et al. 1966), and mixed models (Bass, 1969) that ground on a rich and empirically based theory. The main difference between these models lies in the determination of the driving variables behind the adoption of an innovation.

The internal model considers imitative behavior as the main driving force in an innovation diffusion (Mansfield, 1961). Imitative behavior means that a diffusion mainly occurs through interpersonal word of mouth or contact among the members of a social network (Ntwoku et al. 2017). The internal influence model is represented in Eq. (6.1).

$$dN(t)/dt= aN(t)[m-N(t)] \qquad (6.1)$$

where N(t)= cumulative number of adopters at time t; m = total number of potential adopters in the social system; a = probability that each adopter would independently reach a nonuser ; (t)⁄dt = the first derivative of N(t) representing the rate of diffusion at time t.

The external model considers that the adoption of technological innovation is solely driven by information that exists outside the adopting organization. This model suggests that communication among the society members does not exist and no interaction has occurred between prior and potential users (Mahajan et al. 1990). It proposes that factors such as governmental regulations, media, and client demands are the complementary communication channels through which potential adopters of the new technology obtain relevant information for decision making. The external model can be represented as follows in Eq. (6.2)

$$dN(t)/dt = b[m-N(t)] \qquad (6.2)$$

where b = coefficient of external influence in each period (b⩾0).

The mixed model assumes that the diffusion of an innovation is driven jointly by internal and external factors. This model incorporates the external and internal influence models and subsumes parameters and factors from both models, suggesting that the adoption of a new system is partially caused by imitation and partially triggered by pressures from outside the social system (Mahajan et al. 1990). Eq. (6.3) represents the mixed influence model.

$$dN(t)/dt = [\mathrm{b} + a * N(t)]\,[m - N(t)] \qquad (6.3)$$

Many previous authors have made use of the above influence models to examine the diffusion of innovations. For example, Thneibat et al. (2022) employed the mixed model to analyze the diffusion of value management in construction projects as a sustainability tool and found that mass media and external incentives will increase the uptake of value management more than other factors. Ahmed (2018) found that financial support and government initiatives are essential for IT diffusion. Zhao et al. (2020) studied the evolution of renewable energy price policies based on an improved Mixed model and concluded that policies from feed-in tariff can successfully and rapidly evolve to renewable portfolio standards based on the internal influence of the interaction among power generation enterprises and the external influence of government behaviors. Gholizadeh et al. (2018) employed influence models to examine the diffusion of integrated technologies in the AEC industry and stated that the internal factor of copying sheer companies in adopting technologies is the main incentive for innovation diffusion. Similarly, when examining the diffusion of safety innovations in AEC companies using influence models, Lagoe et al. (2021) showed that the internal factors played a predominant role over the external factors. Xu et al. (2020) have based their examination of information and communication technology adoption on the innovation diffusion theory and proved that technology diffusion is mostly driven by the strength of the company and found that companies having rich experience and strong capabilities are better at accepting new technologies.

6.2.2 BIM and Innovation Diffusion

As BIM has been conceptualized as a technological innovation in several studies (Cao and wang 2014; Alhumayn et al. 2017), and as the literature reported the diffusion of BIM to be strongly associated with innovation diffusion (Hosseini et al. 2016, Xu et al. 2020), perceiving BIM through the lenses of innovation diffusion theory is recommended as an effective approach for exploring its diffusion patterns among construction companies (Gholazideh et al. 2018). In this sense, Hosseini et al. (2016) proposed a diffusion model to quantify the impact of BIM adoption on various stakeholders within the Australian construction industry. Lee et al. (2015) used structural equation modeling to outline an acceptance model for BIM in construction firms, and their results revealed that users' perception of usefulness is one of the main factors affecting technology acceptance. Shi et al. (2020) grounded on diffusion models to confirm that BIM acceptance occurs when individuals are willing to use BIMs tools and data in their work process and when the company is willing to make use of BIM to create a collaboration system. Ahmed and Kassem (2018) studied the effect of three types of isomorphic pressures, coercive that comes from governmental regulations, mimetic that emanates from the pressure of competitors, and normative that stems from the shares norms of stakeholders, on the diffusion of BIM technology. Their results indicate that for successful adoption of BIM, firms need not only to address internal process problems but also external isomorphic pressures that are associated with acquiring institutional legitimacy. Samuelson and Björk (2013) studied the diffusion processes of 3-D models for integrated design (BIM) using influence models and found that the BIM adoption decision is initially taken by individuals with a high level of knowledge and that BIM implementation initially starts "bottom-up", i. e. BIM is driven by individuals pioneering the technique. Hosseini et al. (2016) examined the effect of the company size on BIM diffusion and concluded that SMEs are more flexible in adapting their innovation processes to the changed conditions than large companies. This opposes the results of Hajj et al. (2021) that low BIM adoption is an issue in SMEs, and that most available studies focused on big companies and large projects. Based on the above, the examination of the diffusion patterns of BIM functionalities within AEC firms, a topic that is underrepresented in the literature (Alhumayn et al. 2017) particularly within the Middle East and North Africa context (Hajj et al. 2021), is necessary

6.2.3 BIM Functionalities Diffusion in the AEC Sector

A BIM functionality is defined as "a method of applying BIM during a facility's lifecycle to achieve one or more specific objectives" (Ahmed 2018). GhaffarianHoseini et al. (2017)

classified BIM functionalities under five categories: gathering, generating, analyzing, communicating, and realizing the facility information.

BIM was credited in previous studies for its various functionalities that can address the limitations of 2D drawings. Kim and Yu (2016) have examined BIM usage during the early conceptual stages of construction and ranked rapid visualization, reduced decision-making latency, code checking, and improved communication as the most significant functionalities of BIM. Babatunde et al. (2018) acknowledge the importance of BIM incorporation into the quantity surveying profession to identify significant cost-sensitive features and help with construction estimation and procurement. Shi et al. (2020) employed BIM in examining the energy utilization of existing buildings to create energy-saving impacts by modifying the building envelope design. Other researchers such as Kim and Yu (2016). concentrated on the use of BIM for life-cycle assessment (LCA) and life-cycle costing and established a BIM-based decision-making model to optimize investment costs for informed decision-making objectives. Apart from the above, other studies examined the implementation of BIM to improve the environmental sustainability of a project, and underlined key factors affecting safety practices in construction sites, and explored the deficiencies of BIM functions, focusing on the effect of using BIM on the total safety level of the site (Lagoe et al. 2021). As shown in table 1, the various functionalities of BIM can provide numerous benefits for construction projects. Yet, it is the responsibility of project managers to clearly define BIM functionalities and select those that most properly fit the project characteristics and objectives.

Reviewed studies on the topic of BIM functionalities have integrated methods for assessing the efficiency of these functionalities, such as economic efficiency, energy efficiency, and 4D schedule performance (Lagoe et al. 2021, Azhar et al. 2012, Wang et al. 2019). Nevertheless, only a few studies assessed the variation in their adoption rate and the patterns behind their diffusion. Most previous studies ended with one penetration rate of BIM regardless of its various functionalities. This result might not be accurate, as the results of Kim and Yu (2016) showed that only two BIM functionalities “Visualization and clash detection are widely used by US practitioners (63 and 60% respectively), however, other functionalities such as code review are rarely used (12%). These authors confirmed that the provision of clear definitions of BIM tools and the decision criteria behind the selection of a given function can improve the understanding of the value and purpose of BIM deliverables. Similar results were found by Becerik-Gerber and Rice (2010), who agreed that architecture firms in the US construction industry employ BIM heavily for design-related functions. They also showed that only a minority of users are using BIM for environmental analysis. Their results also reveal that the use of BIM for facilities management is still limited. Notwithstanding the various uses of BIM technology, there is a lack of studies that examine the effect of BIM functionalities on various project objectives (reduce time, reduce cost, improve quality, and ensure client satisfaction). (Ahmed 2018, Hajj, 2021).

In this study, statistically proven diffusion models that ground on robust theories was used to interpret the diffusion of BIM functionalities in the AEC sector of the MENA area. Studying BIM adoption using innovation diffusion theory is beneficial as these diffusion models allow scholars to build mathematical models to envisage the potential number of adopters and permit to verify the effect of internal and external influence factors on innovation diffusion. This study attempts to describe the temporal diffusion patterns of BIM functions grounding on three innovation diffusion models: internal, external, and mixed. Moreover, this will be the first study that will base on the user’s perspective to examine the impact of using BIM functionalities on various project objectives.

Table 6.1: BIM functionalities in the construction sector

Nb	BIM Functionalities	Explanations	Ref
F1	3D visualization	To form a realistic and accurate representation and feedback of a facility	(Eastman, Teicholz, Sacks, & Liston, BIM handbook: A guide to
F2	Design Review & code validation	This function allows for iteratively reviewing design materials and compliances with the project's regulatory	(Azhar, Khalfan, & Maqsood, Building information modelling (BIM): now and beyond, 2012)
F3	3D coordination - clash detection	Ensure the efficiency and harmony of the relationship of facility elements through automatically identifying 3D objects that	(Lee, Lee, Min, Kim, & Kim, Building ontology to implement the BIM (Building Information
F4	Program and space validation	BIM allows the extraction of information related to the area and the program which enables participants to track the	(Eastman, Teicholz, Sacks, & Liston, BIM handbook: A guide to building information modeling for
F5	Engineering analysis	This BIM tool allows participants to test and amylase alternative design options, as	[15]
F6	4D scheduling	BIM allows the planning and phasing of project tasks. Using the time-based simulation function, project sequencing	(Wang, Pan, & Luo, Integration of BIM and GIS in sustainable built environment: A review and
U7	5D quantity and cost estimation	BIM automatically calculates accurate quantity take-offs that in terms enable	[28]
F8	Logistics planning	By modeling the detailed logistics objects, BIM offers fast, accurate quantities for material tracking and a unified	[15]
F9	Safety analysis	BIM allows the design of a complete safety plan that enables better	(Azhar, Khalfan, & Maqsood, Building information modelling
F10	Energy analysis	BIM allows the assessments and comparison of the performance of alternative energy systems to meet the	(Eguaras-Martínez, Martin-Gomez, & Vidaurre-Arbizu,, Eguaras-Martínez, M., Vidaurre-Arbizu, M.,
F11	Shop drawing	The needed geometry and data from the BIM are detailed for shop drawing and can be exported to fabrication software. The accurate dimensions presented using	[24]
F12	Documentation	The documentation of all the project information increases owners' satisfaction as it ensures that all project	[30]
F13	Facility management	Asset managers might plan the asset installations that make the maintenance	[27]

6.3 Research Methodology

This chapter focuses the research on the pattern behind the diffusion of various BIM functionalities in the MENA construction industry. To do so, the experiences of the stakeholders and their perceptions towards the use of BIM features in their practice were assessed. The review of the literature revealed 13 main functionalities of BIM that were shortlisted by previous scholars whose works were reviewed (Eastman et al. 2011, Azhar et al. 2012, Lee et al. 2008, Bryde et al. 2013, Gholizadeh et al. 2017, wang et al. 2019). These functionalities established the basis of the survey prepared for the aim of this study. Questionnaires, one of the most popular methods in the current management quantitative research, were used because they generate data in a quantitative form which can be used for rigorous quantitative analysis (Schwab-McCoy 2016). Questionnaires are credited for their ability to accurately transform the research objectives into problems enabling researchers to get high-quality research outcomes (Siniscalco and Auriat 2005).

As BIM has numerous functionalities, and as organizations have distinct technical capabilities, and different levels of BIM functions understanding, it was important to collect data from many organizations in order not to bias the results. To include records from a large number of companies, this study collected data through e-mails and online questionnaires. Online surveys were used as they are available to large target audiences, have no cost-based geographic restrictions, allow leveraging data automation, and support the flexible design of various question types (Siniscalco and Auriat 2005). To ensure that the sample providing answers is the right one, the survey was sent only to firms listed either on the Institute of Architecture and Engineering register of the MENA countries or in the business directory under the chamber of commerce of civil and construction work, which were in total 700 firms. To avoid information distortion, a pilot study with six experts as recommended by llieva et al. (2002) was undertaken to identify construction professionals in the MENA region. In line with their feedback, the confusing expressions were modified, and the structure of some questions was adjusted.

A total of 319 complete questionnaires were received, which yielded a 95% confidence level with a confidence interval of 5% indicating that the sample correctly represents the population. Participants consisted of contractors, designers, construction engineers, construction managers, general managers, and owners.

The questionnaire started by briefly presenting the research objectives, then participants were assured about the confidentiality of the answers and the anonymity of the respondent's identity. Subsequently, participants were asked to answer questions organized and divided into three sections. The first focused on the characteristics of the respondents and the company they are working in, as per the recommendation of In (2017) to promote the integration of research and practice. Questions were namely related to the participants' role, position, years of experience, and country of operation, as well as the company project sizes, the percentage of new contracts, and the delivery method used in their projects. These characteristics are important to ensure that participants can deliver a realistic means of data collection (Schwab-McCoy 2016), and to establish the credibility of the results (llieva et al. 2002, Kale and Ariditi 2010, In 2017, Gholizadeh et al. 2017). This section ends with the question of whether participants are using BIM in their projects or not, based on their answers, respondents were directed to the next section.

The second section was designed for respondents who are using BIM as it starts with introducing the 13 BIM functions and then asks the respondents if they are using each function and the date each function was introduced in their company. The six-point Likert scale ranging from 1 (low) to 6 (High) was utilized to assess the frequency of use, the difficulty, and the value of each BIM functionality. The use of the six stimuli Likert scale is recommended by Lissitz and Green (1975) to perfectly describe the human performance and minimize cognitive failures The scale also provided the 'I don't know' option for respondents unknowledgeable about a question. Alternatively, the third section was designed for respondents who are not using BIM in their projects. In this section, the reasons behind being reluctant to adopt BIM functions were examined in detail. The data collection started in May 2020 and ended in July 2020 resulting in 319 completed questionnaires.

To test the reliability of the results, Cronbach's alpha test using the Statistical Package for the Social Science SPSS was examined, and a reliability coefficient value of 0.879 was obtained indicating that the questionnaire (including the Likert scale) was significantly reliable as it is greater than the threshold of 0.7 mentioned by Brown (2002).

The time-series data retrieved from section 2 of the questionnaire were examined using the three influence models presented above (internal, external, and mixed) to analyze the pattern of BIM diffusion into the MENA construction industry. This step involves the estimation of three parameters (a, b, and m) of the 13 BIM functionalities. Various approaches are recommended to approximate these parameters. This research study makes use of the Levenberg and Marquardt method of Nonlinear Least Squares (NLS) to estimate the diffusion parameters using SPSS. This method has proved its ability to correctly predict the diffusion parameters and present reliable and more conservative results (Mahajan and Muller 1979, Rogers 1983, Kale and Arditi 2010, Gambates and Hallowel 2011, Naseri and Elliott 2013, Gholizadeh et al. 2017). The three resulting influence models were then compared based on their goodness of fit to decide on the best model in explaining the pattern of BIM functionalities diffusion. Figure 6.1 outlines the research methodology used in this study.

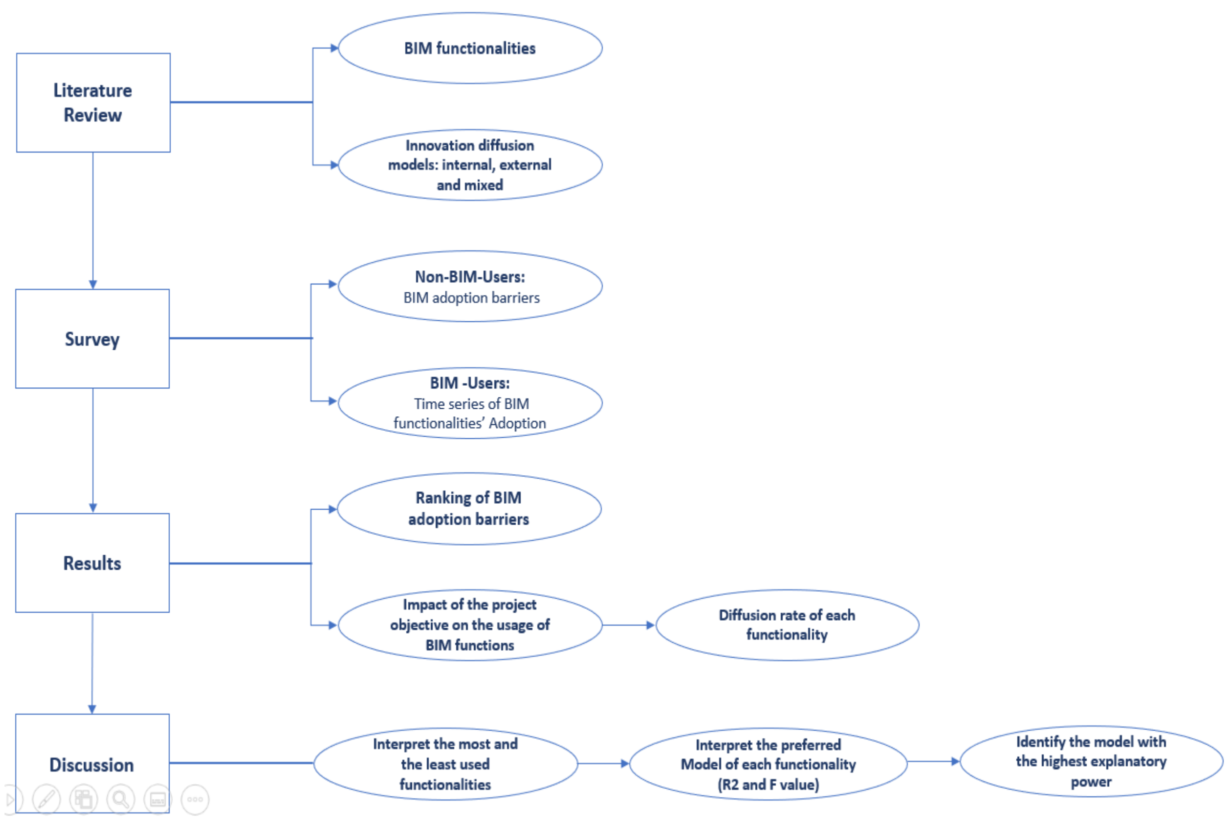


Figure 6.9: Research methodology

6.4 Results

Out of the 700 questionnaires sent to AEC companies, 319 complete questionnaires were collected from respondents of which 124 were BIM users and 195 were BIM non-users. The data were collected from a big number of construction firms with different types and locations and included a variety of respondents that are involved in construction works which ensures the representativeness of the construction sector. The distribution of participants fits the objective of the study as non-users were asked to assess the significance of the barriers and users were asked to determine the used functionalities and the year of adoption of each function.

6.4.1 *Participants and Companies Characteristics*

The results demonstrated the participation of various targeted divisions of construction professionals in the questionnaire. Most of BIM users' participants held a managerial position (53%), while the largest group of non-BIM users are project owners (32%). The results showed that BIM users mostly use two delivery methods to carry their projects: the design-bid-build which is used by 40% of BIM users and the design-build which is used by 32% of the BIM users, while non-BIM-users mainly employ the-design-bid-build as their delivery method. Table 6.2 summarizes the main characteristics of the participants and their companies. As well figure 2 shows that participants operate from 12 different countries in the MENA region, indicating a consistent representation of the studied geographical area.

