QATAR UNIVERSITY

COLLEGE OF ENGINEERING

INTEGRATING LEAN CONSTRUCTION AND BIM FOR FACILITIES MANAGEMENT: A PARADIGM FOR PERPETUATING LEAN BENEFITS IN THE QATAR CONSTRUCTION INDUSTRY

BY

MINA SHOKROLLAH DANSHVAR

A Thesis Submitted to

the College of Engineering

in Partial Fulfillment of the Requirements for the Degree of

Master of Science

January 2021

COMMITTEE PAGE

The members of the Committee approve the Thesis of
Mina Shokrollah Daneshvar defended on 26-11-2020

Dr. Farayi Musharavati
Thesis/Dissertation Supervisor

Dr. Khalid Kamal A A Naji
Committee Member

Dr. Murat Kucukvar
Committee Member

Dr. Murat Gunduz
Committee Member

Dr. Onur Behzat Tokdemir
Committee Member

Approved:

Khalid Kamal Naji, Dean, College of Engineering

ABSTRACT

DANESHVAR, MINA, S,. Masters, Masters of Science in Engineering Management: January: 2021, Masters of Science in Engineering Management.

Title: Integrating Lean Construction and BIM for Facilities Management: A Paradigm for Perpetuating Lean Benefits in the Qatar Construction Industry.

Supervisor of Thesis: Dr. Khalid, Naji and Dr. Farayi, Musharavati.

This study aimed to develop a conceptual framework for effective Facilities Management (FM) in developing countries through exploring the benefits, barriers and success factors associated with the synergy between Lean Construction (LC) and Building Information Modeling (BIM). This was accomplished by using a mixed method approach comprising literature reviews, surveys, interviews (structured and semi-structured) and framework development. The Qatari construction industry was used as an illustrative case study. Key findings of this research show that Facilities Management can be improved by capitalizing on the synergy between Lean Construction and BIM. In addition, the wide-ranging responses from the majority of participants in the construction industry in Qatar revealed that integration of Lean Construction, BIM, and Facilities Management requires a collaborative effort among construction companies that will hinge on success factors such as: sharing of training for employee development, continuous improvement, and leadership. This integration was also found to face challenges that include: culture and language barriers; high implementation costs; inadequate organizational infrastructure; and less trained, skilled, and educated staff. Based on extensive literature reviews, survey responses, and input from the synergy between Lean Construction and BIM, a 4-level strategic conceptual framework for Facilities Management was designed in the form of interactive matrices between; Lean Construction and BIM, Lean Construction and

Facilities Management, BIM and Facilities Management, and BIM, Lean Construction, and Facilities Management, and an implemental level framework was designed between BIM functions and Operations and Maintenance principles. The framework was validated through a mix of structured and semi-structured interviews, which led to the identification of important themes and development of a generic model for the proposed conceptual framework. Overall, the study showed that BIM and Lean Construction principles can be integrated to fulfill the desired targets of an effective Facilities Management framework. Implementation of such a framework is expected to provide a new perspective on Facilities Management that perpetuates lean benefits throughout the life cycle of a constructed facility. This is expected to maximize value in the built environment to the satisfaction of facility owners, users, and customers.

DEDICATION

Dedicated to my parents and teacher,

whose support and prayers helped me in

accomplishing this research study.

ACKNOWLEDGEMENTS

This has been a very challenging and a fulfilling journey at the same time. It is crucial that I mention and thank those who made this journey more joyful despite the challenges and restrictions that have been imposed as a result of the Coronavirus pandemic.

Firstly, I would like to express my sincere thanks to my supervisor for his patience, support and advice throughout this journey. I have learnt so much from my supervisor who was always happy to help and guide. Providing feedback on my drafts and showing me different ways of doing things was very helpful for me to be able to complete this research. I am forever grateful for his support and assistance.

Secondly, my family and friends were also a source of joy, motivation and encouragement. Their kind words and continuous belief in my ability gave me the strength and power to continue my studies. It was their motivation that helped me to overcome any challenges that I encountered through this journey.