Table 6.2: Respondents and their companies characteristics

Features	Subcategories	Respondents Percentage	
		BIM users	Non-BIM users
Technology Adoption Status		39%	61%
		124	195
Average Work Experience	Less than 3 years	4%	5%
	3-5 years	11%	15%
	6-10 years	32%	31%
	More than 10 years	53%	49%
Role	Consultant - Architect	12%	19%
	Owner	4%	32%
	Shop-Drawer	3%	2%
	Management positions (CM, PM, GM)	53%	14%
	Designer	13%	22%
	Engineer	11%	8%
	Other	4%	3%
Project Size	Small (less than $1 Million)	8%	43%
	Medium ($1Milion to $10 Million)	26%	41%
	Greater than $10 Million	64%	16%
Project Delivery Method	Design-Bid-Build	40%	73%
	Design-Build	32%	22%
	Construction Management at Risk	21%	3%
	Integrated Project Delivery	3%	0%
	Others	4%	2%

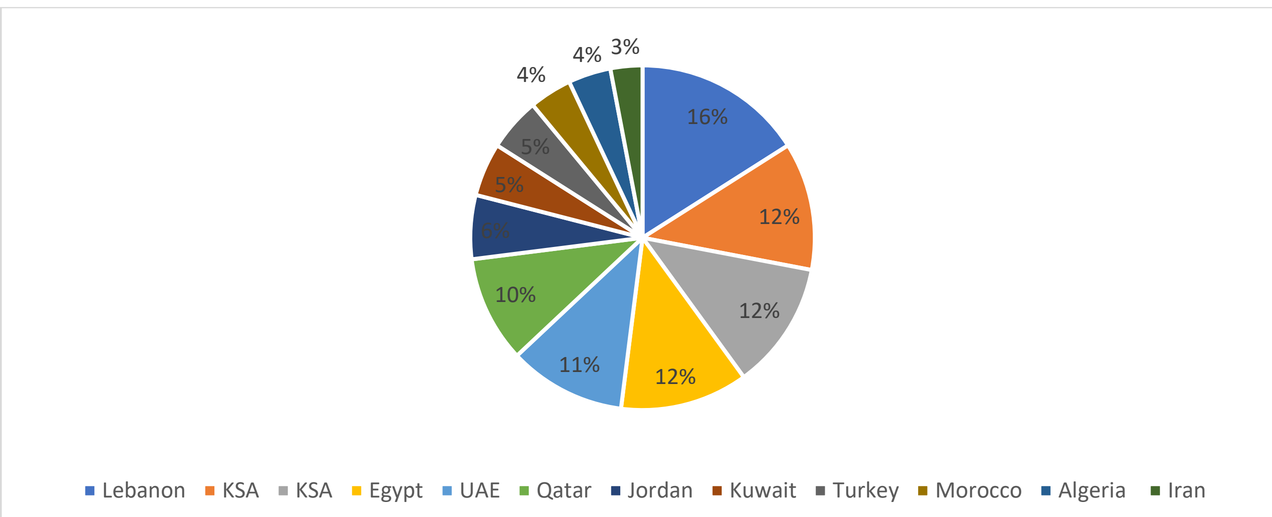


Figure 6.2: Respondents' country of operation

6.4.2 Non-Users Perception to BIM Barriers

Non-users rated the impact of 18 possible reasons to not adopt BIM as retrieved from the latest literature (Banawi 2017; Ahmad 2018; Oesterreich and Teuteberg 2018; Chan et al.

2019, Mohammed et al. 2019). Figure 6.3 shows the top 10 barriers that were identified as having high or extremely high impact according to the Likert scale. Lack of client's demand tops the list by 61 % of participants ranking it as being a significant barrier. However, the examination of the results shows a regional difference between those who consider this factor highly impactful, with more than 86% citing this challenge as being highly significant in Saudi Arabia, Lebanon, Egypt, and Alegria, compared with less than 35% in UAE and Qatar. A similar gap exists between designers (71%) who are often waiting for owners to generate BIM demand and contractors (41%) who are more frequently being encouraged or required by design firms that are already using BIM.

The need for high investment costs to adopt BIM functions ranks second, followed by problems related to the availability of training, and the time needed to take the training. Interestingly, twice as many design firms rated these top barriers as did contractors. Strategic issues about the awareness and knowledge of BIM, and how project roles in terms of responsibility allocation and model ownership were the subsequently ranked barriers. The results were somehow similar between contractors and designers except for the data ownership that was understandably ranked higher by designers (51%) than contractors (25%) among regions. Non-users in the UAE and Qatar express the least overall concern with these strategic issues. Figure 6.3 presents the percentage of users who ranked each barrier as having a high or very high impact on BIM adoption.

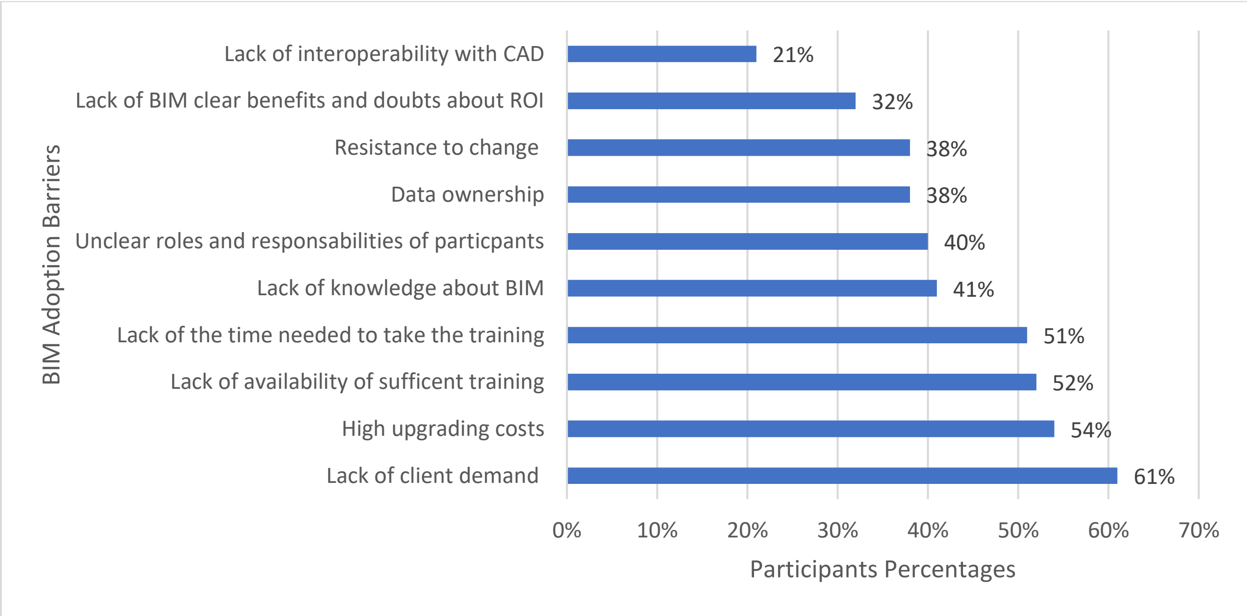


Figure 6.3: Percentage rating of high impact of the main BIM adoption barriers

6.4.3 Users Perception of BIM Functions

6.4.3.1 *Adoption Rate of BIM Functionalities*

The results of table 6.3 show that the most implemented BIM functionalities are 3D visualization, which was used by all BIM users, followed by clash detection that is adopted by 94% of the users, and shop drawing that is employed by 68% of BIM users. Alternatively, the least adopted BIM functionalities are safety analysis with a total adoption rate of 3% and logistic planning that was adopted by only 5% of the participants, along with energy analysis that was adopted by only 6% of the selected sample.

6.4.3.2 *Effect of BIM Functionalities on the Project Objectives*

Although much previous research has focused on the benefits of BIM to meet project objectives, this is the first study that examines the relationship between a given BIM functionality adoption and the objective of the project. To reach this aim, four project objectives (reduce cost, reduce time \schedule, improve the quality, and ensure owner's satisfaction); which were concluded from Schwab-McCoy et al. (2015) study; were examined using the questionnaires to determine the main rationale behind the adoption of BIM functionalities.

BIM users confirmed that the project objective impacts the decision of using BIM functions. The results presented in table 4 show that the only BIM functionality that had a very high impact on all the project objectives is 3D coordination, indicating that this function can significantly help in reducing the project cost, reducing the project time, increasing the quality of the work and ensuring clients satisfaction. However, if practitioners aim to significantly increase client satisfaction, they need to employ the documentation function of BIM or use BIM for facility management as these functions can boost the clients' satisfaction more than any other function (table 4). Yet, the latest functions have a lower impact on affecting the project time and squeezing the schedule. On the other hand, BIM functionalities such as 3D coordination which scored 5.8/6, logistics planning, and 4D scheduling which scored 5.2/6 can significantly help in decreasing the time of project cycles and eliminate construction schedule setbacks more than other functions. These results are novel and will help future practitioners to decide on the function to use based on their objective.

6.4.3.3 *Diffusion Models and BIM Functionalities Diffusion*

Apart from the above, users were asked to specify the year in which they have started to adopt BIM functionalities. The results of figure 6.4 show that the first adoption of BIM functions among the MENA participants was detected in 2007. The examination of the results shows a gradual increase in the number of 3D visualization users, while 3D coordination and shop drawing reveal slower growth over time until 2013. Nevertheless, other functions such as code validation, and energy analysis were not used by users until after 2013, however, after that time these functions have started to diffuse rapidly in the MENA construction market. The subsequent analysis will base on the above results to compare the significance of the three diffusion models in explaining the dissemination of the 13 BIM functionalities, and their goodness of fit to the collected data.

Among the three models, the external influence model had the worst fit, having the lowest coefficient of determination R^2 and the highest AIC value for all the BIM functionalities. The external model failed to approximate the m parameter for all BIM functions i.e. the total number of potential adopters in the social system found from the external model does not fit with and overestimates the real number of adopters found from the questionnaire results. Therefore, the external model was omitted from the analysis. Alternatively, the other two models (internal and mixed) presented more precise approximations of the needed parameters (a, b, and m). The internal and mixed models were successful in estimating the model parameters for 12 and 10 BIM functionalities respectively. Nonetheless, both models were not capable of estimating the parameters for the safety analysis BIM functionality, due to the small number of practitioners using this function.

the reliability of the estimations at a 0.05 level of significance for all BIM functionalities for both models was checked. The mixed model has statistically failed in approximating the potential number of adopters, m, for two BIM functionalities: 5D quantity and cost estimation (p-value = 0.127) and shop drawing (p-value = 0.006), while the internal model has presented statistically significant estimations of their value for all the 12 presented BIM functionalities. Therefore, the BIM functions in both models that had a p-value of greater than 0.05 were considered statistically insignificant and were excluded from further analysis as recommended by Schwab-McCoy (2016).

After estimating the parameters for each model, I attempted to identify the best model for the 10 BIM functions to decide which one better explains their diffusion. For the four BIM functionalities, design review and code validation, 4D schedules, 5D cost, and quantity estimation, and shop drawing, where the mixed model did not generate good estimations, the internal model was chosen as the only good alternative. For the remaining eight functionalities, the adjusted values of the coefficients of determination (R^2) as well as the Akaike's information criterion (AIC) for both models were compared to decide on their goodness of fit. These measures explain the discrepancies between actual results and the results of the model in question. Adjusted R^2 is a **measure of goodness of fit**, and AIC is the approximation of the anticipated distance between the fitted model and the unknown true process that produced the real data. A higher R^2 adjusted value indicates a better model fit, however, a lower AIC value indicates better results.

The results of table 6.5 confirm that for all the eight compared BIM functionalities, the mixed model showed superior performance and better goodness of fit. Moreover, comparing a, and b values, the findings reveal that for all BIM functionalities the influences of the internal factors exceed those of the external factors. BIM functionalities with the most significant internal influences are design review and code validation (a = 0.782) and 4D scheduling (a = 0.826). In contrast, shop drawing (a = 0.417) and 3D coordination (a = 0.424) have the lowest internal influences indicating that their diffusion is barely affected by the word of mouth or imitative behavior.

Table 6.3: Percent adoption of each BIM functionality

BIM Functionalities	N	% of BIM Users	% of Total Sample
3D visualization	124	100%	39%
3D coordination - clash detection	117	94%	37%
Shop drawing	84	68%	26%
4D scheduling	75	60%	24%
Engineering analysis	74	60%	23%
5D quantity and cost estimation	74	60%	23%
Program and space validation	61	49%	19%
Documentation	46	37%	14%
Design review & code validation	32	26%	10%
Facility management	26	21%	8%
Energy analysis	19	15%	6%
Logistics planning	16	13%	5%
Safety analysis	9	7%	3%

Table 6.4: Impact of various BIM functionalities on the projects objectives

BIM Functionalities	Reduce Project Cost	Reduce Project Time	Improve Project's Quality	Increase Client Satisfaction
3D visualization	4.2	4.1	5.4	5.9
Design review & code validation	3.0	3.8	3.8	3.9
3D coordination - clash detection	5.9	5.8	5.8	5.1
Program and space validation	4.0	4.1	4.6	4.9
Engineering analysis	4.9	4.8	5.0	4.1
4D scheduling	4.1	5.2	4.2	5.3
5D quantity and cost estimation	4.3	4.2	4.0	4.1
Logistics planning	3.1	5.2	3.7	4.2
Safety analysis	3.5	3.5	4.5	4.0
Energy analysis	4.1	3.2	5.1	4.9
Shop drawing	4.2	5.1	5.2	4.3
Documentation	4.0	3.1	4.2	6.0
Facility management	4.1	3.5	4.3	5.9

Table 6.5: Parameters of BIM functionalities diffusion in the MENA region

BIM Functionalities	Model	N	m	a	b	R^2 adjusted	AIC
3D visualization	Internal	124	129	0.570	N.A.	0.996	366.81
	Mixed		139	0.452	0.008	0.998	274.17
Design review & code validation	Internal	32	30	0.782	N.A.	0.971	105.6
	Mixed		1205	_	_	_	_
3D coordination - clash detection	Internal	117	151	0.533	N.A.	0.992	423.65
	Mixed		135	0.424	0.007	0.994	412.66
Program and space validation	Internal	61	68	0.518	N.A.	0.992	179.31
	Mixed		66	0.531	0.007	0.993	168.04
Engineering analysis	Internal	74	90	0.434	N.A.	0.994	212.17
	Mixed		84	0.481	0.004	0.996	183.94
5D quantity and cost estimation	Internal	74	74	0.513	N.A.	0.978	262.01
	Mixed		532	_	_	_	_
Logistics planning	Internal	16	24	0.337	N.A.	0.963	61.14
	Mixed		17	0.583	0.007	0.993	24.97
Energy analysis	Internal	19	19	0.760	N.A.	0.986	31.14
	Mixed		20	_	0.51	0.992	24.08
Shop drawing	Internal	84	117	0.417	N.A.	0.981	355.1
	Mixed		259	_	_	_	_
Documentation	Internal	46	53	0.629	N.A.	0.995	80.13
	Mixed		53	0.529	0.017	0.996	66.66
Facility management	Internal	26	36	0.448	N.A.	0.986	60.94
	Mixed		31	0.535	0.12	0.995	31.58

Notes: Underlined is the chosen preferred model for each function. Highlighted are the functions that needed model's comparison.

6.5 Discussion

6.5.1 *Non-Users Perspectives*

When examining the MENA construction industry survey results, it is evident from the perspectives of non-BIM-users that clients are ultimately the driving force behind adopting BIM technology. Non-users believe that clients will adopt, prompt, and push the adoption of any trend if it helps in making the work processes easier. The precedent confirms the need for external factors namely client demand or government support to induce the adoption of the BIM system (Jawad et al. 2019, Hajj et al. 2021). This is consistent with the results of Hosseini et al. (2016) that policymakers, managers, and BIM supporters have to focus their effort on clients on the higher end of the supply chain. Other barriers were stemmed from the negative perceptions about the high costs and the amount of time to be allocated for the adoption of BIM. This is consistent with the results of Hosseini et al. (2016) that the lack of resources and interest of SMEs affect the acceptance of BIM adoption risks. As mentioned before, most companies in the MENA region are SMEs that are striving to persist in the market (Hajj et al. 2021), therefore it is understandable that taking such adoption risks that are associated with high investment costs while the clients are not demanding it is beyond firms' acceptable level, therefore SMEs around the globe tend to adopt reliable methods with guaranteed Return on Investment (ROI) (Poierier et al. 2015).

6.5.2 *BIM-Users' Perspective*

Concerning the perceptions of BIM users, the results confirm that the project objective has a potential impact on the implementation of various BIM functionalities. Therefore, before embracing BIM functionalities, project managers should define project objectives along with their relationship to BIM implementation. The project might aim to develop a more economical energy design or simulate more accurate record models, among many others. Once the project objectives are identified, managers should determine the proper tasks that participants would like to perform using BIM. This implies that project managers should begin with the operation stage and consider the added values as well as the risks incurred with each BIM use.

Focusing on the actual adopters, while the study encompasses 124 BIM users, only two functions (3D visualization and 3D coordination) were found to be used by more than 75% of the participants. The Pareto principle, in this case, indicates that 75% of BIM users are making use of only 15% (2/13) of the functionalities. This might be explained using Roger's assumptions that any technology is composed of hardware, that is usually more visible to users, and software that needs to be effective and accessible for users (Rogers, 1983). Yet, despite the presence of manuals that can help in conveying significant knowledge about the software, user interaction and sharing of information is the most effective way to understand the convenience and usefulness of any technology.

To understand the relationship between the adoption rate of BIM functionalities and their ease of use, I will refer to the conclusions reported by Bhoir et al. that the most difficult BIM features to implement are code validation, material tracking, energy analysis, and safety management (Bhoir et al. 2015). This conclusion might help in explaining the rationale behind having energy analysis (15%), logistics planning (13%), and safety planning (7%) as the least adopted functions among participants of this study. The examination of the above indicates that some BIM functions are only used if the users have already practiced and mastered other functions. The results of figure 4 demonstrate that users have passed through the utilization of all BIM functions, before adopting the safety planning usage of BIM which was the latest and the least function to adopt, i.e., the safety planning function was adopted for the first time in 2018 by only one participant, while in 2018 all the other functions were already adopted by a higher number of participants as shown in table 4. This indicates that only mature users who are familiar and professional with the usage of a variety of BIM functions can start operating BIM for safety planning.

6.5.3 *Internal versus External Factors*

The diffusion of all BIM functionalities among the MENA construction industry is mainly driven by the imitative behavior (internal factors) rather than the changes in government regulations and the client's demand (external factors). These findings were not expected, since governmental regulations, client demand, and other external factors were ranked among the top adoption barriers by BIM non-users. A possible conclusion of the above is that an external push is needed to induce non-users to adopt BIM, i.e. the external factors are extremely needed in the pre-adoption stage of BIM. Yet when the adoption occurs, and one is in the post-adoption stage, the internal factors are those affecting the utilization or the favoring of one functionality over the others. This study found that client demand which is an external factor is significant for the quick start of BIM and its successful adoption of BIM in the AEC industry.

In addition, this study also found that imitative behavior (internal factors) was an effective predictor of BIM functionalities adoption, pointing out that users wait for other peers to use a given function before they start using it. It seems that the construction industry in the MENA region was less likely to be influenced by various external pressures but rather was influenced by its specific needs for growth and development. Users in this region do not instinctively adhere to the external agencies in their decision to adopt BIM functions. Although these conclusions oppose earlier studies (Cao and Wang 2014), they were consistent with the outcomes of Ahuja et al (2016) who studied BIM diffusion in the Indian construction market. To summarize, the external factors, affect the adoption of BIM, yet the internal factors (imitative behavior) affect the decision-making on which BIM functionality or usage to employ in the project.

The imitative behavior observed in the MENA AEC industry might be explained by the rationale efficiency and bandwagon pressure hypotheses. The first hypothesis suggests that in adopting innovation, practitioners need to receive substantial information about the costs and benefits of the adoption (Abrahamson & Rosenkopf, 1993). The main concern of this hypothesis is that firms adopt an innovation when information about its profitability and efficiency is available to users at a given point of the diffusion process (Abrahamson & Rosenkopf, 1993). However, as most BIM benefits realize in the long run and as many of them are intangible such as improved customer satisfaction, better image, and reputation among many others, the technical efficiency and profitability of BIM functionalities are arguable. To solve this problem, previous authors have used a set of predictive techniques namely Internal Rate of Return (IRR), Net Present Value (NPV), and (ROI), to evaluate the profitability of BIM functionalities (Clark and Augustine 1992), yet I cannot assume that firms are performing these mathematical calculations as the base for their decision to adopt a given BIM functionality. Based on this uncertainty, the technical profitability alone is not the sole criteria to decide on adopting BIM functionalities as it cannot completely justify the diffusion process of BIM functionalities in the AEC sector.

Apart from the efficiency theory, the bandwagon hypothesis suggests that the social pressure generated from the sheer number of adopters induces individuals to adopt an innovation (Abrahamson & Rosenkopf, 1993). This implies that firms that have not implemented BIM tools may appear not to be legitimate to customers and give the notion that the company is not qualified and up-to-date even if it has supplied great services throughout its lifespan. The above implies that AEC firms might feel obliged to embrace BIM functionalities in order not to lose their competitive advantages. The fade bandwagon theory assumes that even when efficiency and profitability data are not clearly conveyed to organizations, sometimes organizations rely on the number of previous adopters and their reputation to adopt a technology (Meyer and Rowan 1977; DiMaggio and Powell 1983). In other words, when profitability information is not present, firms tend to follow other social cues such as the market share of the adopting companies to make the adoption decision. Considering the above, the bandwagon pressure might more comprehensively describe the spreading of BIM functionalities in the AEC sector (Abrahamson & Rosenkopf, 1993). However, examining the exact effect of bandwagon pressures is not within the scope of this chapter.

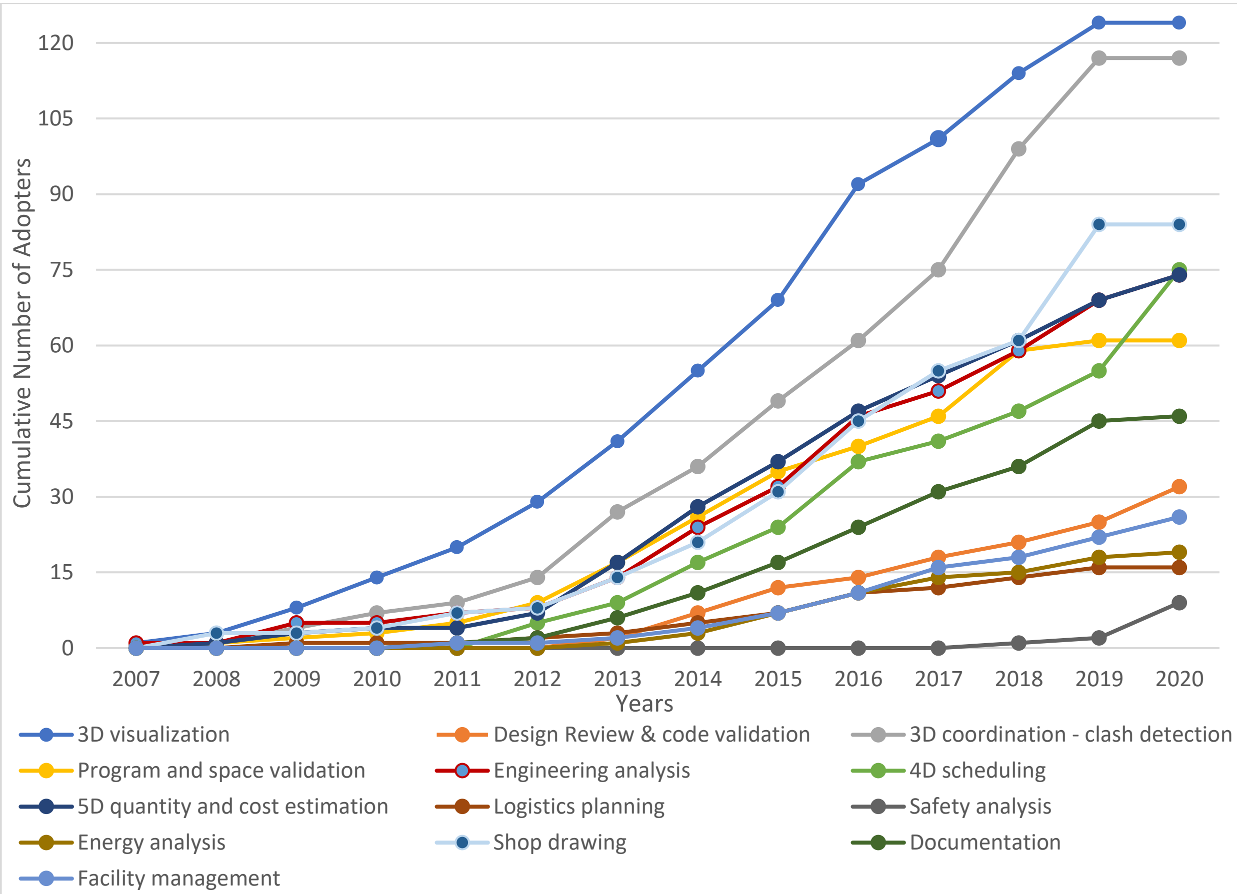


Figure 6.4: Cumulative number of adopters for each BIM functionality

6.6 Conclusion

This chapter has examined the adoption trends of BIM functionalities in the MENA construction sector. Studying this region is important as its construction sector is becoming a key driver for its economy. Numerous findings emerged from the study. First, the results point out that BIM functionalities diffusion has increased gradually between before 2011 and rapidly from 2012 to 2020 where it has reached an adoption rate of 39%. This implies that the AEC sector has not yet reached saturation concerning BIM functionalities.

Moreover, the results show that although some functions are well defined such as logistic planning and energy analysis, they are not expected to be sufficiently adopted by AEC firms (m=17 and 20 respectively). The above implies that while practitioners are aware of the hardware needed to implementation BIM functionalities, other more effective communication channels are required to boost their diffusion. Therefore, construction firms that are willing to stay competitive need to invest more in specific functions.

Three diffusion models (internal, external, and mixed) were used to analyze the diffusion patterns of the BIM functionalities. The findings reveal that the mixed model most accurately translates the diffusion patterns of most BIM functions. Moreover, the results demonstrate that although both the internal factors and the external factors add to the mixed model description of the data, the influence of the imitative behavior outperforms the clients' demand, governmental regulations, and other external factors in the diffusion of BIM functionalities. The above confirms the significance of the bandwagon pressure in the diffusion of BIM functionalities across the MENA AEC industry.

Implications:

The study provides new information and understanding of a topic by filling the knowledge gaps which is a substantial contribution to knowledge. Therefore, the study enlarges the effort of assessing BIM diffusion and offers insights on the holistic understanding of the factors that affect the diffusion of BIM functionalities within the MENA AEC environment, a region previously under-researched, and recognized as having BIM at the early stage of adoption. This study is among the first applications of the influence models to examine the adoption of BIM functionalities in the AEC industry and the very first across the MENA region.

The findings of the study contribute to assisting managers and industry practitioners in enhancing the systematic implementation of BIM in AEC projects as they present the situation of the adoption of BIM in the MENA region and the untapped opportunities that this technology can bring to its industry. As MENA AEC firms are operating in the natural context of the construction sector which accommodates a variety of competitive pressures, they are stimulated to adopt technology innovations, even if they know that the adoption will not bring about any development to the firm's performance. Hence, construction firms must be conscious of the subtle operation of competitive bandwagon pressures in their natural environment. Moreover, the internal pressures combined with the increasing rate of IT adoption compels construction firms to carry out a thorough strategic analysis before the adoption of BIM. The study confirmed that the provision of clear definitions of BIM tools and the decision criteria behind the selection of a given function can improve the understanding of the value and purpose of BIM deliverables. The study presents results that can be useful to decision-makers as they guide how each BIM functionality might affect the project objective as each function has a different effect on the project performance.

Limitations

While the study has many contributions, it has several limitations. First, although the research shows that some functions are diffused more broadly than others, the reason behind this disparity was not examined. Therefore, future research should be conducted to understand the precedent. Second, as stated by Mahajan et al. (1990), the technology diffusion can reach its peak at any phase of the construction, and the patterns of the diffusion might differ among firms. However, both influence models do not offer flexibility to this issue. Thus, future research is needed to check whether other more flexible models enable the provision of a better fit to the data. Moreover, the models consider that the internal and the external factors were constant over time, therefore, to increase the accuracy of the results future authors might examine dynamic influence factors in an attempt to enhance the model. Finally, the models assume that users start adopting a technology after receiving information about its benefits from internal, external, or both sources, however, as a time lag might occur between receiving this information, being convinced of them, and eventually taking a final decision to adopt a technology, future research that focuses on the importance of communication channels should be conducted to give a better understanding on the decision mechanisms behind the successful adoption of information technology.

Chapter 7

The financial Implications of Investing on BIM

7.1 Introduction

While the movement towards supporting technological innovations and employing full digitization have lately governed the manufacturing environment of many sectors (Kagermann et al., 2015), the Architecture, Engineering, and Construction (AEC) industry in many countries is still following the conventional project delivery method in which the design and documentation are non-parametric, manual, and paper-based (Leviäkangas et al., 2017). To push the industry to move forward, digitization advancements that enable improved project performance, schedule planning, and cost management throughout the construction value chain are being advocated (Alaloul et al., 2018). In this sense, 9 (BIM) is considered as the key to increasing the digitization of the AEC industry, as it proficiently empowers coordination, collaboration, and information exchange across company borders (Chan et al., 2019).

Yet, despite the advancement of BIM and the numerous benefits it offers to the sector, many firms are still reluctant to invest in it (Ahmed, 2018). Doubts about the directly proved financial returns of BIM are referred to in the literature as key barriers to its adoption (Alhumayn et al., 2017).

In the past years, many BIM researchers have addressed these doubts and recognized a plethora of limitations mainly related to the absence of methods that can quantitively estimate BIM costs and benefits before its adoption (Dainty et al., 2017). Therefore, providing approaches that deliver evidence of the costs and benefits of BIM are recommended to support firms in weighing the risks versus the opportunities and determine whether the investment in BIM pays off in the long run or not (Francom & El Asmar, 2014).

Published studies mainly focus on the Ex-post evaluation (post-adoption-evaluation) of BIM on the project level, however, the actual financial implications of BIM on the organizational level are not recognized. Moreover, the review of the literature reveals the lack of clear approaches that allow firms to measure or evaluate the intangible benefits reaped from the adoption of BIM. Another gap is that previous studies have overlooked the complexity of the organizational environment and did not examine the interrelations between the costs and benefits of BIM.

Adding to the above, the literature shows that BIM has been widely ignored in the IS domain (Merschbrock & Munkvold, 2012), and is rather allocated in the engineering field (Eastman et al., 2011). The above is surprising as IS literature provides a broad overview of techniques that might be used to evaluate the investments in information technologies (Irani & Love, 2002) such as the Cost-Benefit Analysis (CBA) technique that is commonly used as an economic evaluation approach to quantitatively measure the needed investing expenses and the reaped returns of any system (Lu et al., 2014).

To address these gaps, this study will employ the CBA technique from the IS discipline to evaluate the financial implications of BIM on construction firms. The study aims to propose a novel quantification model that assesses the costs and benefits of investing in BIM from a System Dynamics perspective to provide an improved understanding of the financial impacts of investing in BIM on the complex corporate system environment.

This study contributes to the body of knowledge by proposing the first step for evaluating the complex financial implications arising from the adoption of BIM technology in the construction context. To do so, the chapter starts with introducing the research method and follows by presenting the theoretical backgrounds of BIM costs and benefits. Subsequently, I performed a design analysis to develop a CBA framework focused on BIM. In light of the proposed framework, a model that quantitively measures the variables is developed and examined using a case study. The quantitative analysis is conducted by means of System Dynamics Modeling. At last, the results of the simulation models are discussed in-depth, and the concluding propositions are presented.

7.2 Methodology

This chapter aims to tackle the dilemma of quantitatively calculating BIMs costs and benefits before making the investment decision (Ex-ante Evaluation). To do so, an evaluation Model that assists in quantitatively evaluating the financial impacts of investing in BIM using the design-science approach was developed. The latest assumes that the understanding of a problem and its solution is achieved through developing and applying the designed artifacts (Hevner et al., 2015). Previous authors confirm that the decisive artifact can be characterized as a model (Cabitza & Simone, 2012) as they focus on presenting real-world situations and increasing the knowledge about the problem. This study aims to combine the phases of IS Ex-ante evaluation technique by means of a CBA (Irani & Love, 2002) with the rules of design science (Hevner et al., 2004) to create an innovative model.

Two main studies formed the basis of this research: (1) the study of Sassone and Schaffer that recommends a five phases framework for conducting CBA consisting of defining the problem, designing the analysis, collecting the data, performing the analysis, and then presenting and validating the findings (Sassone & Schaffer, 1978), and (2) the study of Hevner et al. that provides seven Guidelines (G) for design science in IS research namely: G1: design as an artifact, G2: problem relevance, G3: design evaluation, G4: research contributions, G5: research rigor, G6: design as a search process, and G7: communication of research (Hevner, March, Park, & Ram, Design science in information systems research, 2004). The process of developing the artifacts based on the above-mentioned studies is outlined in figure 7.1.

1-Defining the Problem:

- Emphasis: Detailed description of BIM investment scenario
- Guidelines: G2 and G4
- Research Method: Systematic literature review
- Artefacts: CBA framework

2- Designing the Analysis:

- Emphasis: Developing the analytic structure of the CBA + Identifying BIM costs and benefits
- Guidelines: G1 and G5
- Research Method: Systematic literature review
- Artefacts: CBA framework

3- Collecting and Analysing the Results:

- Emphasis: CBA modeling
- Guidelines: G6
- Research Method: Case Study
- Artefacts: Numerical Model

4- Validate the Results:

- Emphasis: Detailed description of BIM investment
- Guidelines: G3 and G7
- Research Method: System Dynamics Modeling
- Artefacts: Numerical Model

Figure 7.1: Research design of the study based on the cost-benefit analysis framework.

7.3 Literature Review

7.3.1 Systems Theory and System Dynamic

This study applies the general systems theory as an approach to develop a model that assists in improving the understanding of BIMs financial implications on the organizational level. From the systems theory perspective, every system element is implanted in the organization's processes and is influenced by its environment. A system has synergy and emergent behavior, implying that changing one part of a system may affect other parts or the whole system (Kast & Rosenzweig, 1972). The assessment of a system in systems theory takes into account: (1) the system as a whole, (2) the interactions and interdependencies among a system's elements, and (3) the emergence of a system and its properties that are generated by non-linear interactions. In this context, figure 7.2 portrays BIM from the lens of the systems theory as a cohesive accumulation of interrelated and interdependent components that are embedded in an organizational process. The figure shows that BIM has the characteristics of a system and has elements that interplays. As shown in figure 7.2, BIM gets inputs from its environment and transmutes them into outputs through BIMs subsystems. These outputs are transferred back to the organization that collects its data from the environment and transforms them into services\products that comply with the company's business goals. Finally, the system obtains remarks from its external environment through a feedback series.

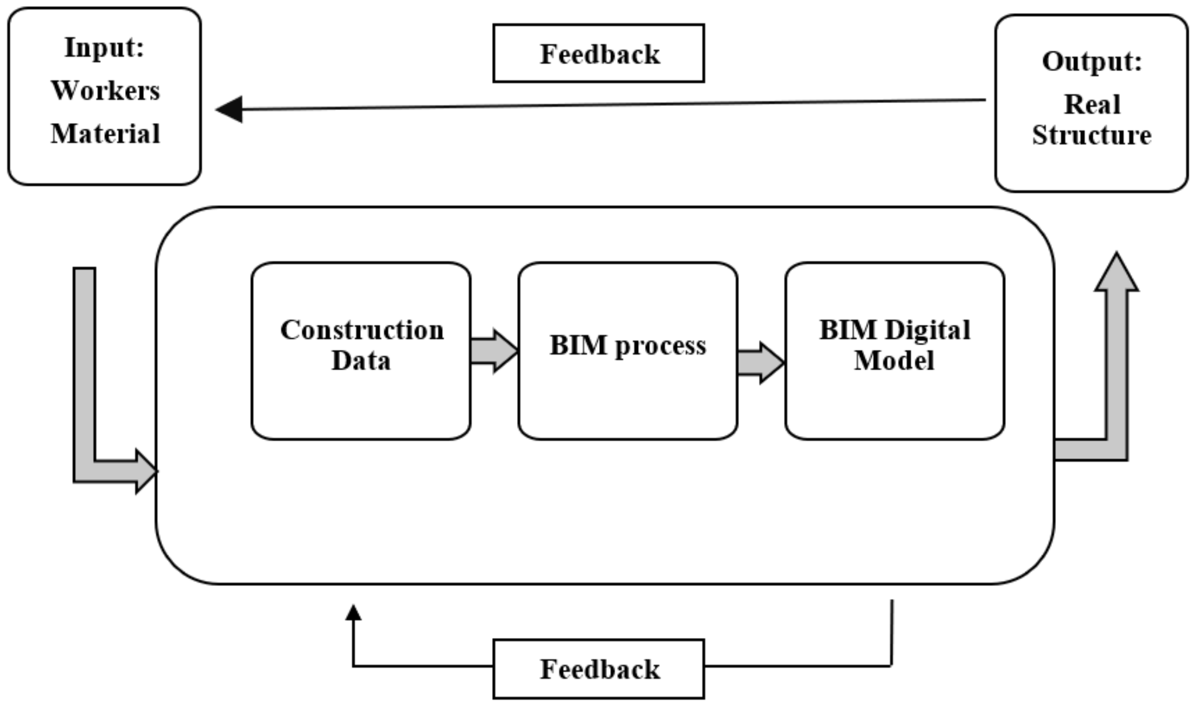


Figure 7.2: The interrelated elements of BIM from the systems theory lens

Based on the fundamental concepts of general systems theory, the System Dynamic (SD) model is an evaluation model for examining the dynamic process of a technology value creation. The SD manages the dynamic performance of complex systems through quantitively calculating and measuring the effect of the interrelations among a system's components. The advantage of using SD modeling for IT investment evaluation is that the wide range of implications arising from the investment proposal on the organization can be simulated without disturbing the running system [33].

Past IS evaluation researchers have proven the effectiveness of the SD model for demonstrating nonlinear cross-impact interactions emerging from the financial impacts of investing in technologies (Coyle, 1997). For the aim of this chapter, the systems theory perspective and SD approach were brought together to optimize the development process of the artifacts and deliver an improved knowledge of the financial implications evolving from investing in BIM.

7.3.2 Related Studies

Research from the last decade on the topic of the business value of BIM shows that it is a long way from being sufficiently studied. Yet, there are some studies tackling the gains\benefits resulting from BIM adoption (Giel & Issa, 2013) (Azhar et al., 2012) (Barlish & Sullivan, 2012). Table 7.1 presents a synopsis of the referred BIM studies that focus on the specific costs and benefits of BIM rather than on its overall economic value.

Table 7.1: Literature review of BIM costs and benefits

Authors	Year	Level	Type	Focus	Research Method	Outcomes
Azhar	2012	Project	Ex-Post	Benefit + Evaluation	Case Study	ROI Analysis
Barlish & Sullivan	2012	Project	Ex-Post	Cost + Benefit	Literature + Case Study	Calculation Model
Love et al.	2013	Organizational	Ex-Post	Cost + Benefit	Literature	BIM Evaluation
Bryde et al.	2013	Project	Ex-Post	Benefits	Literature	Ranking criteria model
Sanchez et al.	2016	Project	Ex-Post	Benefits	Case study+ Survey	BIM Value Realization
Oesterreich &Teuteberg	2018	Project	Ex-Post	Benefit+ Cost+	Literature	Adoption Framework

The first study on this topic goes back to 2012 and concentrated on analyzing BIM benefits on the project level (Azhar et al., 2012). In this study, Azhar conducted prescriptive evaluations (Ex-post) to assess the performance of BIM (Azhar et al., 2012). The rationale of this post-implementation analysis was to compare the expected benefits to the actual benefits. In line with the above study, Barlish and Sullivan used three different case studies on completed projects to examine the major BIM metrics that allow cost savings (Barlish & Sullivan et al., 2012) on the project level. Other related research primarily focuses on presenting frameworks to assess the costs and benefits of BIM adoption. The most prominent contribution in this topic goes to Love et al, who proposed a conceptual BIM benefits evaluation framework that goes beyond the basic quantification of expenses and profits, allowing the classification of the costs into direct and indirect and the benefits into tangible and intangible (Love, Simpson, Hill, & Standing, 2013). Yet the same authors pointed out that the quantification of the intangible benefits is not possible.

Grounding on the above framework, Sanchez et al. presented another framework that defines indicators to measure the tangible and intangible benefits of BIM across the project lifecycle (Sanchez et al., 2016). Differing from the theoretical framework presented by Love et al., the framework proposed by Sanchez et al. is constructed based on expert consultation and case studies. However, neither of the two frameworks quantitatively measures the financial benefits of BIM. Moreover, Oesterreich & Teuteberg have proposed a novel holistic framework for the evaluation of BIM that grounds on using various costs and benefits, yet the framework has several limitations as it was based on several assumptions in the specific context of the single case setting and can thus not be generalized (Oesterreich & Teuteberg et al., 2019).

The in-depth examination of the literature on the business value of BIM shows reveals many predictive techniques that were previously used to appraise the investment in BIM namely: Internal Rate of Return (IRR) (Abbasianjahromi et al., 2019), Net Present Value (NPV) (Sanchez, et al., 2016), and Return on Investment ROI. Yet, the use of these linear calculations does not depict the overall economic business value of BIM on the organizational level.

Moreover, all previous studies provide knowledge into particular features of a cost-benefit analysis, however, studies that give a holistic overview of all the costs and benefits implications and propose an appropriate method for evaluating the financial effect of BIM on the organizational level are dearth. For instance, vital costs as the ongoing expenses of in-house application, creation of standards, and upgrading expenses among many others were not addressed in the past literature.

Despite the presence of numerous publications that provide lists of wide-ranging BIM benefits (Barlish & Sullivan, 2012), there are so far neither attempts to explain the interactions of these benefits. Besides, the extent to which their interdependencies affect the organizational subsystems was never addressed. To conclude, studies that have presented a quantitative method that uses financial measures to predictively (ex-ante) evaluate the costs and benefits of BIM on an organizational level are dearths. Previously developed BIM benefit frameworks do not take into consideration all the interactions between BIM benefits and leave an open question about how the financial gains of BIM can be estimated in terms of monetary values. Driven by the need for more research on the business value of BIM, this research study aims to contribute to the body of knowledge by merging the knowledge base from the IS domain with the dynamic development of the BIM subject.