Finally, I should thank all the staff at the University of Qatar and at the College of Engineering for being always ready to help and support students. I should also thank all the participants in the data collection stage and for the friends and contacts who helped me arrange and facilitate the process of data collection in these challenging circumstances.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter One – Research Overview

Introduction

Globally, the construction industry has experienced an exponential growth. This is even more evident in rapidly developing countries like Qatar, in which massive constructions are underway to meet new construction needs for FIFA World Cup 2022. Under such circumstances, it is important to ensure quality and continuous improvement in all construction projects. This will ensure that the constructed facilities are of high quality and the resulting built environment will provide satisfaction to the owners, users and customers. Since most of the massive constructions in Qatar are for public use, the National Public Works Authority, Ashghal, is heavily involved in the construction and management of these facilities from design to end of life. Consequently, the public works authority in Qatar has expressed the need for all contractors to implement lean construction principles. To this end, the construction industry in Qatar has embraced lean and a Lean Construction Institute chapter in Qatar has been established. However, the depth of lean implementations across the construction industry in Qatar has not been evaluated. Therefore, various companies and contractors are at different levels of applying lean starting with lean awareness, lean preparedness, actual lean implementations, and lean maturity.

While the construction industry in Qatar has recently embraced lean, construction industries in other parts of the world have been implementing lean with benefits. In addition, most construction industries around the world have been effectively using the Building Information Modelling (BIM) tool. Like most developing countries, the construction industry in Qatar has taken time to fully deploy BIM in construction management. Some construction industries are using the Building Information Modelling (BIM) tool to enhance and deploy information in their construction projects. However, research has shown that some of the functions of BIM can be applied in Lean Construction deployment with benefits. For example, BIM can capture data that can be made available for integrated lean implementations and decision making through data visualization techniques. Hence, the advantages of integrating BIM and Lean Construction can never be overemphasized. Albeit, some parts of the world and some construction companies are yet to embrace the benefits of integrating Lean Construction and BIM.

While the integration of BIM and Lean Construction has proved to be very useful in construction management, the impact of this integration on facilities management is not well known and has not been thoroughly explored, particularly in developing countries like Qatar. Currently, most facility managers regard BIM as a mere modelling tool, thus foregoing the capabilities of BIM in data visualization in addition to the potential benefits associated with capturing, integrating, and deploying lean construction information. In this regard, the use of BIM in construction management can be tailored to produce high quality information that may be essential for more effective and more efficient facilities management.

In the integration of Lean Construction and BIM, BIM can be used to capture important construction information generated during the construction phase. Although lean principles can be applied directly to facilities management (as in lean facilities management), it is crucial to investigate how information captured in BIM during the design and construction phase can be used to inform facilities management. For example, appropriate operational and maintenance methods that reduces operating and maintenance costs can be derived and verified at the design and construction stages and the resulting information captured in BIM. In addition, the information and data captured in BIM can also be used later in facilities management to simulate and optimize various scenarios of operating and maintaining the lean constructed facility. Hence, it is worthwhile and necessary to investigate how the integration of Lean Construction and BIM can be developed to support the management of constructed facilities throughout their life cycle.

While the transition from construction management to facilities management can be enhanced by data and information captured through BIM during the design and construction phases, the usefulness of BIM in facilities management has been relatively less researched. This is despite the potential capabilities of BIM, such as: data visualization, simulation of alternative operating scenarios of a constructed facility, and information deployment. Although BIM can capture useful information, the large volumes of data and information captured in BIM is overwhelming and hence; may also lead to information inefficiencies (a type of lean waste). Hence, there is a need for streamlining BIM data and information collected at the facility design and construction phase to realize effective and meaningful contribution of BIM to facilities management. This data can prove to be very useful in decision making as well as in guiding facilities management in achieving an excellent built environment that will perform the functions for which a facility was designed and constructed. This line of thought brings in the need for a new way of looking at Facilities Management, i.e. knowledge-informed facilities management that is expected to lead to sustainable management of constructed facilities. This leads to the following research question: How can Lean Construction, BIM and Facilities Management be integrated in a collective model for continued lean benefits throughout the life cycle of a constructed facility?