7.4 Design Analysis

The costs and the benefits of investing in BIM within the natural setting of a mid-sized construction company operating across the Middle East (ME) region have been examined. Therefore, BIM costs and benefits need to be first identified and then inputted into the simulation model. the below sections explain with care (1) the identification process of BIM costs and benefits, (2) perspectives used to develop BIM benefits and costs frameworks, (3) decision criteria on the significance of the used metrics indicators, (4) and the integration of the selected BIM benefits and costs in the simulation model.

7.4.1 Benefits of Investing in BIM

The benefits framework proposed in this study is grounded on the BIM evaluation model developed by Love et al., which comprises 20 tangible and intangible benefits and concentrates on content, context, and process (Love et al., 2013). While Love et al. framework is conceptual in nature, it is developed after a comprehensive review of the normative literature and based on the authors' wide knowledge and experience in information systems evaluation. While the backed framework offers a comprehensive understanding of BIM benefits along with useful insights on their materialization process, there are several limitations to be overcome before integrating them into a cost-benefit analysis (Zhou et al., 2017). Although the framework of Love et al. answers the question of who, what, and why the evaluation needs to be considered, it does not guide on how the benefits can be measured financially and tend to ignore the role of evaluation in organizational learning and the strategic value of systems.

Additionally, Love et al. did not analyze the apparent interrelations between the benefits and did not analyze the end benefit arising from the intermediate ones. For example, the benefits “improved automation assembly” and “improved planning” are expected to result in “reduced change order” which in sequence results in a “reduction in the operational expenses”. Examining the interdependencies that arise from all the interactions of the benefits is vital to avoid duplications in the quantification procedure.

This study will assess these shortcomings and propose a new evaluation method for BIM benefits. To reach this goal, the study abides by the utility effect approach and allocates the 20 BIM benefits presented by love et al. into the four impact levels proposed by Schumann and Linß as elicited in Figure 7.3.

Starting at the operational level, the immediate impacts of BIM usage are examined according to their utility effect. As an additional step, direct and indirect potential functions of the new system are derived on the managerial level to estimate further implications. Then, the impacts of investing in BIM are examined on the organizational level, and the overall utility effect is aggregated at the strategic level. In other words, the benefits assigned to the operational level are those activities that can be realized more effectively using BIM such as “Improved Safety”. While BIM benefits at managerial or organizational levels are based on the potential functions resulting from the benefits on the operational level such as “reduced Labor cost”, which is expected to increase the “competitive advantage” of the company at the strategic level.

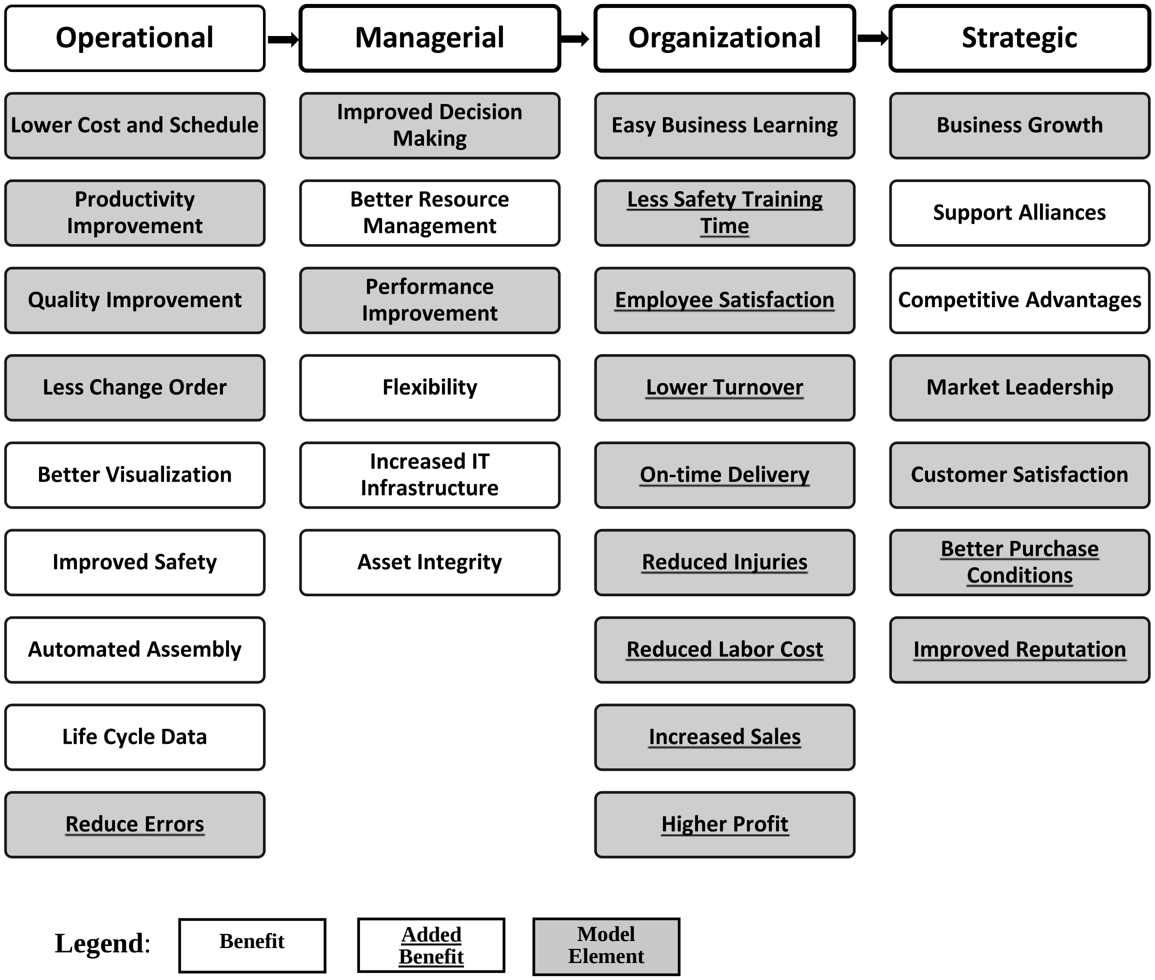


Figure 7.3: BIM benefits based on the impact level

Yet, due to the difficulty of assigning meaningful dollar values to the intangible benefits, quantitative measures that can account for their direct value were needed. Therefore, additional BIM benefits (the ones that are underlined in figure 7.3) were included to be able to measure their effect using metrics. For instance, Love et al**.** recommended the benefit "improved safety" which needs tangible metrics to be measured. Therefore, new benefits were developed to quantify this benefit namely: "reduced number of injuries\fatalities" and "reduced time to take safety training".

Therefore, a modified BIM benefits framework that grounds on the process-oriented view (utility effect) of the benefits on different impact levels was developed as shown in figure 7.3. The benefits highlighted in grey are those designated to be incorporated in the quantification model due to their significance as metrics indicators that can be used to help organizations in measuring their progress towards their goals. To summarize, a complete and relevant set of attributes related to BIM benefits was identified and assigned different impact levels to these attributes

However, to test the performance of BIM adoption on the identified levels, the benefit of any performance gain needs to be linked to the cost of delivering the information to establish the financial impact. The fundamental rationale of such approaches is that the investment costs need to be linked to the benefits to be materialized. A dilemma with this balancing task is that expenses arise immediately, while the advantages take longer to materialize. Thus, the identification of the costs of adopting BIM is essential.

7.4.3 Costs of Investing in BIM

Only little of the BIM evaluation literature focused on clarifying the cost implications of the investment. Jin et al confirm that there is a need for a mechanism to recognize and allocate BIM investment costs (Jin et al., 2017). Scholars have focused on emphasizing the BIM costs at the operational level. Only two identified researchers, Love et al. and Rae Hoffer, tackled BIM adoption costs on the organizational level (Love et al., 2013) (Hoffer, 2014). Therefore, to create a more consolidated framework, the cost implications presented in these two studies were brought together with the cost evaluation taxonomies from the IS research domain developed by Irani et al. (Irani & Love, 2002).

What makes the process of cost identification more problematic is the complexity of quantifying the hidden and the indirect costs. Based on the above-referred studies, BIM investment costs can be categorized as being direct or indirect as figure 7.4 shows (Love, 2013). The direct cost element is assigned to the information technology component, these include the initial investment costs such as software, hardware, and consulting costs in addition to the ongoing costs such as maintenance costs, training costs, and overheads. However, the indirect element relates to the effect of the information systems on the organization and the people and includes the people related costs such as costs of administration and operation activities and turnover, in addition to the organizational related costs such as employee motivation and productivity losses resulting from the resistance to change attitude. As stated previously, measuring the direct costs by means of quantifiable methods is easier than metrically measuring the indirect costs that are mostly intangible (Human resources and organizational) (Succar et al., 2012).

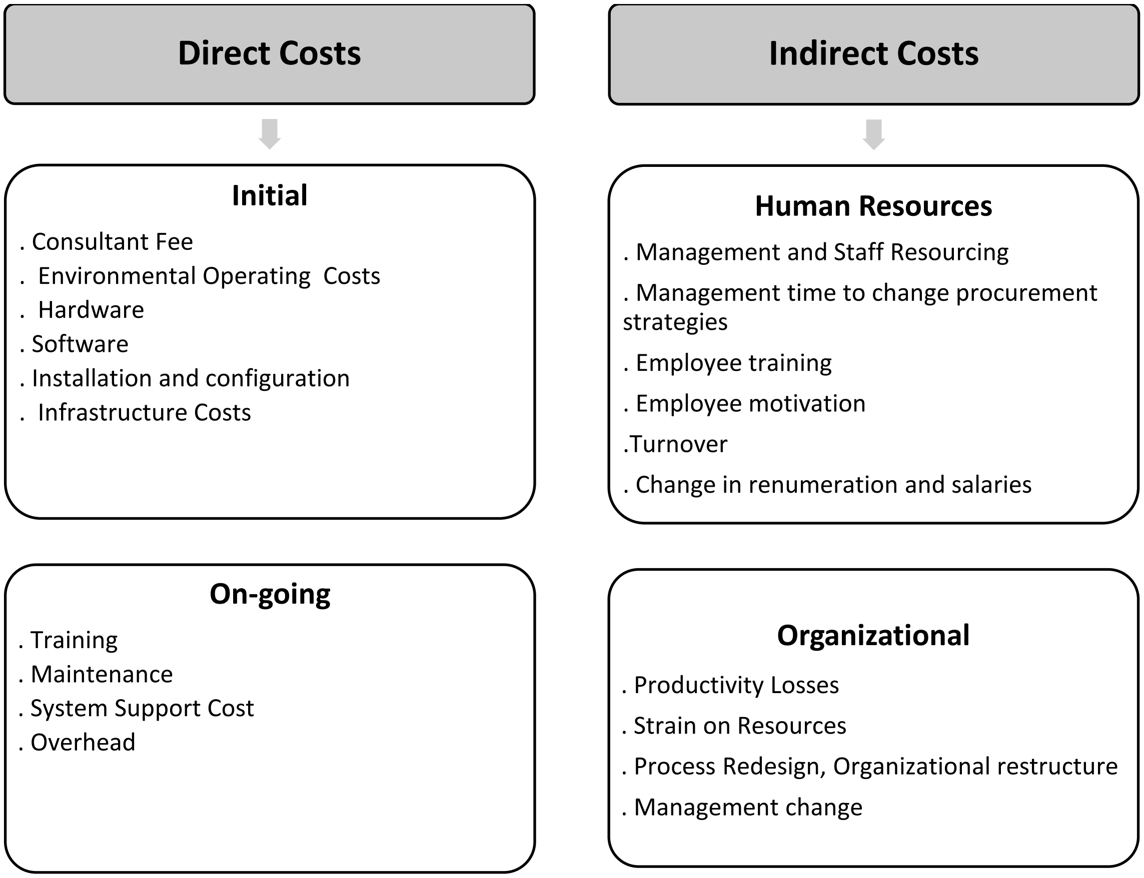


Figure 7.4: BIM direct and indirect costs (Irani & Love, 2002) (Love et al., 2013) (Hoffer, 2014)

7.5 Quantitative Analysis

This section focuses on developing a quantification model based on BIM's costs and benefits introduced in figures 7.3 and 7.4. To reach this aim, I examine the business value of BIM within the natural setting of a construction firm that operates across the MENA region. The chosen company is a regional construction firm, having a portfolio that encompasses a range of medium-scale projects in the sectors of infrastructure, residential, and commercial. The company employs around 3000 personnel and has an annual revenue of approximately 150 Million Dollars (M$) and provides professional services in both the private and public sectors.

The company's management system aims to accomplish projects on time , to the highest standard of quality, and within budget. Therefore, the company seeks a holistic transformation process with a long-term organizational plan. In line with the above, the company started the process of BIM adoption at the end of 2020. Yet, the investment decision was made without an evaluation of its economic impact.

Yet, as it is essential to investigate the long-term effects of BIM adoption on the financial performance of the firm, a model that captures the financial implications of BIM on various subsystems and on the whole organization was developed and regulated to fit an average firm in the MENA construction industry.

To do so, all the costs and the benefits of BIM were integrated into the firm's subsystem, and the investigation of their interdependences was investigated at the organizational level instead of considering them as isolated system components.

Yet, the model development faced some challenges such as assigning dollar values to the intangible benefits such as "improved safety". Moreover, whether the costs and benefits interact, how and to which degree they do so, and what is the complete financial effect this has on the organizational level was another challenge to be confronted in this study. While straight linear mathematical equations to approximate the monetary effects of a system are frequently used in CBA (Vince, 1992), in this study, they appear to be inadequate for the above-mentioned explanations.

Therefore, the SD modeling approach was employed to determine the effect of each cost or benefit on one of the three organizational subsystems presented by Clark and Augustine (Clark Jr & Augustine Jr, 1992): the workforce subsystem, the client and market subsystem, and the finance subsystem while including the prevailing significant interrelations and calibrating the model according to the special characteristics of the chosen firm in the MENA region.

To take the extra mile, I linked each cost and benefit to one of the company's subsystems. For instance, the benefit "reduction of errors" is supposed to impact the *client and market* subsystem, especially the "output quality" variable, that triggers an improved output quality and therefore higher customer satisfaction.

For an easier interpretation of the model structure, the most significant variables and their influencing costs and benefits were identified as shown in table 7.2.

Each variable was then assigned either the letter C or B or both to specify whether they are influenced by the *Costs* of investing in BIM, or they have anticipated consequences of the *Benefits*. Whilst the costs of BIM have impacts on both the finance subsystem (overhead costs) as well as the workforce subsystem (Labor cost), the benefits of BIM extensively affect the client and market subsystems (improved reputation) as seen in table 7.2.

Table 7.2: Main model variables

	Variables	C	B	Description
Workforce	Training & Expertise	x		Users' training on BIM is associated with extra costs.
			x	Training results in more skilled, and competent expertized employees.
	Accidents		x	Trained and skilled employees result in a lower number of accidents.
	Satisfaction		x	Higher skills and safer sites lead to better working conditions which increase workers' satisfaction.
	Productivity	x		BIM adoption process and training sessions will decrease productivity at time 0.
			x	BIM adoption reduces errors and RFI which reduces the time and capacity needed for corrections and thus increases productivity.
	Turnover		x	Workers' satisfaction decreases workforce turnover and recruitment costs.
	Workforce costs	x		Skilled employee requires higher salaries.
			x	Due to the improved overall performance and productivity, labor costs will decrease.
Customer & Market	Schedule		x	Reduced errors, fewer reworks, and higher skills lead to a project punctual time frame delivery and improved schedules.
	Quality		x	Reduced errors, skilled personnel lead to better-undefeated products.
	Clients		x	On-time delivery and good quality increase the client's satisfaction, which increases the clientele or the customer base.
	Projects		x	A higher customer base leads to more contracts and more incomes.
	Image		x	Improved working environment and client's satisfaction and a low number of injuries enhance the image and the reputation of the company.
	Shares		x	Larger revenues lead to more market shares and a higher market position.
Finance	Costs & Revenue	x		The investment in BIM is associated with high costs (initial and ongoing costs).
			x	BIM reduces indirect costs and thus increases revenues.
	Debt	x		The investment budget might require external funding, which leads to debt balance and results in interest payments.
	Depreciation			Software and hardware are depreciable investments.
	Returns		x	BIM increases the financial returns at the corporate level.

Building on the above, Vensim PLE software was used to create a causal loop diagram. This software is a well-recognized SD tool as it has wide feature sets and a large number of simulation models (García, 2020). As shown in figure 7.5, the causal loop diagram outlines the key system elements just as the significant benefits and costs of BIM adoption. To enhance the comprehension of the major interactions of the system variables and make them clearer, this diagram was kept as simple as possible. For this reason, I purposefully did not integrate all factors and thus do not guarantee the model to be complete.

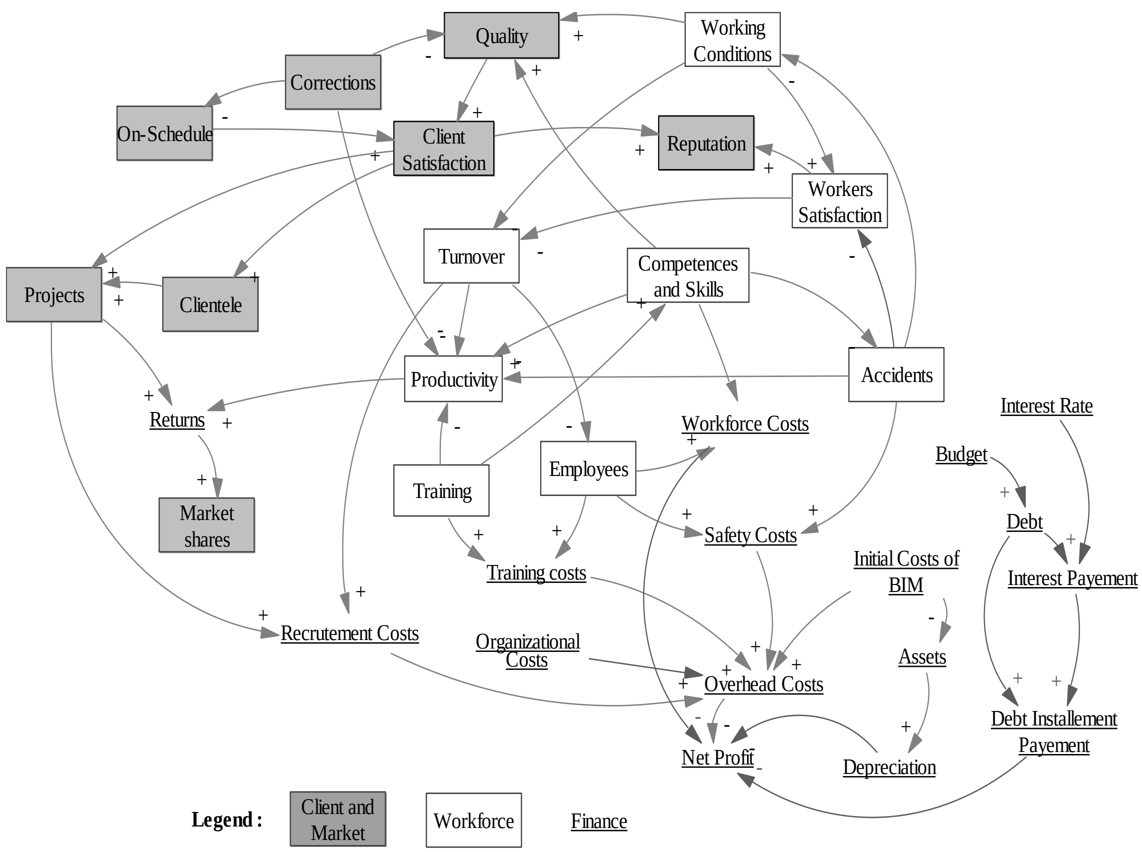


Figure 7.5: Causal loop diagram including the key variables of the simulation model.

The direction of the influence is illustrated by the arrow between the variables, a positive sign nearby the arrowhead indicates a proportional relationship between the two variables and vice versa (Eberlein & Peterson, 1992). The causal loop diagram presented in figure 7.5 shows the interrelations between the system elements within the whole system.

Within the *client and market subsystem*, the causal model assumes that a decrease in the errors and corrections leads to delivering projects on time and with a higher quality which results in higher customer satisfaction. These variables directly affect the image and the reputation of the company and lead to a higher clientele base, which results in a higher number of new contracts or received projects and a larger market share.

In the *workforce subsystem*, the causal loop shows that the number of accidents and injuries does not only affect the employee's satisfaction, but also the overall working conditions and environment. The last determines the turnover rate and affect the total productivity of the employees.

Alternatively, in the *financial subsystem,* the model shows that the initial costs of BIM that include the cost of the software, hardware, data modification, consulting, and infrastructure costs affect the assets of the company. Other costs such as the management and employees' costs or salaries affect the overhead cost in this subsystem.