In line with the concepts discussed in previous paragraphs, it is therefore, necessary to investigate the benefits, barriers, challenges, and success factors for integrating Lean Construction and BIM into a Facilities Management framework. This thesis argues that the synergy from the integration of Lean Construction and BIM can provide an effective and efficient framework for perpetuating lean benefits from design to end of life of a constructed facility. In addition, the interactions among lean construction, BIM and facilities management theories can provide more guidance to facility managers on how to optimize the performance of facilities.

Research Background

Lean Construction: Lean construction refers to a means of designing production systems within a construction setting, which aims at decreasing efforts, time, and waste materials (Emuze A & Saurin A, 2016). Lean construction makes sure that a project is performed quickly and at a lower cost without compromising on quality. Additionally, it aims to maximize value and productivity by reducing costs such as design, project maintenance, and activation. Certain characteristics characterize lean manufacturing. For instance, it involves concurrent designing and engineering. Also, objectives for delivery systems are set explicitly and project control is implemented across the project cycle from design to delivery.

Lean Implementations: Insightful lean implementation is essential for great-value productivity and corresponds to strategic decision-making concerning the delivery of construction projects. Nonetheless, lean construction is challenging to implement and requires high levels of coordination and communication. For instance, it becomes more challenging when deciding which of the lean tools to implement and the time to implement them. Also, changes in management greatly influence lean implementation. Lean implementation can be referred to as a transformational process that is required to support organisational development along with process improvement. Thus, during the lean implementation process, it is vital to determine the lean tools that are most suitable for a particular setting. By doing so, contingency and situational variables can be permitted and accommodated in the lean transformation. However, several vital aspects determine the successful implementation of lean construction. Among these factors are: finance organisational culture, leadership, management, expertise, and skills alongside others (Saad et al., 2006). These factors are among the most relevant critical concerns for any successful implementation of lean construction.

Lean Construction Productivity: For any construction project to remain competitive and profitable, it is necessary for management and construction teams to find methods of maximizing value and efficiency, minimising waste, or completing more practical construction with fewer costs. Lean construction productivity focuses on the means through which lean construction principles are applied in order to challenge old-fashioned processes and continually assess methods to eradicate waste and inefficiencies (Thomas, Horman, Minchin & Chen, 2003). As a result, productivity is increased, quality is enhanced, operational costs are minimised, a smoother operation is maintained, and advanced execution is realized.

Building Information Modelling: Building Information Modelling (BIM) is an intelligent 3D model-based process that gives architecture, engineering, and construction (AEC) professionals the insight and tools to more effectively plan, design, construct and manage buildings. BIM has proved to be one of the most promising recent development implementations in AEC. Through the application of BIM technology, an accurate virtual model of a building is digitally constructed. This BIM model is usually employed by AEC professionals to plan, design, construct, and operate the facility. Therefore, a high-quality BIM model can prove to be vital in managing the constructed facility. A BIM model aids the architects, engineers, and constructors in visualizing the building that will be constructed in a simulated setting. Through this model, they can identify any potential design, construction, or operational issues, thus further providing an insight into the best way to manage the constructed facility (Azhar, 2011). BIM brings about a new paradigm within the AEC, which inspires the integration of the roles across all the stakeholders within a project. Furthermore, this model is essential during the generation of design documentation necessary for the construction process. Also, BIM helps in bringing about ways that are more effective in designing and constructing buildings, not just as a means to satisfy the global demand of increasing population but to create spaces that are smarter and more useful too. BIM mandates have increased across the globe since BIM allows the building teams to work more efficiently and enables them to capture data that they create during the process to benefit facilities management i.e., maintenance and operations activities.