The above-presented causal loop helps in understanding the interplays among the variables. I built on these feedback structures to develop a complete simulation model derived from a stock-flow diagram using Vensim software. To keep a simple model, several assumptions were taken such as considering the size of the construction sector in the MENA region to be constant in the next decade.

The majority of general settings input values (number of training hours, number of accidents, the average cost of accidents, contracts in process, and installation costs) that are necessary to simulate the status quo of the MENA firm before investing in BIM technology were identified using the internal data of the company.

When the company data are missing, the averages taken from statistics of the MENA region AEC industry (Market size) or assumptions from the previously validated models of Khaledi (Khaledi, 2012) and Nasirzadeh et al. (Nasirzadeh, Khanzadi, & Rezaie, 2014) were used to complete the model.

Besides the general setting variables, I refer to Sanchez et al model to estimate the value ranges of BIM benefits such as the training efficiency improvement rate and request for information variation rate and change order variation rate (Sanchez, Hampson, & Vaux, Delivering Value with BIM: A whole-of-life approach., 2016). For example, Sanchez et al proved that the variation rate in change orders after BIM adoption falls between 10 and 40 %, therefore we assumed this input value to be 25% in our model.

Concerning the costs input values (such as the number and cost of BIM training sessions), I used both real data and assumptions. Examples of the input values of the model parameters are presented in table 7.3.

Table 7.3:Examples of model input parameters values

Subsystem	Parameters	Input Values
& Workforce	Average accidents number	720
	Average accident cost ($)	50
	Cost of BIM training hour per person ($)	25
	Number of training hours per months per person	10
	Average engineers' salary ($)	1,500
	Error reduction rate	10%
	Assumed rework reduction rate after BIM adoption	10%
	Assumed reduction rate in VO and RFI after BIM adoption	25%
	Approximate Number employees dealing with BIM	20%
	Approximated Change rate in salaries due to the acquired BIM skills	20%
Client Market	Total Number of Projects	17
	Average Project Volume m3	30,000
	Average on schedule delivery rate	15%
	Change rate of on-schedule delivery rate	20%
Finance	Pre-BIM material costs per project ($)	700,000
	BIM Hardware cost ($)	2,000
	BIM Software cost ($)	5,000
	The interest rate on the company Debts	5%
	Chane rate of the materials cost	10%
	Change rate in contingency costs	15%

Note: the input values for the exogenous input factors (underlined) that are required for simulating the impact of the costs and benefits associated with BIM are defined based on the value range provided by Sanchez et al. (2016).

A more fiscal perspective is depicted in the third subsystem (finance), where the direct costs (e.g., Workforce, materials, and equipment), the overhead costs (e.g., recruitment costs), and the returns are aggregated at the organizational level. Other costs such as the organizational costs (e.g., cost of change management and organizational restructure) and the ongoing costs (e.g., maintenance and upgrade costs) are modeled as exogenous variables. The people-related costs are modeled based on the number of staff, managers, and employees and their average salaries. It worth mentioning that BIM benefits express themselves in the model in terms of reduction in costs and increase in revenues. Therefore, BIM benefits variables are expressed in other endogenous variables (e.g. accident costs reduction, recruitment costs reduction). Although the financial implication of investing in BIM can be summarized in the net profit as it includes the reduction of costs and the increase in the return, in addition to the assets, the depreciation and the debts of the company and the interest payments allows the comparison of the corporate economic performance before and after the adoption of BIM. The stock-flow diagram of all BIM parameters embedded in the model is shown in figure 7.6.

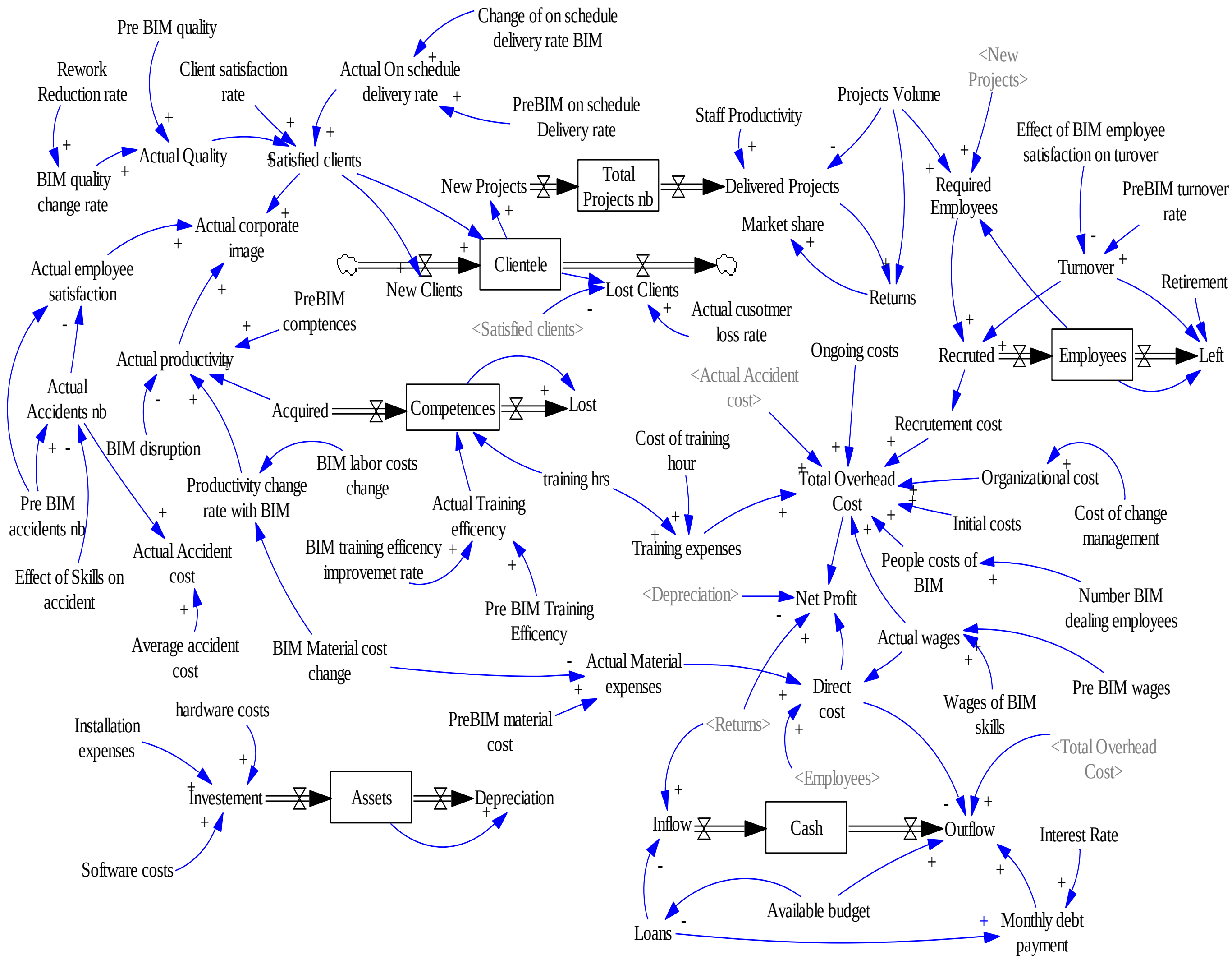


Figure 7.6: Stock flow diagram of BIM variables

7.5.1 Model Results

To test the constructed model, two different scenarios were created. The first tests the economic performance status quo of the firm and how its upcoming performance will be in the next 10 years if BIM is not implemented, and the second simulates the economic performance of the company if BIM technology is employed and show how BIM's costs and benefits interplays impact the future growth of the company. The outcomes of the simulation models derived from Vensim Plus software are presented in table 7.4.

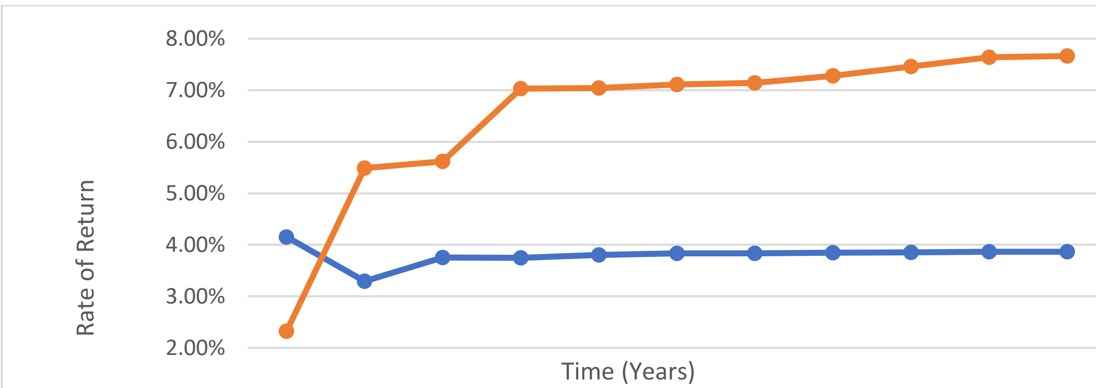
Table 7.4: Pre-BIM and Post-BIM adoption scenarios

Time	Annual Revenue in Million Dollars		Net Profit in Million Dollars	
	No -BIM	Post-BIM	No-BIM	Post-BIM
t=0	156.20	134.05	6.24	3.12
t=1	136.74	141.02	4.50	7.74
t=2	139.67	145.31	5.24	8.16
t=3	139.08	148.82	5.21	10.47
t=4	139.67	161.11	5.32	11.35
t=5	139.86	170.28	5.36	12.11
t=6	140.25	181.98	5.38	13.00
t=7	140.64	193.69	5.41	14.10
t=8	141.03	206.36	5.43	15.39
t=9	141.23	220.02	5.46	16.81
t=10	141.62	234.65	5.48	17.98

The results of the first simulation scenario indicate that the business value of the company will remain steady in the coming 10 years if BIM is not implemented. A minimal change in the rate of return (ROR) from 4.15% to 3.87% is detected with an approximated workforce of 2287 employees, annual revenue of 141.62 million dollars, and a net profit of 5.48 million dollars in t=10. The results show that no significant improvement in the business value of the company will be realized in this scenario, instead, the profits are stagnating at a low rate.

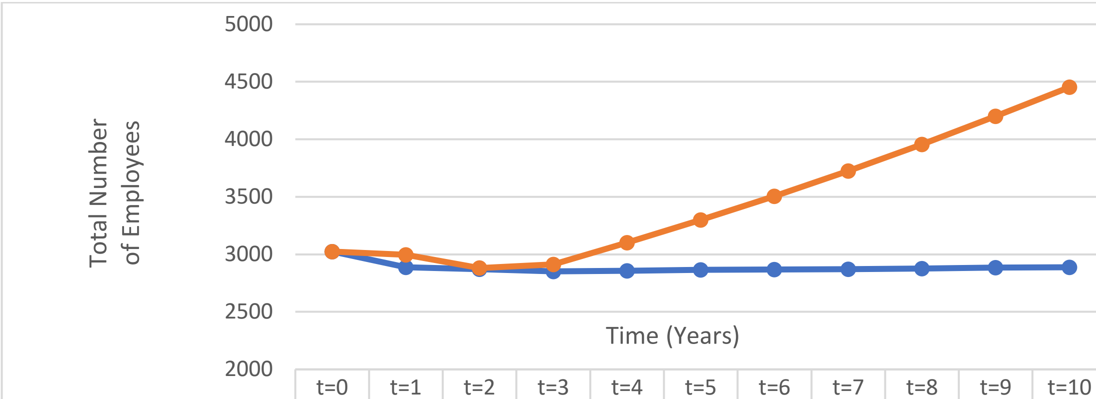
The parameters of the second scenario rely on the ones of the first scenario with an addition of the exogenous costs and benefits factors associated with BIM adoption. For example, the actual on-time delivery rate in the first scenario is the pre-BIM on-time delivery rate, however, in the second scenario, it is the change of on-time delivery rate induced by BIM adoption multiplied by the pre-BIM on-time delivery rate. The results of the second scenario indicate that at t=0, BIM negatively affects the ROR of the company that decreases to 2.32% (figure 7.7) as BIM adoption is associated with high initial expenses, ongoing costs, disruption in the tasks, lower employee productivity due to disruptions and BIM training, while the benefits of the investment manifest at later periods. The latter explains the drop in the annual revenues of the company at t=0 from 150.2 M$ to 134.05M$ as a lower number of projects might be delivered in this period. However, in the long run, the interplay of BIM costs and benefits prove to have a significant impact on the business value of the firm as the annual revenues increase to 234.65 M$, the net profit reaches 17.98 M$ (Table 7.4), the ROR scores its highest rate of 7.66 % at t=10 (Figure 7.7), and the workforce increases to 4453 staff (Figure 7.8).

The comparison of both scenarios confirms that investing in BIM will enlarge the workforce by 54% = (4453-2887/4453) *100, increase the annual revenue by 66%, triple the net profit, and double the rate of return. The simulation's results prove that investing in BIM technology is valuable, and the financial impacts of BIM are supposed to positively affect the studied construction company.



	t=0	t=1	t=2	t=3	t=4	t=5	t=6	t=7	t=8	t=9	t=10
ROR PreBIM	4.15%	3.29%	3.75%	3.75%	3.81%	3.83%	3.84%	3.85%	3.85%	3.86%	3.87%
ROR Post BIM	2.32%	5.49%	5.62%	7.03%	7.04%	7.11%	7.14%	7.28%	7.46%	7.64%	7.66%

Figure 7.7: Comparison of the rate of return for Pre-BIM and Post-BIM scenarios



	t=0	t=1	t=2	t=3	t=4	t=5	t=6	t=7	t=8	t=9	t=10
Employee PreBIM	3025	2887	2871	2852	2859	2865	2868	2871	2878	2884	2887
Employee Post BIM	3025	2996	2881	2913	3102	3300	3505	3726	3957	4200	4453

Figure 7.8: Comparison of the workforce growth for Pre-BIM and Post-BIM scenarios

7.6 Discussion of BIM Cost-Benefit Model

There is a lack of studies that investigates how BIM adoption affects the Business Value of the firm (Munir et al., 2019). Driven by the will to fill the research gap in tackling the economic implications of investing in BIM, and grounding on the socio-technical nature of BIM technology, the costs, and benefits of BIM were consolidated into a cost-benefit framework that takes into consideration the tangible and intangible benefits of BIM and the manifold impact levels. This study ~~is probably the first of its kind to~~ articulate the interactive relationship between the costs/benefits of BIM and the elements of the organizational system.

The results quantitively reveal that investing in BIM is valuable for the company. BIMs ROR analysis shows that the net profit of the company will most likely increase for companies working with BIM. This might be a result of the greater workload occurring during the earlier phases of a project designed using collaborative tools. The model confirms that BIM is paying off in higher productivity and higher rates of returns. This organizational level study shows that the investment of BIM positively and significantly affects the economic growth of the company.

The findings can be used to validate the promotion of a widespread embracement of BIM in the construction industry to improve the productivity, fragmentation, and discontinuity of the sector.

The CBA employed in this study uses new methodological approaches. Divergent from previous studies, this research relies on empirical data collected from real-life construction projects in the studied region and verified models from the literature. In addition, the use of an actual stock-flow diagram that is based on causal and feedback loops for cost-benefit analysis is a rarely used methodology that has other research applications. The stock-flow diagram is a useful graphical tool for evaluating the cost-benefit patterns of projects adopting BIM.

The study not only examines the costs/benefits of investing in BIM but also validates the argument that the interrelations between BIM benefits\costs and the elements of the corporate system can be visualized and measured more effectively using the lenses of systems theory by means of SD modeling.

The study compares two scenarios, the first for a company that is not adopting BIM and the other for a company that is adopting BIM. The simulation model confirms that BIM implementation will substantially increase the net profit of the company.

The results add to the body of knowledge as it consolidates the well-established BIM knowledge from the construction domain with the current knowledge base from the information system research domain which resulted in novel conclusions for professionals and academics in both disciplines. The approach aids in generating new outcomes for academics and industry professionals in both domains and boosts the role of the IS discipline in the engineering research field.

Also, the study is of interest for industry practitioners as it helps managers in accurately identifying the costs and benefits of BIM at the organizational level, and effectively understanding and measuring the interrelations between BIM benefits\costs and the elements of the corporate environment.

The study addresses its implications for practice in terms of five main propositions that will help managers to reach the above goals.

- BIM costs must be assessed as socio-technical system costs comprising both the social and technological related expenses and include all the organizational and human resources related costs. This joint focus is essential to reveal the hidden costs of investing in new technology.
- Concerning the benefits, they can be tangible and intangible and might occur at both the organizational and the strategic levels. Assigning these benefits into various impact levels grounding on the utility effect chains allows managers to have a comprehensive process-oriented view of the benefits.
- To evaluate an IS technology that has far-reaching organizational implications, the use of simple linear calculations for the appraisal is problematic (Hu & Shealy, 2018) because of the complexity of real-world corporate system environments. In contrast, the study confirms that system thinking can help managers in examining and understanding the causal relationships between the system elements using feedback loops.
- As the adoption of BIM is associated with considerable initial expenditures and high ongoing costs, and as BIM benefits are not reaped at the beginning of the adoption process, managers need to perform a long-term rather than a short-term assessment to capture a holistic picture of the investment implications.
- Although this study encourages project managers to use the demonstrated CBA to support their decision-making process, it is important to mention that this methodology serves as a single input factor in decision-making. The final decision has to be based on a set of factors including the legal and organizational factors (Serafeimidis & Smithson, 2003).

Like other quantitative research, this study has some limitations to be considered. Although the results reveal that investing in BIM technology has shown positive impacts on the business value of the studied company, and even though the model was developed using real data, I do not assume that the model captures the reality of the natural system with all its complexities. Additionally, I have made various assumptions to simplify the simulation model and make it readable. Therefore, future studies might replace these assumptions by real input values and re-test the model. For example, the assumption that the inflation will be zero in the future years and that the size of the market will remain constant were taken, hence, the simulation model might be improved by adding a real inflation value or calculating the real expecting market size in the next decade. The quantitative findings of this study strongly depend on the input parameters and the relationships between BIM costs and benefits. To make the results more generalizable, future studies might perform a sensitivity analysis to study the effect of the assumed input variables on the output factors of the study.

Moreover, benefits realization, one of the commonly addressed issues in IS studies, is an essential task to be achieved within the corporate context. The simulation model did not develop provisions of the decision criteria in terms of the calculated returns. Consequently, the ex-ante evaluation of BIM adoption must be followed by an ex-post perspective that offers the option of evaluating the artifact in reality.

7.7 Conclusion

Although BIM proves to be one of the most relevant technological advancements for the AEC industry as it brings a wide range of perceived benefits for the adopting company, numerous organizations are still reluctant to allocate resources for its embracing. The rationale behind this hesitation is the absence of clear financial implications for the costs associated with BIM adoption.

While there is expanding literature attempting to address the benefits of BIM, minor guidance is presented on how BIM costs and benefits can quantitatively be estimated to assess the general economic value of adopting BIM on the organizational level. Driven by the need to fill these gaps, ~~the authors~~ this research brings together the outcomes from the information system evaluation body of knowledge and the outcomes from BIM research to create a holistic BIM cost-benefit framework.

~~In t~~his study defined the main critical archetypes driving the company system performance, to explore the pattern of the company revenues and economic value over time. Three subsystems (workforce subsystem, the client and Market subsystem, and the finance subsystem) were examined in the model by coupling the costs and the benefits of investing in BIM through a System Dynamics approach. Each subsystem was examined using a high number of key variables and reached a satisfying level of complexity without losing any understanding. Based on this framework, a quantification simulation model was developed for the assessment of the financial implications of investing in BIM technology.

The study attempted to examine the interplay of BIM costs and benefits on different levels before examining the complete economic value of BIM adoption on the entire company. Likewise, viewing BIM from the lenses of the systems theory enables the introduction of an improved and more comprehensive picture of the non-linear system environment and to explains how a cost-benefit analysis might be successfully used to help in the decision-making process. This ex-ante evaluation was applied to estimate the effects of investing in BIM on company growth. Future examinations should keep on giving techniques to deal with the ex-post evaluation of BIM costs and benefits.

Finally, ~~our~~ research brought out the relevance of the System Dynamics method for representing and analyzing potential, multi-scale, and multidisciplinary models. In line with the above, future studies might assess how BIM can affect the external rather than the internal environment of the corporate system by adding a macro-environmental perspective to the model, which might help in determining the financial impacts of BIM on the whole industry. As commonly addressed in IS financial implications literature, the realization of the benefits is a key task to be achieved in the corporate context. As the process of investment appraisal does not end with the establishment of the decision criteria in terms of the calculated revenues, the ex-ante evaluation should be accompanied by an ex-post perspective.

Chapter 8

BIM Adoption Barriers in the MENA region

8.1 Introduction

The complex nature of the construction industry is mainly triggered by the multidisciplinary network of participants that compose the Architecture, Engineering, and Construction (AEC) value chain (Ahmed and Suliman 2020). This fragmented nature results in time and cost overruns, and quality problems (Babatunde et al. 2020). BIM is suggested to be the gateway to resolve these issues, as it is a tool for generating and managing building data (Alhumayn et al. 2017). BIM proved to enhance the design, collaboration, and communication among parties (Saka and Chan 2019).

The integration of BIM is on the rise due to figuring out its potentials in creating a procedural evolution in the construction industry (Chan 2014). The European Union has mandated the use of BIM in construction projects (Eadie et al. 2013). Finland, Norway, the United Kingdom (UK), and Sweden are considered the leading countries in developing and implementing BIM (Eadie et al. 2013) within Europe, where BIM is gaining wide industry awareness and adoption. BIM in the US is required in all governmental projects and the US Army Corps of Engineers have worked with BIM models since 2003 (Bosch-Sijtsema et al. 2017). In 2011, Singapore released its national BIM implementation roadmap to increase BIM usage for numerous aspects in construction (Rogers et al. 2015). In Hong Kong, BIM implementation is moving rapidly because clients have started to realize various BIM benefits (Chan, 2014). In Australia, 70% of stakeholders have been involved in BIM-related projects (Aibinu and Venkatesh 2013).

While BIM adoption rate is promising in the above countries, the overall level of BIM adoption in the construction industry varies across geographical regions and is considered to be relatively small in developing countries especially when considering the Middle East and North Africa (MENA) region (Saka and Chan 2019). The status of BIM in North Africa differs from one country to another, while BIM awareness is high in Egypt, it is facing huge challenges in Morocco and Libya (Babatunde et al. 2020). Similarly, BIM implementation in some Middle East countries namely Jordan and Lebanon is still lagging behind other countries such as Singapore and the UK (Jawad et al. 2019). Likewise, BIM implementation in Jordan is in a very primitive phase and the current experience of BIM is still low (Matarneh and Hamed 2017). However, more encouraging figures reveal in Qatar, the United Arab Emirates (UAE), and the Kingdom of Saudi Arabia (KSA) which are witnessing a rapid increase in BIM adoption, and are excepting the use of BIM to be mandated by governments shortly (Gerges et al. 2017).

When examining the global status of BIM, it can be argued that BIM adoption varies among countries and regions. According to Aibinu and Venkatesh (2013), the recognition of the adoption limitations is a prelude to its widespread embracement. Given the MENA region's unique institutional, political, and cultural contexts, the limitations to BIM adoption faced in this region need to be carefully examined (Louca and Kamsaris 2013).

In this sense, previous scholars attempted to identify these limitations and examine their significance. For example, Gerges et al. (2017) recognized a plethora of technological and social limitations that are hindering the widespread adoption of BIM in the Middle East. Jawad et al. (2019) categorized BIM barriers in the Levant as technical (i.e., technology) and non-technical (i.e., individual and organizational culture) and emphasized their impact in affecting the adoption rate of BIM. Saka and Chan (2019) concluded that the barriers to BIM adoption in Northwest Africa are mainly rooted in the social behavior of the participants involved in the construction network as well as the structural nature and the specific characteristics of the construction industry. Hamada et al. (2016) assessed BIM challenges in Iraq and confirmed a drop in the understanding of BIM from design down to operation and maintenance stage. To give a more holistic view on the subject, Umar (2021) investigated BIM adoption barriers across the Gulf Cooperation Council (GCC) including Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and UAE, and identified cost, and design-related issues as largely contributing factors to the lack of the extensive adoption of BIM.

Despite the valuable contribution of the above studies, none of them have included empirical results from developing countries across the whole MENA area. However, studying this region is important as its construction sector is set to outpace the global growth, expanding by 5.8% in 2020 to hit $225 billion, according to BMI Research.

Moreover, existing studies on BIM adoption in this region focused on specific topics in single countries such as BIM barriers for sustainable development (Saka and Chan 2019), and BIM barriers for construction safety (Enshassi and AbuHamra 2017). Other studies have examined BIM barriers in different construction processes (Jawad et al. 2019), or among companies with different sizes (Small and Medium Enterprises (SMEs) versus large companies) (El Hajj et al. 2021). Adding to the above, past research focused on investigating BIM barriers for specialists in a given profession such as quantity surveyors (Stanley and Thurnell 2014), and facility managers (Naghshbandi, 2016). Nevertheless, few of these studies paid attention to the barriers of BIM from the perspective of various stakeholders including owners, designers, and contractors and none examined the adoption phenomenon from the perspective of industry stakeholders. In light of this gap, this chapter aims to examine the significant barriers to BIM adoption among construction firms in the MENA region through a quantitative approach based on the perception of industry professionals. It is in the achievement of this purpose that three different AEC stakeholders roped in as respondents in this study comprising owners, designers, and contractors.

In addition, although previous studies contributed to the body of knowledge by examining the limitations to BIM adoption in this region (Jawad et al. 2021, Enshassi and AbuHamra 2017, and Hamada et al. 2016), none have examined the relationship between the significance of the barriers and the level of users' involvement in BIM projects. This study aimed at filling this gap and providing results regarding the significance of the barriers from the perception of two groups of practitioners (BIM users- and non-Users) according to the level of utilization of BIM tools in their projects. Adding to the above, there is a lack of systematic research on the categorization of BIM adoption barriers factors that are properly designed for easing the execution of construction projects within the MENA area (Hamada et al. 2016), therefore this study will examine the latent factors behind the adoption of BIM in developing countries of the studied region.

To sum up, the review of these previous studies related to BIM adoption barriers revealed that:

1) *No studies have been performed in identifying the barriers to BIM adoption in developing countries across the whole MENA region;*
2) *There have been limited studies focusing on the categorization of these barriers;*
3) *The existing body of knowledge has not examined BIM from the lenses of MENA construction stakeholders;*
4) *Previous studies did not inspect whether the utilization of BIM tools affects practitioners' perception of the barriers.*

In this respect, this research aims to fill the above gaps through presenting a comprehensive view of BIM adoption barriers in the MENA developing countries to explain their theoretical and practical implications through answering the below Research Questions (RQ):

- *RQ1: Do stakeholders with different roles have a different perception of BIM adoption barriers?*
- *RQ2: Do BIM users and non-BIM-users have a different perception of BIM adoption barriers?*
- *RQ3: Do construction professionals operating in different MENA countries perceive differently of BIM barriers?*
- *RQ4: What are the latent components of BIM barriers in the MENA?*

Answering these questions would enhance the richness of literature regarding BIM by attempting to quantify the impact of the various BIM adoption constraints faced by local stakeholders. Therefore, the results of the study will present practical guidelines and recommendations for improving BIM adoption and implementation in construction firms. The outcomes of the study will provide a consultative guide or tool for governmental bodies, policymakers, construction firms, and industry practitioners concerned with construction technologies.

8.2 **Theoretical Background**

BIM Adoption Barriers in the MENA Countries

Opposing the apparent advantages that BIM brings to construction projects are the challenges confronted in employing BIM. Chan (2014) confirmed that the fragmented nature of the construction industry and the reluctance to change the traditional working methods, in addition to the lack of government support are the foremost deterrent to BIM adoption. Kodaneva et al. (2019) investigated the status quo of BIM in a sum of Arabic countries and deduced that the adoption typically requires new software and necessitates upgraded hardware to operate the processing-intensive software. As the precedent is a considerable investment for some firms, BIM is seen as a source of financial difficulties. Another study in African countries shows that BIM adoption is confronting enormous encounters related to contractual issues, and personnel inadequacies (Saka and Chan 2019). The process, human and legal factors were highlighted as general challenges to BIM in the GCC region (Umar 2021).

Moreover, a set of limitations that form an interdependent circle namely: lack of awareness of BIM added value; lack of skills and expertise; cultural resistance; and contract type delivery method have also been recognized as factors that disturb the smooth adoption of BIM in Bahrain (Ahmed and Suliman 2020). The shortage of expertise in Qatar and KSA was identified as a generic barrier to the implementation of the technology (Gerges et al. 2017). Alternatively, the lack of policy initiatives to enforce BIM, and the need for re-engineering of numerous structural projects were found to be profound barriers to successful transition towards BIM in KSA (Al-Yami and Sanni-Anibire 2021). It was further identified that the lack of skilled personnel and lack of support from governments hinder BIM adoption in Iraq (Hamada et al. 2016). Issues such as the high cost of training, lack of BIM standards, and lack of BIM awareness are often cited by Jordanian construction stakeholders as the extreme barriers to BIM adoption (Matarneh and Hamed 2017). As previously approved by existing research, the efforts desired to attain the different BIM levels are considerable, also, the degree of complexity and interoperability shown to carry new technological and social challenges to the adoption process for quantity estimators in Palestine (Enshassi and AbuHamra 2017). The findings of the survey conducted by Elyamany (2016) brought to light the fact that Egyptian designers have a good understanding of BIM; nevertheless, the lack of guidance and governmental supports are slowing the adoption rate of BIM. This points out the necessity for improved arrangements between the educational sector and policymakers to equip future engineers. The studies of Amer and Binhanafi (2016) and Shibani et al. (2019) on BIM to constructors revealed that BIM adoption in Libya and Morocco is hindered by the unavailability of staff, lack of BIM training, and lack of client demand.

Table 8.1 tabularizes a summary of BIM adoption barriers found in the literature, and table 8.2 shows the gaps in previous research. It is evident from tables 8.1 and 8.2 that many previous studies have examined the barriers to BIM adoption in the construction sector, nonetheless, few have been conducted across several developing countries in the MENA region. Although other countries (apart from the MENA countries) have highlighted similar factors for not adopting BIM to those mentioned by current research in MENA countries, the factors mentioned above in section 2.1 motivate considering the MENA as a whole entity. Adding to the above factors, most construction practices within the MENA region apply comparable standards (American or British) and protocols, which stimulate the need for a complete examination of current BIM practices from various MENA countries.

For these reasons, it is expected that this study will provide a more solidified status of BIM in the MENA to support both its adoption and implementation more effectively. To the best of our knowledge, research that examines the key barriers to BIM adoption amongst construction practitioners in the MENA developing countries via a quantitative approach and that underlines the structure of BIM adoption barriers was not accomplished yet. Therefore, investigating the challenges to BIM adoption from the perception of different construction professionals in different countries across a region that has many similarities will offer a richer and more practical knowledge of BIM adoption barriers.

Table 8.1: Identified barriers to BIM adoption in the construction industry

BIM Adoption Barriers	Citations
Lack of awareness and knowledge	(Bataw et al., 2016; Alhumayn et al., 2017; Ahmed et al., 2018)
Waste of time	(Alhumayn et al., 2017; Dainty et al., 2017; Jawad et al., 2019)
Lack of project finance	(Ezeokoli et al., 2016; Ahmed et al., 2018; El Hajj et al., 2021)
Lack of collaboration and information sharing	(Bataw et al. 2016; Dainty et al. 2017)
Lack of client demand	(EL Hajj, 2021; Jawad et al., 2019)
Lack of BIM skills, qualified staff	(Siddiqui et al., 2019; Jawad et al., 2019)
Lack of Government Support	(Bataw et al., 2016; Jin et al., 2017; Chen and Lu., 2019)
Resistance to change	(He et al., 2012; Dainty et al., 2017)
Liabilities	(Alhumayn et al., 2017; Jawad et al., 2019)
Legal impact and copyright	(Alhumayn et al., 2017; Alhumayn et al., 2017; Ahmed et al., 2018)
Difficulty in intellectual property allocation	(Alhumayn et al., 2017; Jawad et al., 2019; El Hajj et al., 2021)
Lack of standards and guidelines	(Bataw et al., 2016; Jin et al., 2017; Jawad et al., 2019)
Interoperability	(Hosseini, et al., 2016; Monozam et al., 2016; Dainty et al. 2017)
Lack of training	(EL Hajj, 2021; Jin et al., 2019)
Insufficient Infrastructure	(He et al., 2012; El Hajj et al., 2021)
Lack of management support	(He et al., 2012; Babatunde et al. 2020)
Absence of contractual requirement	(Bataw et al., 2016; Monozam et al., 2016; Dainty et al. 2017)
Lack of incentive\satisfaction with old methods	(Eadie, et al., 2013; Alhumayn et al., 2017)
Lack of immediate benefits /ROI	(Liu et al., 2015; Bosch-Sijtsema et al., 2017)
Complexity of implementation	(Bataw et al., 2016; Ahmed et al., 2018)
Commercial issues and investment cost	(Dainty et al., 2017; Ahmed et al., 2018)
Lack of compatibility	(Jin et al., 2019; Babatunde et al. 2020; El Hajj et al., 2021)

Table 8.2: The Focus of BIM Barriers Studies in the MENA Region

References on MENA BIM Barriers	Country \Region	Comparison Criteria			Barriers Classification
		BIM Users and Non-Users	Stakeholders with different Roles	Cross Countries Comparison	
Amer and Binhanafi (2016)	Lybia	-	-	-	X
Elyamany (2016)	Egypt	-	-	-	X
Hamada et al. (2016)	Iraq	-	-	-	-
Matarneh and Hamed (2017)	Jordan	-	X	-	X
Enshassi and AbuHamra (2017)	Palestine	-	-	-	-
Gerges Et al. (2017)	Middle East	-	-	-	-
Saka and Chan (2019)	African Countries	-	-	X	X
Shibani et al. (2019)	Morocco	-	-	-	-
Kodaneva et al. (2019)	Few Arabic Countries	-	-	X	-
Al-Yami and Sanni-Anibire (2021).	KSA	-	-	-	-
Ahmed and Suliman (2020)	Bahrain	X	-	-	-
Umar (2021)	Gulf	-	-	X	X
This Study	MENA	X	X	X	X

8.3 Methodology

This empirical research aims to study the relative importance of the limitations facing BIM adoption in the AEC industry in the context of the MENA region. Towards this aim, the researchers focused on construction professionals in the MENA AEC industry. The total list of the selected AEC firms was obtained from the chamber of commerce that provides high-level seminars to experienced professionals in their respective countries and promotes the integration of research and practice. The study adopted the following procedure:

Literature review

An extensive literature review was performed in this study. For the literature search, Scopus was used as the search engine, to begin with. To guarantee that most of the relevant studies were enclosed, the search terms remained broad, and keywords such as ("information modeling "OR "BIM ") AND (“barriers" OR "challenges" OR "limitations") AND ("construction") were used. The comprehensive literature review of previous studies on BIM adoption barriers (He et al. 2012; Bataw et al. 2016; Hosseini et al. 2016; Monozam and Monazam 2016; Jin et al. 2017; Alhumayn et al. 2017; Ahmed and Suliman 2020; Dainty et al., 2017; Chen and Lu 2019; Jawad et al. 2019; Siddiqui et al. 2019; El Hajj 2021) among others, resulted in the identification of 22 barriers to BIM adoption in the broader setting as shown in table 8.1.

The identified BIM barriers were used to design a questionnaire, which therefore forms the basis of inquiry for the data collection and analysis in the MENA region.

Identification of Developing Countries in the MENA

Before structuring the survey, the list of developing countries in the MENA region was defined. As some countries in this region (Israel, UAE, Qatar, KSA) are more developed than the others (Lebanon, Iraq, and Syria), the classification of a developed and developing country was based on the World Economic Situation and Prospects (WESP) report published in 2016. This report was prepared by the Department of Economic and Social Affairs of the United Nations Secretariat and categorizes all countries from around the globe in one of three wider groups according to their economies: developed countries, countries in transition, and developing countries. According to the report, all the countries in the MENA region (except Israel and UAE) are developing countries. As this chapter focuses on BIM adoption in MENA countries developing countries, Israel, and UAE were excluded from the analysis.

Survey

Questionnaires, one of the most popular methods in the current management quantitative research, were used in this study because they generate data in a quantitative form which can be used for rigorous quantitative analysis (Scheuren 2004). Before sending the questionnaire, and to avoid information distortion, the instrument had been revised by two groups of specialists including three academic faculty members and four industry professionals for the content validity process and to improve the solidity and practicability of the questionnaire. Participants from both groups confirmed the relevancy of the survey items to the respondents with some suggestions for changes. In line with their feedback, the confusing expressions were modified, and the structure of some questions was adjusted. To ensure and improve the validity of the results, the survey was re-verified concerning the language and the ease of understanding the questions by Civicom which is a large and respectable marketing research firm in the Middle East. The help of an external professional research company has improved the survey validity and reliability in different levels of quality control in the data collection process.

To include records from a large number of companies, online tools were used to distribute, fill, and collect the questionnaire results. To ensure that the sample providing answers is the right one, the survey was sent only to firms listed either on the Institute of Architecture and Engineering register of the MENA countries or in the business directory under the chamber of commerce of civil and construction work, which were in total 790 firms. Therefore, a total number of 790 invitation links were sent to the HR department of the companies wishing for it to be sent to the employees to increase the number of respondents through a snowball effect. The expectation was to reach at least two respondents from each company. Thus, the total population is (2*790) = 1580.

The questionnaire survey included 11 questions which were divided into two parts. The first tackled the basic information of participants namely their affiliation, demographic features, years of experience, academic qualification, the role of the participants, and the degree of BIM involvement. The second was designed to examine the relative importance of each barrier by using a five-point Likert scale, where 5 means the barrier has a very high impact and 1 means the barrier has a very low impact.

Initially, 634 responses were collected. Through the process of data screening, some responses were excluded for being either non-targeted respondents, incomplete questionnaires, or having invalid responses. Moreover, to target experienced professionals, the results of participants having less than three years of experience were excluded. A total of 528 responses were finally collected which yielded a 95% confidence level with a confidence interval of 5%, and a response rate is (528) /1580 =33.4 %.

To ensure that the sample is appropriate for factor analysis, the authors refer to Hair et al. (2010) recommendation was followed that necessitates a sample size of at least five time s the number of variables. The ratio of this survey is 528/22=24.

Data Analysis

The Statistical Product and Service Solutions (SPSS) software version 23 was used with few other techniques presented below to analyze the collected data.

Reliability: to test the reliability of the results, Cronbach's alpha test using SPSS was used, and a reliability coefficient value of 0.866 was obtained indicating that the questionnaire (including the Likert scale) was significantly reliable as it is greater than the threshold of 0.7 mentioned by Pallant (2010).

Normalization of Criticality Assessments on Variables: this test was used to identify the critical barriers and compare them. This technique was used in several previous studies (Ma et al. 2020; Chan 2014) as the benchmark of criticality. Based on the computed Nominalization Value (NV), the critically of a variable is determined. Only factors with NV greater than 0.5 are considered critical. This assessment is used later in this chapter to identify the critical BIM adoption barriers.

Non-parametric Tests: considering various roles of stakeholders in construction projects, the different levels of involvement with BIM projects, and the different countries of operation, possible discrepancies of their assessments were compared. As the assessed values on BIM adoption barriers by all the survey participants were found to distribute non-normally, non-parametric tests, namely Mann-Whitney and Kruskal-Wallis, were used in this study to examine the data. Before performing the precedent tests, the Kolmogorov–Smirnov test was performed to discover the normality of the data distribution. The significance level of the analysis was set at 0.05 as utilized by Pallant (2010).

Kruskal-Wallis test is widely encouraged by earlier researchers when one needs to compare ranges with more than two samples with ordinal data (Pallant 2010), However, the Mann-Whitney test is used when there are two samples to be compared for their variation (Field 2005).

Additionally, the factor analysis was employed on the 22 BIM adoption barriers retrieved from the literature to reduce the number of variables and establish the underlying interactions that potentially occur between them.

8.4 Results

8.4.1 Participants and Companies Characteristics

According to the participants' answers, 65% of the participants had been engaged in a project where BIM was used in some way, and 35% were never involved in such projects. The results presented in Table 3 demonstrated the participation of various targeted divisions of construction professionals in the questionnaire. Most of the participants hold the positions of designers (44%) and contractors (38%), while few are project owners (18%). The majority of the respondents (66%) have more than five years of work experience. Moreover, only 12% of the respondents are Higher National Diploma holders, 51% are bachelor's degree holders, and 47% are master's degrees and higher holders. This shows that the participants are well educated to provide meaningful information, and have sufficient knowledge and experience, and thus one can rely on their responses.

As well figure 8.1 shows the country-based distribution of the respondents. The results show that participants operate from a sum of 16 different developing countries in the MENA region, indicating a consistent representation of the studied geographical area.