Building Dimensions: There exist certain pre-defined purposes for which the BIM Model is used. These purposes are called use-cases in which existing BIM information is integrated with particular parameters. Such additional pre-defined used cases are known as BIM dimensions (Charef, Alaka & Emmitt, 2018). BIM dimensions help in terms of enhancing BIM model-based data, which in turn enhances the overall understanding of any construction project (Vanhoucke, 2013). Its dimensions include basic ones such as 3D and 4D, and other sophisticated ones such as 5D, 6D and 7D. The 3D dimension is related to geometry, i.e. three-dimensional geographical structure. The 4D dimension is related to scheduling, timeline, and duration. The 5D dimension is related to budget analysis and cost estimation. The 6D dimension is related to energy efficacy and self-sustainability. Finally, the 7D dimension is related to facility management information (Charef et al., 2018). Besides these BIM dimensions, BIM is also use by the ISO 19650 standard. The international standard focuses on information management throughout a building lifecycle by employing BIM (Vanhoucke, 2013).

Data Visualization: Data visualization refers to the process through which small data is transformed into big intelligence. This whole process is achieved by taking the raw data, which is then converted into something attainable, and subsequently displayed to drive meaningful conversations. Currently, data visualization has led to the transformation of the construction industry and continues to transform (Chau, Anson & Zhang, 2003). However, there exists a challenge in the construction industry. Just like other industries, much of the data collected cannot contribute to the big picture, which is necessary for helpful, profitable, analytic, and information availability. Since the construction industry is characterized by huge amounts of resources, it also has high amounts of data. This may lead to information inefficiencies that can translate to less productivity.

Data visualization is very helpful in the construction industry in many ways. For instance, through data visualization, a platform is provided whereby owners and constructors can see the variation in price between costs in the future, changes in plans, among others. In data visualization, every element in the design is tied up to a cost estimate, and they are integrated fully so that the solution changes visually. In the present, the tools available for AEC companies have put an end to the waste of materials, money, and time. Through data visualization, all the stakeholders that are involved in the construction are brought together. Every stakeholder has the ability to see the numbers in real-time and can contribute to the discussion. Consequently, this reduces risk and offers a higher reward in the construction industry. However, data visualization software has a major downside in that it lacks realistic site management features, such as analysis of resource necessities for individual construction activity, generation of site facility layouts, quantification of construction materials, and cost evaluation over a specified time period. These drawbacks can be addressed by combining data visualization with BIM.

Facility Management: Facility management is a profession that entails multiple disciplines like planning, design, and construction. It also entails managing space to make sure that there is adequate functionality in the built environment by integrating people's processes and technology. Facilities management theory entails an enormous scope. It can take the context of property management and maintenance. It can also include other contexts such as renovation, refurbishment, and retrofitting in constructed facilities. Under construction management, the best concept of construction is already put in place, but as the world continues to change, it is necessary to revise it. Facilities management also significantly contributes towards creating new and better knowledge, leading to the betterment of construction industries. It encompasses enhancing corporate facilities policies, real estate space inventories, long-range forecasts, building operations, maintenance plans and furniture inventories, and projects. Simply, facility management may be defined as the processes that are involved in managing all the multiple services that enable a facility to be profitable to the investment owners and a productive environment for the users.

Since constructions are complex physical structures, they require a wide spectrum of services in order to run properly and efficiently. Facility management relies on the skill, vision, and experience of its practitioners. However, currently, it also depends on powerful computer-aided techniques. This methodology offers, with pinpoint accuracy and an everyday picture of how all the facility-related services are functioning, where the problems lie, and in what way they are affecting costs of generating synergy, alongside other factors (Yassin & Razali, 2020). In construction, facilities management can be offered by managing agents, full or partial-service offered by multi-service companies. There are a significant number of activities that form the integral management criterion of facilities management. Some of these activities may include asset management, space management, estates strategies, procurement management, sustainability, budget management, quality assurance, asset exploitation, and income generation, alongside others. Therefore, facilities management is a crucial undertaking that can mean the difference between the success and failure of a constructed facility. Due to the wide scope of facilities management, illustrative facilities management examples in this thesis will be derived from facilities operations and maintenance.

The importance of facilities management cannot be overstated. It is expected that there be continuous improvements in facilities management in order to maximize facilities performance and the built environment while minimizing operating and maintenance costs. In this regard, lean manufacturing principles have been identified as strong contenders in improving facilities management. While lean construction has taken centre stage in the design and construction phase of a facility, many researchers have made attempts to harness lean manufacturing principles into facilities management. This has led to the concept of lean facilities management.

Lean Facilities Management: Lean facility management is defined as an effective approach of identification of waste so that facility management costs can be minimised (Gao, Pheng & Tay, 2020). Organisations apply lean facility management in order to identify wastes, examine their potential effects, and thus, eliminate the defined wastes for attaining proactive facility management (Olesen et al., 2015). Construction managers in a facility apply lean facility management in terms of identifying different types of waste that arise daily in any facility. Common types of wastes in lean facility management are related to transport, inventory, waiting, motion, over-production, skills, over-processing, and defects (Wyton & Payne, 2014). Generally, lean facility management should be applied throughout the construction facility lifecycle, such that it initiates with preliminary concept development and ends up to final recycling or deconstruction (Gao et al., 2020). However, the most common application is to apply lean manufacturing principles in facilities management after project delivery. In this sense lean facilities management is more of a reactive approach that is implemented to improve facilities management after project delivery. The argument presented in this thesis lies in that facilities management should start at the design stage of a constructed facility and carries on during the construction phase until end of life of the constructed facility. BIM functionalities can be used to capture data and information relevant to facilities management from the design phase up to the end of life of the constructed facility. It is expected that this proactive approach can enable the realization of more benefits in, for example, facilities management functions such as operations and maintenance, in comparison to benefits that can be attained using lean principles as a reactive approach to in adequate facilities management.

Research Problem

The construction industry has undergone a number of transformations in the past decade. This industry has seen the rise and implementation of tools like BIM and concepts like Lean Construction. As highlighted in previous sections, the body of literature is mainly researched and based in the western context and there is very limited research on lean construction and BIM in developing countries. While some developing countries are aware of the importance of tools like BIM and concepts such as Lean Construction, the levels of lean construction preparedness and implementations are yet to be sufficient to accrue tangible benefits. A number of barriers are also imminent in addition to lack of knowledge and misconceptions about BIM and Lean Construction. High construction quality of public facilities produces a high-quality facility whose operations are expected to provide excellent service to users. To continue to offer excellent service, public facilities need to be operated and maintained at optimal levels. However, operations and maintenance costs may spiral out of control if the facility was poorly designed and poorly constructed for operations and maintenance considerations, i.e. optimized operational and maintenance issues were not considered at the design and construction phases of the facility. A proactive approach is to consider the impact of the construction quality on operations and maintenance of a facility at the design and construction phases. If Lean Construction quality data that takes into cognizance operational and maintenance issues is integrated into BIM at design and construction phases of a facility, such data and information from BIM can be simulated to identify optimal operating and maintenance scenarios that can provide high quality facility service throughout the life cycle of the constructed facility. This data and information can also prove to be a valuable input to facilities management in terms of helping to minimize operating and maintenance costs.

In line with the quest for improving construction quality, many scholars have indicated that construction quality can be improved by integrating Lean Construction and BIM (Laine et al., 2014; Liu and Shi, 2017). However, the impact of such integration on improving the performance of a facility in developing countries, needs further investigation. Further, there are gaps in the research around the interrelationships, interactions and synergies among BIM, Lean Construction, and Facilities Management. This thesis aims to explore the synergies between Lean Concepts and BIM and how they can be harnessed to enhance Facilities Management. The construction industry in Qatar will be used as a case study.

Improving quality in the construction sector requires an understanding of the contextual and organizational factors that hinder the adoption and implementation of quality improvement initiatives that are based on the outcomes of integrating Lean Construction and BIM. Such quality improvements are also based on the presumption that BIM is being used comprehensively in construction and lean construction implementations are beyond awareness and preparedness levels. Although some companies in Qatar are using BIM and lean concepts, this may not be true for some of the developing countries.