Table 8.3: Respondents' characteristics

Features	Subcategories	Respondents Percentage
Users Involvement in BIM projects	Yes	65%
	No	35%
Participant Role	Designer	44%
	Contractor	38%
	Owner	18%
Academic Qualification	Higher National Diploma	12%
	Bachelor's degree	51%
	Master's degree and Higher	37%
Average BIM Work Experience	3-5 years	34%
	6-10 years	47%
	More than 10 years	19%

Table 8.4: Ranking of BIM adoption barriers in the MENA construction industry

Barrier	Rank	Total Mean	SD	NV
Lack of knowledge and BIM awareness	1	4.64	0.618	1.000[a]
Commercial issues and investment cost	2	4.53	0.849	0.933[a]
Lack of skills, and BIM specialist	3	4.36	0.632	0.882[a]
Interoperability	4	4.33	0.608	0.877[a]
Lack of client demand	5	4.32	0.749	0.802[a]
Resistance to change	6	4.31	0.719	0.799[a]
Lack of project finance to support BIM	7	4.28	0.618	0.791[a]
Lack of training on BIM	8	4.24	0.707	0.778[a]
Complexity of the program	9	4.23	0.749	0.772[a]
Lack of collaboration	10	4.20	0.774	0.635[a]
Lack of government support and legal backing	11	4.19	0.628	0.632[a]
Legal impact and copyright	12	4.16	0.713	0.614[a]
Absence of BIM standards and guidelines	13	4.04	0.754	0.603[a]
Difficulty in assigning intellectual property	14	4.00	0.911	0.584[a]
Waste time and human resource	15	3.95	0.753	0.571[a]
Lack of management support	16	3.83	0.810	0.571[a]
Lack of immediate benefits /ROI	17	3.80	0.753	0.469
Lack of incentive \ satisfaction with old methods	18	3.78	0.906	0.411
Liabilities	19	3.62	0.771	0.411
Insufficient Infrastructure	20	3.56	0.713	0.402
Lack of software compatibility	21	3.42	0.890	0.316
Absence of BIM contract Document	22	3.35	0.894	0.000

[a] Critical Barrier

8.4.2 Ranking BIM Adoption Barriers

The normalization of criticality assessments on variables was performed on the barriers to recognizing the critical barriers. In this study, the NV of all the barriers was computed to identify critical ones. As shown in table 8.4, 16 out of 22 barriers had an NV over 0.5 and are considered critical barriers. Lack of BIM knowledge and awareness of BIM with a mean value of 4.64 positions first as the utmost critical barrier, followed by Commercial issues and investment costs associated with BIM adoption with a mean of 4.53. Lack of skills, and BIM specialist, which has a mean value of 4.36, is the third critical barriers, and Interoperability and Lack of client demand are the following most critical adoption challenges.

8.4.2.1 Users Versus Non-Users Perception to BIM Barriers

The examination of the results shows that the two groups of participants (BIM-users and non-users) rank the barriers differently as seen in table 8.5.

Table 8.5: Rankings of BIM adoption barriers among BIM-users and Non-BIM-users

	User		Non-User		Inferential Statistics	
Barrier	**Rank**	**Mean**	**Rank**	**Mean**	**Mann-Whitney Z score**	**Sig**
Commercial issues and investment cost	1	4.91	17	3.81	2.756	0.011*
Lack of knowledge and BIM awareness	2	4.60	2	4.74	-0.741	0.774
Lack of project finance to support BIM	3	4.55	18	3.80	-0.926	0.023*
Resistance to change	4	4.47	11	4.01	0.278	0.588
Lack of government support and legal	5	4.41	13	3.77	0.534	0.593*
Lack of skills, and BIM specialist	6	4.2	5	4.66	-0.925	0.671
Interoperability	7	4.12	3	4.73	-0.619	0.509
Legal impact and copyright	8	4.12	8	4.23	-1.523	0.957
Lack of training on BIM	9	4.1	7	4.5	-1.744	0.483
Difficulty in assigning intellectual property	10	4.01	10	4.02	0.902	0.456
Absence of BIM standards and guidelines	11	4.00	9	4.12	0.036	0.088
Complexity of the program	12	3.99	4	4.68	2.988	0.021*
Waste time and human resource	13	3.99	16	3.87	-0.416	0.043*
Lack of collaboration	14	3.98	6	4.6	-0.054	0.358
Lack of management support	15	3.98	22	3.54	1.407	0.522
Lack of client demand	16	3.97	1	4.98	-2.771	0.016*
Lack of immediate benefits /ROI	17	3.88	21	3.65	1.365	0.366
Lack of incentive\ satisfaction with old	18	3.79	20	3.75	-0.278	0.536
Liabilities	19	3.54	19	3.78	1.470	0.125
Insufficient Infrastructure	20	3.35	15	3.96	-0.699	0.128
Lack of software compatibility	21	3.12	13	3.98	-0.852	0.427
Absence of BIM contract Document	22	3.01	12	3.99	2.639	0.014*

Note: * Significant at $p < 0.05$

BIM users identified “commercial issues and investment cost” as the greatest challenge, with a mean score of 4.91. Another monetary barrier that was prioritized by BIM users is “lack of project finance to support BIM” which was ranked third earning a mean score of 4.77. The precedent indicates that BIM users worry the most about the financial expenses associated with BIM adoption which include hardware cost, software purchasing, licensing fees, upgrading cost, project management fees, and ongoing maintenance costs among many others (El Hajj et al. 2021; Jawad et al. 2019, Hosseini et al. 2016). This was slightly puzzling because it could be claimed that by downloading a viewer, contractors can easily start learning the visualizing proficiencies of BIM (Bosch-Sijtsema et al. 2017). Lack of BIM knowledge and awareness” was ranked second by both BIM users and non-users with a mean score of 4.88 and 4.77 respectively, highlighting the significance of this barrier for the adoption. This conforms with the results of Jawad et al. (2019) that there is a lack of knowledge related to information and commination technologies in general within the complex setting of the multidisciplinary AEC industry, highlighting the need for workshops/seminars and training to be organized by various bodies.

Concerning non-users ranking of the barriers, “lack of client demand”, “lack of BIM knowledge”, “interoperability of BIM”, and “complexity of the program” have been reported as main challenges of BIM adoption, with mean scores of 4.98, 4.77, 4.73, and 4.68 respectively. Non-users perceived these barriers as more significant encounters than “commercial issues” and “resistance to change” that were given lower ranks as seen in table 8.5. The rationale behind the apparent difference in the significance of the client demand barrier might be that users were involved in construction in which owners might designate a need for BIM adoption. However, non-BIM-users did not yet deal with owners that mandated BIM utilization.

To examine whether these differences in the ranking of the identified barriers between BIM users and non-BIM users are statistically significant, Mann–Whitney test at a significance level of 5%. was used as shown in Table 8.5 column 4. The distribution of the barrier is considered different between the two groups of participants when the p-value for the factor is less than 0.05. The results show that BIM users and non-BIM users are not equal in terms of perceiving all BIM adoption barriers. When comparing the perception of both groups, the p-value suggests that the significance of BIM barriers is considerably different across these two groups for seven out of 16 barriers. Two out of these seven barriers are related to the financial dimensions namely Commercial issues, and lack of project finance which were ranked highest by BIM users, three of them are related to the institutional governance or the structural aspects of adopting technology namely lack of government support, lack of client demand, and absence of BIM contract documents which were found to be more significant for non-users, and the remaining two barriers that show to have a statistically significant difference among the two groups are related to the technology itself namely the complexity of the program and waste of time to shift for BIM which are more significant barriers for non-users.

Overall, the results show that BIM-users carry more about the financial expenses associated with the adoption, however, non-BIM-users fear most of the lack structural incentives and the technical aspects of BIM technology.

8.4.2.2. Stakeholders Perception of BIM barriers

The survey results offered a comprehensive project perspective with the participants from the main construction players comprising designers, contractors, and owners. It is a common practice in the construction management literature to divide AEC stakeholders into these three main categories to capture a holistic view of the practitioner's perspectives (Babatunde et al. 2020, Ma et al., 2020). The results in Table 8.6 present the ranking of the 22 identified BIM adoption barriers from the perspective of three different stakeholders (designers, contractors, and owners).

Table 8.6: Ranking of BIM adoption barriers from the perspective of various construction stakeholders

		Owner			Contractor			Designer		
Barrier	KW sig	Rank	Mean	SD	Rank	Mean	SD	Rank	Mean	SD
Lack of knowledge and BIM awareness	0.184	1	4.87	0.657	1	4.87	0.844	6	4.35	0.705
Commercial issues and investment cost	0.172	2	4.81	0.741	2	4.54	0.722	4	4.42	0.701
Lack of project finance to support BIM	0.077	3	4.59	0.778	9	4.22	0.712	9	4.21	0.701
Complexity of the program	0.059	4	4.57	0.635	4	4.32	0.635	14	4	0.766
Legal impact and copyright	0.096	5	4.38	0.805	15	3.96	0.632	8	4.25	0.721
Lack of skills, and BIM specialist	0.654	6	4.35	0.895	10	4.21	0.715	2	4.49	0.612
Waste of time and human resources	0.07	7	4.28	0.657	13	4.09	0.745	19	3.69	0.762
Lack of government support and legal backing	0.369	8	4.17	0.756	11	4.21	0.609	11	4.19	0.601
Lack of client demand	0.258	9	4.12	0.699	12	4.12	0.708	1	4.58	0.603
Lack of training on BIM	0.086	10	4.05	0.789	5	4.31	0.625	7	4.28	0.775
Interoperability	0.074	11	4.01	0.778	3	4.42	0.717	5	4.39	0.612
Lack of collaboration	0.175	12	4.01	0.741	6	4.28	0.607	10	4.21	0.654
Resistance to change	0.068	13	3.99	0.757	7	4.27	0.601	3	4.45	0.756
Difficulty in assigning intellectual property	0.563	14	3.97	0.895	14	3.99	0.88	12	4.03	0.711
Lack of software compatibility	0.258	15	3.77	0.657	20	3.5	0.892	22	3.24	0.632
Absence of BIM standards and guidelines	0.074	16	3.74	0.684	8	4.25	0.61	13	4.01	0.852
Lack of incentive \ satisfaction with old methods	0.289	17	3.65	0.647	17	3.81	0.762	17	3.81	0.898
Lack of management support	0.453	18	3.62	0.681	18	3.77	0.824	15	3.94	0.88
Liabilities	0.436	19	3.59	0.858	21	3.44	0.652	18	3.79	0.712
Insufficient Infrastructure	0.143	20	3.54	0.801	19	3.67	0.632	20	3.45	0.607
Lack of immediate benefits /ROI	0.741	21	3.45	0.651	16	3.87	0.635	16	3.89	0.745
Absence of BIM contract Document	0.123	22	3.12	0.745	22	3.36	0.852	21	3.44	0.61

From the *owners' perspective*: Lack of knowledge and BIM awareness, Commercial issues and investment cost, Lack of project finance to support BIM, and complexity of the program are ranked as the highest significant barriers to BIM adoption with mean values of 4.87, 4.81, 4.59 and 4.57. From the *contractors' perspective*: Lack of knowledge and BIM awareness, Commercial issues and investment cost, Interoperability, and complexity of the program are ranked as the highest significant barriers to BIM adoption with mean values of 4.87, 4.54, 4.42, and 4.32 respectively. From the *designers' perspective*: Lack of client Demand, Lack of skills and BIM specialist, resistance to change, and Commercial issues and investment cost were ranked highest with their mean values of 4.58, 4.49, 4.45, and 4.42 respectively.

Considering the different ranking of the barriers by project stakeholders, the differences in their evaluations are compared using the Kruskal-Wallis test which ranks each barrier by the assessed values to detect possible significant disagreements in the perceptions of the three selected AEC stakeholders. Remarkably, the results shown in table 6 column 2 indicated that there is no statistically significant difference in the perceptions of the three categories of stakeholders in ranking BIM barriers at a significant level of 0.05. This signifies that all the respondents agree on the significance of the barriers.

8.4.2.3 Participants from Different Countries

The cross-country analysis was made to see if dissimilarities exist between the ranking of the barriers by participants from different countries. The examination of the results shows a regional difference between participants who consider the “lack of client demand” barrier very impactful, with more than 80% citing this challenge as being highly significant (scored more than 4 on the Likert scale) in Lebanon, Egypt, and Alegria, Jordan, Iraq, and Morocco compared with less than 41% in Saudi Arabia, Kuwait, and Qatar. Strategic issues about the understanding of BIM, and how and ownership of information would be affected also show a difference in their ranking among the countries. Participants in Qatar and Saudi Arabia express the least overall concern with these strategic issues. This group of strategic barriers presents a good opportunity for construction firms to support their members understand BIM, learn about best practices, and become comfortable getting involved

Although a regional difference in the ranking of some barriers is apparent, the Kruskal-Wallis test at a significance level of 5% was calculated to determine whether this difference is statistically significant. The results show that there is no statistically significant difference in their perceptions since their p-values are greater than 0.05.

To give a holistic understanding of the adoption barriers, the most critical BIM adoption barriers identified by this study were compared with the outcomes of scholars from four different countries\regions including South Africa, Europe, the US, and China.

Firstly, the adoption barriers that show to be very distinct in the MENA are lack of knowledge and awareness, commercial and investment issues, lack of BIM skills, and lack of client demand. Meanwhile, two barriers including lack of clearly defined BIM adoption plans and lack of financial resources are distinct for the US and Europe where BIM implementation is seen as an effort demanding financial support (Bosch-Sijtsema et al2017).

Some similar barriers arise in South African countries, where participants ranked the lack of company investment, the doubts about the directly proved financial returns of BIM, and the absence of defined financial implications as the top hinders contributing to the reluctance of the full adoption and implementation of BIM (Abubakar et al. 2014). Second, lack of skills and lack of client demand in the MENA context are rather consistent with the barriers in the Chinese, which ranked the human-related and the process and incentive related barriers such as practitioners are incapable to run BIM, lack of training and BIM consultancy, lack of government initiatives to support BIM, and absence of a contractual requirement to use BIM as the most critical limitations (Jin et al., 2017). The most common barrier across all these countries\regions is resistance to change. However, it ranks as the sixth most significant barrier in the MENA construction context with a mean value of 4.31.

8.4.3 Factor Analysis

To confirm the appropriateness of factor analysis for these data, Kaiser–Mayer–Olkin (KMO) and Bartlett's test of sphericity were conducted. As shown in Table 8.7, the KMO is 0.788, which is greater than the acceptable value of 0.6 validated by Field (2005). The above was validated by Tabachnick and Fidell (2007) that the KMO index of 0.6 is recommended as the minimum value for good factor analysis. Likewise, Bartlett's test revealed a value of 0.000 which is greater than the significance value of less than 0.05 proposed by Pallant (2010) and confirms the appropriateness of the factor analysis.

Table 8.7: KMO and Bartlett's test results

KMO and Bartlett's test Results		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.788
Bartlett's Test of Sphericity	Approx. Chi-Square	4751.004
	df	510
	Sig.	.000

To further confirm that the results are proper for factor analysis, commonalities on the identified 22 barriers were conducted. Communality describes the amount of variance in each variable that is accounted for. Communalities are beneficial in deciding which variables to keep for further analysis and in determining the adequacy of the sample size (Field 2005). As indicated in Table 8.8, all the identified BIM adoption barriers have communalities greater than 0.50 which confirms the appropriateness of the data for factor analysis. Therefore, factor analysis was performed on the data, and the factors with an eigenvalue greater than 1.0 were considered for further investigation as corroborated by Pallant (2010). The extraction method used in this study is Principal Components Analysis (PCA) with Varimax rotation to define the underlying categories of BIM adoption barriers. PCA was used in this study to examine the relations of the barriers and understand the latent factors. Amongst the statistical approaches to examine the relations between variables and to reduce the dimensionality of datasets, PCA is credited to assemble variables by the intrinsic nature of the data (Field 2005) and is a common practice in construction management that helps in constructing new variables as linear combinations of initial variables, and to represent the direction of the data that explains a maximal amount of variance (e.g., Chan 2014, Ma et al. 2021).

Table 8.8: Communalities

Extraction Method: Principal Component Analysis		
Barriers	**Initial**	**Extraction**
Lack of skills, and BIM specialist	1	0.743
Lack of knowledge and BIM awareness	1	0.802
Interoperability	1	0.811
Commercial issues and investment cost	1	0.612
Lack of client demand	1	0.681
Lack of government support and legal backing	1	0.741
Legal impact and copyright	1	0.854
Lack of training on BIM	1	0.869
Complexity of the program	1	0.785
Absence of BIM standards and guidelines	1	0.843
Difficulty in assigning intellectual property	1	0.688
Absence of Standard BIM Contract Documents	1	0.614
Lack of project finance to support BIM	1	0.674
Lack of software compatibility	1	0.765
Resistance to change	1	0.779
Lack of incentive \ satisfaction with old methods	1	0.713
Waste time and human resource	1	0.746
Lack of management support	1	0.782
Lack of collaboration	1	0.676
Liabilities	1	0.835
Lack of immediate benefits /ROI	1	0.863
Insufficient Infrastructure	1	0.777

It can be seen from Table 9 that four components were taken for additional examination as they have eigenvalues greater than 1. Table 8.10 includes the four factors with their eigenvalues, the percentage of the variance, and the cumulative percentage of the variance in each factor. The four extracted factors account for 71.159 % of the variance explanations for the real case. Tables 8.9 and 8.10 revealed the principal factor extraction with a varimax rotation performed on the 22 retrieved barriers facing the adoption of BIM in the MENA region. The result of the analysis grouped these 22 barriers into four major explainable factors with their components. The four principal factors derived are interpreted as follows:

Table 8.10: Total variance explained by different components

Component	Initial Eigenvalues			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5.144	21.711	21.711	4.074	23.361	23.361
2	3.678	18.601	40.312	3.473	19.674	43.035
3	2.539	16.761	57.073	2.546	16.112	59.147
4	1.658	8.971	66.044	2.391	12.012	71.159
5	0.944	4.569	70.613			
6	0.878	3.789	74.402			
7	0.763	4.192	78.594			
8	0.702	3.650	82.244			
9	0.611	3.593	85.837			
10	0.411	2.583	88.420			
11	0.385	2.223	90.643			
12	0.365	1.995	92.638			
13	0.296	1.681	94.319			
14	0.239	1.361	95.681			
15	0.214	0.926	96.607			
16	0.197	0.827	97.434			
17	0.134	0.686	98.120			
18	0.112	0.584	98.703			
19	0.098	0.401	99.104			
20	0.076	0.367	99.471			
21	0.057	0.330	99.801			
22	0.035	0.199	100.000			

Factor 1: “Structural” barriers, conceptually links nine hindering factors related to the increasing demand of 3D modeling to have levels of support and to the incentives to use these 3D models and explains 23.361% of the variance.

Factor 2: “Human Resources” barriers, links five BIM adoption barriers and are together related to the skills and knowledge, and attitude of personnel towards BIM adoption. This factor explains 19.674 % of the variance.

Factor 3: “Technological” barriers, links five barriers that are related to developing complex vendor-orientated solutions and explain 16.112% of the variance.

Factor 4: “Financial” barriers, links three barriers related to the cost of acquiring the technology whether the implementation costs, the training expenses, or even the doubts of BIM financial returns and explains 12.012% of the variance.

The below discussion will build on established theories from the literature to explain the results of the factor analysis.

Table 8.9: Rotated component matrix

BIM Adoption Barriers	Structural	Human	Technological	Financial
Lack of awareness and knowledge	.861			
Lack of client demand	.822			
Lack of standards and guidelines	.721			
Absence of contractual requirement	.702			
Lack of Government Support	-.693			
Legal impact and copyright	.671			
Difficulty in intellectual property	-.633			
Liabilities	.602			
Lack of Incentives, and satisfaction with	.597			
Lack of BIM skills, qualified staff		.821		
Resistance to change		.814		
Lack of management support		-.807		
Lack of training		-.783		
Lack of collaboration and information		.666		
Interoperability			.874	
Complexity of implementation			.855	
Waste of time			.799	
Insufficient Infrastructure			.763	
Lack of compatibility			.692	
Commercial issues and investment cost				.811
Lack of project finance				.789
Lack of immediate benefits /ROI				.611

8.5 Discussion

Due to the differences in the characteristics of the studied regions and professional backgrounds, the results that emerged from this research study are to some extent different than preceding findings that have examined BIM barriers among construction organizations in developed countries, which reported that the data security matters such as liability and difficulty in assigning intellectual properties are the most significant limitation to BIM adoption (Eadie et al. 2013; Monozam and Monazam 2016, Hosseini et al. 2016). In comparison, participants' responses in this study reveal that they are struggling with deploying BIM and integrating its tools into the organizational workflow as they have ranked the Lack of knowledge and BIM, awareness “Lack of project finance to support BIM”, Lack of skills, and BIM specialist as the most significant barrier to adoption, indicating that users carry the most about the financial and knowledge concerns related to BIM adoption and that issues that are more often perceived at a network-based adoption level such as cybersecurity are less important according to the participants.

Moreover, when the questionnaire outcomes were scrutinized and the user and non-user groups were distinctly analyzed, a more complex image emerged concerning the perceived barriers and included details such as the significant differences between the barriers. BIM users perceived the financial barriers as the biggest obstacles; however, these problems were not perceived as robust and significant by non-BIM users who instead perceived the structural barriers and technological barriers as the biggest obstacles. This confirms the results of Bosch-Sijtsema et al. (2017) that the more participants are involved in BIM projects, the less they fear the technological barriers associated with BIM adoption.