Most of the construction industries in Qatar are aware of the strength and usefulness of BIM but the extent of BIM usage in these industries has not been thoroughly verified. Furthermore, very little research in the public literature has been done to characterize the impact, benefits, and implementations of integrated BIM and Lean Construction in Qatar. Bridging this gap requires empirical work to establish the state-of-art in the synergy between Lean Construction and BIM. It is also vital to identify interventions that would facilitate or fast track the quality improvements in the construction sector through integrated models. This thesis builds on the underlying theme that positions the integration of BIM and Lean Construction as an enabler of effective Facilities Management, which can help in perpetuating lean benefits in constructed facilities. This will in-turn ensure that the constructed facility will perform its intended functions at intended performance capacity, effectiveness, and reliability.

Aim, Objectives and Research Questions

The interactions between the themes Lean Construction, BIM, and Facilities Management, has not been well researched in Qatar and this study aims to promote better understanding of such interactions in the construction industry (Al-Buenain et al., 2020; Al Mohannadi et al., 2013). Therefore, the overarching aim of this study is to develop a conceptual framework for Facilities Management through exploring the benefits, barriers and success factors associated with the synergy between Lean Construction and BIM.

To achieve this aim, the following objectives have been identified:

⇒ To explore the extent of adoption of practices of Lean Construction by the construction industry in Qatar

⇒ To identify the benefits, challenges, barriers and success factors associated with integrating BIM, Facilities Management and Lean Construction

⇒ To develop and validate a conceptual framework for Facilities Management based on inputs from integrating Lean Construction and BIM.

The research seeks to answer the following two questions:

⇒ How can Lean Construction, BIM and Facilities Management be integrated in a collective model for the continued benefits of lean management?

⇒ What are the contextual and organisational factors that may hinder the effective integration of Lean Construction, BIM and Facilities Management?

Overview of Methods

A mixed method approach will be utilized for this research. A mixed method approach enables researchers to combine both qualitative and quantitative research methods in order to answer a research question (Saunders et al., 2015). Creswell (2011) pointed out that a mixed method approach enables researcher to strengthen their findings by collecting different types of data which enhances the validity of the findings. Therefore, this study will adopt the following tools for collecting secondary and primary data:

Literature Review: A systematic literature review using online databases will be carried out to explore the Lean Construction approach and BIM approaches. The literature review will help in identifying facilities management improvement requirements through a comprehensive review of lean construction. Challenges and barriers associated with integrating such approaches will be explored to help establish a strong theoretical basis for the study and provide better insights on the approach adopted for collecting primary data.

Survey Strategy: A cross-sectional survey design will be adopted for the collection of quantitative data from research participants. The population of the survey will be practitioners in the field of construction in Qatar, including but not limited to project managers, surveyors, auditors and quality managers. The purpose of the survey is to understand the current awareness levels on BIM, Lean Construction and Facilities Management theories as well as explore the challenges and success factors as perceived by the participants. The survey will be distributed to large construction companies in Qatar mainly undertaking construction projects as part of the FIFA World Cup 2022 preparations.

Questionnaire and Semi-Structured Interviews: Semi-structured interviews as a qualitative method and online structured questionnaire as a quantitative method will be adopted for collecting textual data. Interviews provide researchers with the opportunity to understand the underlying meanings and factors behind a research problem and gain further insights by interacting directly with the research subjects. It is planned that a minimum of 5 interviews will be carried out with professionals in the field. Following the development of the conceptual framework, interviews will also be used to test the validity of the constructed framework.

Conceptual Framework Development: Based on the synthesis of the literature review along with the analysis of the survey and interviews data, a conceptual framework that integrates BIM, Facilities Management and Lean Construction will be developed, highlighting the key interactions. The Conceptual Framework would detail the organizational changes needed at senior and floor levels to enable the effective integration. To ensure the framework meets the expectations of the users, structured interviews will be used to test the appropriateness and feasibility of adopting the framework.

Study Significance

This study will be of high significance not only to the academic arena but also to policy and practice. Firstly, the study will contribute to the body of knowledge by focusing on an area of research that is not widely explored in the Arab World. The empirical work of this study will provide an insight about the challenges and success factors associated with developing an integrated Lean construction model to enhance the efficiency and quality of construction project delivery. Secondly, the study will also be beneficial to practitioners and professionals in the field as it presents a detailed conceptual framework based on empirical research and involving practitioners in the field to identify areas for improvement and suggest new ways of working. Finally, policy makers will find this study also beneficial in formulating new standards and project management guidance as well as key performance indicators that aim to reduce waste, enhance efficiency and improve collaboration, satisfaction and teamwork across the different stakeholders involved in the construction journey.

Thesis Layout

This final thesis consists of seven chapters. Chapter One presents a research overview. The purpose of this chapter is to present the rationale of the chosen research subject along with presenting the aims, objectives and research questions. The chapter also highlights the content of the thesis and overview of the methods for data collection. Chapter Two comprises a detailed literature review and presents the theoretical context for the study through a comprehensive literature review on lean construction, BIM and facilities management theory. The various sections will identify facilities management improvement requirements through a comprehensive review of lean construction, BIM and facilities management theories within a life cycle analysis framework. The sections also investigate the potential uses of lean construction, BIM and facilities management theories and how these uses can help organisations to continue to accrue benefits associated with lean construction, BIM and facilities management theories. The literature will also look at current research on integrating lean construction, BIM, and facilities management theories in order to improve facilities management of constructed facilities.

Chapter Three outlines the research methodology. It discusses the philosophical approach adopted for the research design and strategy. It explains the differences between inductive and deductive research as well as qualitative and quantitative research, ethical considerations, survey strategy, case study design, data collection procedures and data analysis. It will also discuss the limitations and generalisability of the findings. Chapter Four of case study presents the findings of the empirical study. The survey findings will be presented in this chapter, which will be analysed in SPSS. Discussion on the findings and linking the findings with the literature review will also be presented in this chapter.

Chapter Five presents the development of the Facilities Management framework. A conceptual framework will be developed based on the findings of the research. It will be validated by conducting a mixture of structured and semi-structured interviews with project managers, facilities managers and professionals in the field of quality improvement, lean construction and project management. The thematic content analysis would be used for the creation of themes underlying the proposed facilities management framework. The purpose of the framework is to provide an integrated approach to enhance efficiency, effectiveness, and value in facilities management in developing countries.

Chapter Six shows main results and discussions. It will present the findings of the structured and semi-structured interviews aimed at verifying and validating the proposed facilities management conceptual framework. A generic model of the facilities management conceptual framework suitable for developing countries will be discussed. A comparative analysis of such a model with models that have been implemented in developed countries will be provided. Perspectives on the merits, demerits and implementation of such a framework in developing countries will be outlined. Lastly, chapter Seven states conclusions and recommendations. It presents the key conclusions of the study as well as providing some practical recommendations to help organizations implement the conceptual framework to enhance their performance. The chapter will also discuss the study implications and provides some ideas that could be further researched in the future.

Summary

This chapter provided an overview of the research subject by identifying the research gap and the aims, objectives and the research questions to be answered as part of this research study. This chapter also provides an overview of the methods to be used for data collection which will be further explored in Chapter 3, where the rationale of the chosen methodology would be justified. This chapter also outlines the structure of the thesis and highlights the significance and importance of this research.

Chapter Two – Literature Review

Facilities Management Theory

In terms of facilities management theory, facilities management is defined as coordination between an organisation's work, its physical work setting, and its people (Toe, 2015). Facilities management is comprised of three interlinked areas, including property management. There are four principles of facilities management. The 1st principle states that continually planned and coordinated efforts of designing, facilities management, planning and construction help an organisation in terms of making it able to attain set objectives and improve the job environment. The 2nd principle states that different fields of architecture, engineering science, business and behavioural science integrate within the area of an organisation's facilities management, which facilitates in terms of overseeing all functions. The 3rd principle states that activities are managed in a proactive manner instead of a reactive manner. The 4th principle states that facilities management is a business idea in which organisational objectives, resources and goals guide financial management procedures and policies (Toe, 2015).