However, the results oppose Babatunde et al. (2020) findings that stakeholders with different roles perceive differently to BIM barriers, as MENA participants' results showed that there is no statistically significant difference in the perceptions of the three nominated construction stakeholders on the ranking of the barriers. This designates a strong agreement among the groups of respondents on the ranking of the barriers. This could be explained by the fact that all participants have a good experience and are all familiar with the MENA construction environment.

Concerning the PCA results, the implementation of BIM shows to be not only hindered by the technical aspects of the technology but also confronted by the human, structural and financial dimensions. The below discussion will base on theoretical background and well-established theories from both the information system and engineering domains to explain why all the barriers were found significant in the MENA region and examine the four retrieved barriers' groups.

Structural barriers: This group of barriers explains the highest percentage of the variance. The questionnaire results (table 4) and the PCA results (table 9) position lack of BIM knowledge and awareness as the foremost limitations to its widespread adoption in the MENA region. To understand the mechanism behind the intention of MENA firms to decisively adopt a complex technology, the *push-pull theory* presented by Zmud in 1984 might be of value as it informs that companies ought to adopt a new system if they have enough knowledge about it, or if they have the needed skills to adopt the technology (Zmud 1984). As BIM is not introduced deeply in most MENA universities (Jin et al. 2017), and MENA engineering graduates do not have a sufficient understanding of BIM concepts, one can understand the high perception of practitioners to the significance of the lack of awareness barrier.

The results also show that MENA practitioners feel the lack of BIM needs in their projects. This supports the results of Gerges et al. (2017) that there is an apparent interrelationship among BIM barriers namely lack demand, lack of BIM knowledge and awareness, lack of necessity, satisfaction with the traditional working methods, and lack of government support. These barriers together are affecting the non-widespread adoption of BIM in the MENA region (Gerges et al. 2017) and are giving practitioners the impression of lack of BIM necessity. To understand MENA practitioners' viewpoint towards these structural barriers, we will base the explanation on the *push-pull theory.* The precedent explains that the adoption of new technology is encouraged by the organization's pressure to change due to either the firm's needs or performance gaps. As most companies in the developing MENA region are not surrounded by competitors who have full adoption of BIM, decision-makers feel the lack of an urgent need for the shift towards the new technology with all its complexities.

Adding to the above, the high percentage of SMEs within the studied region and their resource constraints impede BIM adoption. It is important to mention that according to published studies, the percent of construction firms that are categorized as small and medium businesses in the Middle East is 97.6% (Gerges et al. 2017), and laggards in terms of BIM adoption (El Hajj et al. 2021). Therefore, despite the existing competitive pressure in the studied region, construction firms in these developing countries continue to have a wait-and-see attitude and focus on the short-term gains rather than on the long-term benefits of BIM. Moreover, grounding on the *theory of network effects,* the availability of any good or service is dependent on the client's demand to adopt it. Therefore, the handiness of BIM software expands when the adoption rate increases. As the number of suppliers providing BIM software in the MENA region is low (Ahmed and Suliman, 2020), and as most governments in the studied region have not taken any initiatives to mandate BIM adoption, the results of the study are not surprising.

Having a look at the standards and initiatives imposed by different MENA governments to foster BIM adoption, we can conclude that governments are negligent in promoting regulations and standards to enhance the shift towards the new system. None of the MENA developing country's (which exclude Israel and UAE) governments did mandate the use of BIM. Also, none of the countries have a national BIM standard put in place to abide by, thus, firms tend to follow ad hoc standards. Some UK BIM standards became a guide for practice in Oman and Kuwait, due to the absence of their national BIM standards. BIM in Qatar has not yet been requested as an obligation; however, its implementation has increased during the last years especially in stadium projects for FIFA 2022 (Prabhakarans et al. 2021). Other MENA countries such as Lebanon, Syria, and Jordan are having much poorer government initiations to support BIM (Jawad et al., 2019). In North Africa, governments have taken no position on driving BIM practices, and consequently, there is no single African government that has mandated BIM standards. As Well, no trade or professional associations have stepped into this gap to standardize local BIM practice, which implies that companies grapple with implementation in isolation. Most MENA governments did not provide guidelines and regulations to solve legal and contractual issues of BIM and did not even provide motivations and incentives for the diffusion of BIM in the region.

Additionally, the results show that MENA practitioners are worried about the legal aspects of BIM, its copyright, difficulties in assigning intellectual properties, and distributing the liabilities among practitioners which have gained high significance in the region. The open-access to the model in terms of allowing different parties to make contributions raises the problem of ownership issues and intellectual property rights (Yan and Demian 2008). As existing guidelines are not enough to meet the legal requirements. MENA governments are encouraged to develop initiatives and standards to foster BIM adoption.

Human resources barriers

The results imply that a shortage of qualified BIM specialists is present in the studied area and is predominantly hampering BIM adoption. Thong (1999) employed the *Knowledge* *barrier theory* in their SMEs assessment study and confirmed that the lack of skills and expertise is caused by the tendency of small firms to employ generalists and not specialists which make the above results reasonable and positions the lack of skills as the most significant barrier to BIM adoption in the MENA region.

To explain the high resistance of MENA practitioners towards BIM, the *organization culture theory* was used. The theory proposes that the deviations caused by the shift toward an information technology affect the normal distribution of power in the organization and increase the uncertainty toward the integrated system and that practitioner's resistance is affected by the coherence between the actual and the presumed distribution of power within the firm (Pliskin et al. 1993). Examining the results of our empirical study, the findings demonstrate the high significance of resistance in the MENA region which is categorized as a lagging region in terms of BIM adoption (El hajj et al. 2021), and explains that late majorities and laggards will adopt technology only when they are certain that the new concept will not fail.

Besides, the study of Prabhakarans et al. (2021) confirms that the lack of management support increases users' resistance to adopt the technology because the way managers involve workforces in the new system affects their attitude toward it. The precedent confirms the high interdependencies between the two barriers. Grounding on the *organizational influencing theory* the use of upward influencing processes such as intermediaries with formal authority (which are absent in the studied region) might be helpful to increase top management commitment to the new technology and encourage managers to develop a strategic vision around BIM. The results are consistent with the study of Gerges et al. (2017) that managers in this region are not promoting BIM cost-benefit analyses that help MENA practitioners to feel the importance of investing in BIM.

It is the vicious cycle of lack of skills, lack of management support, and delay in the adoption that is accountable for this high resistance to BIM in the MENA region. Therefore, firms should take the correct actions to deliberately change their norms to a degree that might evade resistance and bolster innovation (Alhumayn et al., 2017). This incorporates the development of an organizational culture that fosters continuous development, tolerates risks, and provides a substantial degree of collaboration between parties (Alhumayn et al. 2017).

Moreover, the results show that in the human resource group of barriers, the lack of training is an imperative barrier. This is consistent with the conclusions of Hosseini et al. (2016) that construction companies tend to train practitioners on BIM without educating them on its processes, and that most BIM experts are self-trained. The deficiency of BIM specialists is being a concern for the industry calling for urgently training people on BIM as a prerequisite for its expansion.

The technology barriers

The complexity and incompatibility of BIM were found to be significant in the studied region. Referring to the *technology acceptance model*, the ease of use and the usefulness of technology affect its adoption. The results prove the criticality of these factors and show that the lack of technological infrastructure is a valuable barrier to BIM adoption. The above might be justified based on the *geography of the innovation model* arguing that innovation's capabilities depend on the technological infrastructures of the geographical region it is implemented in, as the infrastructures can provide input resources like knowledge, and technical inputs (Feldman and Florida 1994). The precedents were validated by the results of Chan (2014) that innovations such as BIM tend to emerge in regions having developed technical infrastructures which reveal the need for an environment that encourages experimentation and exploration of the technology.

Adding to the above, interoperability was highly ranked by MENA users, since it concerns communication and collaboration. It is hard to compatible BIM with other programs and easily exchange its data via a common set of exchange formats. To solve this problem BIM suppliers should enable direct export and import of structural software model information to enable further research in the interoperability issues.

The financial barriers

The results of this study do not conform with previous studies, since according to the survey of Monozam and Monazam (2016) in Australia, the cost is not directly related to BIM adoption, while in this study, the costs associated with BIM adoption were found to be key limitations. The difference between the factors that have a direct impact on BIM adoption between the studied developing region and Australia might be attributed to the fact that there are differences in culture and market influence between the two regions. To explain the rationale behind the significance of all the financial barriers in the studied region, the *Resource-Based View* and the *Framework of Resource Constraints* that pose the availability of resources as a key factor for firms to achieve competitive advantages were used (Wernerfelt, 1984). As mentioned earlier, most AEC companies in the studied area are SMEs that are typified by constrained assets in developing countries.

The results also highlight that MENA practitioners are not convinced by the benefits of BIM. The rationale behind this is that BIM benefits are revealed in the long run while the costs of the investment show in the short term. The precedent increases practitioners' doubt of the positive paybacks and directs them to consider the investment as an additional risk on the project. Most MENA users are not performing important evaluations such as Net present value, rate of return, and cost-benefit analysis among others to assess the business value and the financial implications of investing in BIM (El Hajj et al. 2021).

To end, studies on the limitations facing BIM adoption in the AEC industry are becoming common in the last years, raising the flag for the urgent need for effective solutions in the MENA region.

8.6 Conclusion

As BIM adoption in the MENA is at an early stage (El Hajj 2021), it will be problematic and risky for construction firms to adopt BIM without recognizing what challenges it could bring to companies. With the global increasing adoption rate of BIM and the increasing market competition, it is essential for construction firms in the MENA region to examine the barriers related to this region to be able to implement the appropriate overcoming strategies. While there are to date many scholars exploring BIM adoption factors in MENA countries, no empirical study has been conducted across all developing countries in this region that examines the perception of various stakeholders towards the adoption barriers. Therefore, identifying the barriers that might face these organizations holds the key to closing the gap for future BIM development, and guaranteeing its effective application in the MENA.

This study provided an empirical investigation of the barriers to BIM adoption in the MENA construction context. Three different MENA AEC project actors including architects, contractors, and owners of which some are BIM-users and others are not, were involved in the study to rank the significance of BIM adoption barriers according to their perspectives. The analysis of the results confirms the criticality of 16 out of 22 barriers in the MENA context. The most imperative barriers are namely Lack of knowledge and BIM awareness, Commercial issues and investment cost, lack of skills, and BIM specialist, Interoperability, and Lack of client demand.

No statistical significance was found between the project players in ranking BIM adoption barriers, neither between participants from various countries. However, a statistical difference was found between the ranking of the barriers among BIM users, who focused on Commercial issues and investment cost to ease BIM adoption, and non-BIM users, who highlighted the need for demand and support and other structural-related issues as the main factors to be solved before the adoption.

Furthermore, the examination of the PCA that accommodates the barriers found four underlying BIM limitation factors namely: human, technological, structural, and financial.

The hindering factors presented in this study can be perceived as the basepoint or reference list when searching for BIM challenges. Moreover, the research educates about the required concerted efforts from various practitioners, scholars, governments, and industry groups to guarantee the successful adoption of the technology. Finally, this study contributes to serving organizations who are considering the implementation of BIM, by presenting a set of recommendations that might help when making decisions about BIM adoption.

Implications:

The study provides new information and understanding of a topic by filling the knowledge gaps which is a substantial contribution to knowledge. Therefore, the study enlarges the effort of assessing barriers across various countries and offers insights on the holistic understanding of the impediments that hinder the adoption of BIM within the MENA AEC environment, a region previously under-researched, and recognized as having BIM at the early stage of adoption.

Adding to the above, this study has several practical implications. First, the study shows that there is no federal mandate for BIM use at any level in public sector projects in all developing MENA countries, which generally reflects the actual cases of developing countries around the globe. Therefore, government support is a must to increase BIM adoption. Toward this, I urge massive awareness of BIM by professional players, government bodies, and policymakers. Likewise, suitable administrative policies and regulations that back the adoption of BIM ought to be put in place. Governmental bodies mainly in developing countries should release a plan to mandate the use of BIM and collaborative procurement methods on all publicly funded projects. Moreover, governments should deliver sufficient funds for training and procurement of BIM package (hardware costs software costs, upgrades cost, installation, and infrastructure costs).

Moreover, governments and academic establishments in the MENA might consider the following measures to boost the adoption of BIM technology: 1) as in other regions, MENA governments can implement pilot projects intended to gain pertinent knowledge and experiences by conducting seminars that provide guidelines for the implementation. 2) Practices of establishing BIM regional hubs such as those applied in the UK can be employed by MENA authorities. This might turn into links within the countries and act as a channel of information exchange and serve as a useful source of knowledge to respond to on development BIM teams. 3) Creating scientific research inducements and incorporating the academic community with the industry professionals can increase the rate of BIM adoption in the studied region.

Second, as the adoption of BIM requires a systematic effort, decision-makers should refer to these barriers and understand their root causes to ease the adoption. As the prioritization of critical barriers provides a reference list for project practices, future studies can be dedicated to tackling related strategies to reduce these barriers. Third, the study points out the lack of professionals who has BIM skills and experience in the studied region, therefore MENA academic curriculum should be designed to include more component of BIM.

Besides, as BIM users and non-BIM users had noticeably different insights of some BIM barriers, i.e. users are concerned with the benefits reaped from BIM adoption, while non-users are focusing on the absent environmental pressure, future research might examine the root causes for the differences in the perceptions of these professionals.

The results of this study will make available information to construction professionals and policymakers to develop strategic suggestions that constructively impact the widespread adoption of BIM adoptions in the construction sector, Consequently, examining the relevancy of this study necessitates the employment of statistical tools namely partial least squares.

Finally, the full integration of BIM will help the construction sector to eradicate inefficiencies in the processes and open opportunities for assimilation with other emerging technologies. Therefore, another promising road for future research is to deeply investigate technologies that can be integrated with BIM in the construction sector. Moreover, future research can compare BIM adoption barriers with the adoption of other innovative construction solutions namely Lean, and Agile to comment on common approaches, as the aforementioned concepts have a common goal of reducing construction costs and wastes and increasing the efficiency of the construction process.

Chapter 9

Conclusiones

La presente tesis doctoral se ha centrado en la análisis de la adopción del BIM y específicamente en la región de Oriente Medio. Para ello se han examinado con detalle y rigor científico los beneficios de la adopción de BIM, las funcionalidades de BIM, así como las barreras a la adopción y las implicaciones financieras de la adopción del BIM por las empresas del sector. El enfoque principal de la presente investigación se realiza desde la óptica de la teoría sociotécnica, que considera el BIM como un sistema de elementos interrelacionados (personas, estructura, tareas y tecnología).

Una de las principales conclusiones de la tesis es que la dimensión de impacto de las barreras de adopción del BIM no siempre es igual a su dimensión de causa. En lo que respecta a las causas, se observa una considerable tendencia hacia las barreras sociales del BIM. En otras palabras, la mayoría de las barreras de adopción de BIM tienen su origen en el comportamiento social de los interesados y no en los aspectos técnicos de BIM. Además, esta tesis revela un alto grado de similitud en las barreras de las dimensiones de personas y tareas entre varios conceptos innovadores (BIM, Lean, IPD, Six Sigma).

Ha sido posible demostrar que el modelo mixto tiene el mayor poder explicativo de los patrones de difusión de las funcionalidades BIM.

Otra importante conclusión es que aunque tanto los factores internos como los factores externos se suman a la descripción del modelo mixto de los datos, la influencia del comportamiento imitativo supera a los factores externos en la difusión de las funcionalidades BIM.

En cuanto a la implicación exconómica y financiera de la implantación del BIM, la tesis concluye que la inversión en BIM es rentable para la empresa con vocación de permanencia en el mercado (medio y largo plazo). Además, la investigación confirma que el valor empresarial de BIM depende de la perspectiva del usuario, así como de las fases en las que se utiliza BIM. Por lo tanto, el pensamiento sistémico mediante BIM ayuda a los participantes a reconocer las relaciones causales entre los elementos del sistema completo. Los resultados confirman la interrelación directa entre los costes y los beneficios de BIM y su efecto directo en el valor empresarial de la metodología BIM.

La tesis completa así algunas carencias en cuanto a estudios específicos de la implantación del BIM se refiere. La investigación fusiona la base de conocimientos del ámbito de los sistemas de información con el desarrollo dinámico del BIM. El Análisis Coste Beneficio propuesto se considera el primer paso para evaluar las complejas implicaciones financieras que se derivan de la adopción de la tecnología BIM en el contexto de la construcción, por lo que proporcionará a los usuarios una mejor comprensión de las repercusiones financieras de la inversión en BIM en el complejo entorno del sistema empresarial.

Dado que el éxito de la adopción global de BIM requiere los esfuerzos concertados de varios participantes (contratistas, proyectistas, consultores, proveedores y organismos gubernamentales), esta tesis proporciona a los investigadores y a los profesionales del sector un conjunto de proposiciones que pueden tenerse en cuenta a la hora de tomar decisiones para la adopción de BIM.

Estas propuestas deberían servir de ayuda para comprender mejor los obstáculos a la adopción antes de desarrollar estrategias de respuesta. Esta tesis contribuye a servir a las organizaciones que están considerando la implementación de BIM, mediante la presentación de un conjunto de recomendaciones que podrían ayudar a la hora de tomar decisiones sobre la adopción de BIM.

Conclusions

The current Ph.D. thesis focused on the adoption of building information modeling, an intelligent 3D model-based process that gives construction stakeholders the insight to design, construct, and manage buildings more effectively. The thesis was achieved through the study of the Middle East region. It examines with detail the benefits of BIM adoption, the functionalities of BIM, as well as the barriers to the adoption, and the financial implications of BIM. This thesis mainly examines BIM from the lens of the socio-technical theory which considers BIM as a system of interrelated elements (people, structure, tasks, and technology).

The thesis reports that the impact dimension of BIM adoption barriers is not always equal to its cause dimension. A considerable leaning towards the social barriers of BIM is evident when regarding their causes. In other words, most BIM adoption barriers are rooted in the social behavior of the stakeholders not in the technical aspects of BIM. Moreover, this thesis reveals a high degree of resemblance in the people and task dimensions barriers between various innovative concepts (BIM, Lean, IPD, Six Sigma).

The thesis states that the mixed model has the highest explanatory power in explaining the patterns of BIM functionalities diffusion, moreover, the results demonstrate that although both the internal factors and the external factors add to the mixed model description of the data, the influence of the imitative behavior outperforms the external factors in the diffusion of BIM functionalities.

Concerning the financial implication of BIM, the thesis reports that BIM investment is worthwhile for the construction company. Revenues and workforce are expected to triple when BIM is adopted in the long run. Moreover, the thesis confirms that the business value of BIM depends on the user's perspective as well as the stages in which BIM is used. Therefore, system thinking using system modeling aids participants to recognize causal relationships between elements of the whole system. The results confirm the direct interrelation between BIM costs and benefits and their direct effect on the business value of BIM.

The thesis responds to the gaps in the literature and aims to merge the knowledge base from the IS domain with the dynamic development of the BIM subject. The proposed CBA framework is considered as the first step for evaluating the complex financial implications arising from the adoption of BIM technology in the construction context and thus will provide users with an improved understanding of the financial impacts of investing in BIM on the complex corporate system environment.

As the global successful adoption of BIM requires concerted efforts from several participants (contractors, designers, consultants, suppliers, and governmental bodies), this thesis provides researchers and industry practitioners with a set of propositions that can be taken into account when making decisions towards BIM adoption. These propositions should serve as an aid for gaining an enhanced understanding of the adoption barriers before developing coping strategies. This thesis contributes to serving organizations who are considering the implementation of BIM, by presenting a set of recommendations that might help when making decisions about BIM adoption.

Part IV:

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Part V:

PUBLICATIONS

Publication 1:

Journal Articles

Hajj, C., Jawad, D., Montes, G.M., 2021, Analysis of a Construction Innovative Solution from the Perspective of an Information System Theory. *Journal of Construction Engineering and Management*, 10.1061/(ASCE)CO.1943-7862.0002120.

Publication 2:

Hajj, C. E., Montes, G. M & Jawad, D. (2021). An Overview of BIM Adoption Barriers in the Middle East and North Africa Developing Countries. *Engineering, Construction and Architectural Management*, , (IF: 2.16, H-index : 58).

Publication 3:

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Conference Papers

Jawad, D., **Hajj, C**. "The Penetration and Impact of BIM Implementation in the Construction Industry in Lebanon," *in 34th IBIMA conference*, Madrid, 2019.

C.Hajj, D.Jawad, J. Mattar " Status of BIM in the Construction Industry: A pilot Study in Lebanon", in *34th IBIMA conference*, Madrid, 2019.