Facilities management supports service management, and information technology (IT) management (Chen, 2017). It is a function of management, because it coordinates building management, planning and designing efforts, and associated equipment, system and other fixtures. As a result, facilities management facilitates lean construction since organisations are better able to attain lean construction goals and gain competitive advantage within the rapidly varying business environment (Barker, n.d.).

A study by Tucker & Masuri (2016) identified the readiness of facilities management by showing that it is integrated into construction processes. The study highlighted the need for development of a facilities management – construction process integration model so that the profile of facilities management can be enhanced within the construction industry. This would lead to better application and attainment of sustainable development. According to Jawdeh (2013), there exist several concerns related to facilities management in the Middle East construction industry, due to which facilities management is considered during the design stage. Another study by Yassin & Razali (2008) showed that construction companies in Malaysia are inclined towards adopting facilities management due to several reasons, such as for development of strong business associations, for enhancement of coordination between various services, for better sharing of information between various departments, for controlling the construction process, for attainment of better decentralisation in companies, for reduction of environmental damages, for enhancements of job flexibility, for granting autonomy to workers, for reduction of personnel costs, for improvement of job conditions, for controlling work putout, for accelerating the innovation process, and for enhancement of the ethical competitiveness of companies.

The study by Jawdeh (2013) showed that facilities management is included and accepted in the design stage of construction projects in the Middle East because the key personnel are educated, well-aware and responsible towards implementing it. Another Yassin & Razali (2008) study revealed that facilities management is implemented within the Malaysian construction industry in the form of Virtual Private Networks (VPN), Location Independent, Computer Added Facility Management (CAFM), Environmental Management System (EMS), Three-Dimensional Computer-Aided Design (CAD), Computerised Maintenance Management System (CMMS), Planned Preventive Management System (PPMS), and Computer Control and Monitoring System (CCMS).

The study by Tucker & Masuri (2016) showed that facilities management offers benefits in the construction industry in terms of better application and attainment of sustainable construction. It further stressed that when facilities management is integrated into the construction process, then it encourages facilities managers to show the value of facilities management within the construction industry. As a result, four main advantages are gained, including innovation, sustainable development, decision-making processes, and value-added construction. Similarly, Yassin & Razali (2008) revealed several benefits of facilities management for construction processes, such as high responsibility among employees, higher organisational profits, effective monitoring of construction projects, friendly job environment, and adoption of cutting-edge technology.

The study by Tucker & Masuri (2016) adopted the mixed-method design for identifying associations between facilities management and construction processes within the UK construction industry. Moreover, Yassin & Razali (2008) adopted a quantitative approach in which surveys (questionnaires) were conducted, whereas, the study by Jawdeh (2013) adopted a qualitative approach within which semi-structured interviews were conducted.

Lean Facilities Management

There are different industries which have adopted lean, such as healthcare, construction and service industries. However, there exists lack of knowledge related to the extent of implementation of lean in facility management (Gao et al., 2020). Nevertheless, personnel in construction facilities apply several lean management principles related to the scope of work. These lean management principles include using reliable technology, continuous improvement or kaizen, people development, and leadership (Olesen et al., 2015). Furthermore, lean is implemented in construction facilities by starting with collection of preliminary data related to spaces, assets, and maintenance of facilities. Such data helps facilities in measuring their current performance, and thus, devise a cost and waste reduction plan related to, for example, facilities maintenance (Gao et al., 2020). In this way, engineering managers, maintenance managers, and technicians attain benefits from lean facility management by identifying and eliminating potential wasteful activities and processes beforehand (Wyton & Payne, 2014).

Lean Construction

Lean principles were developed after the World War II, and include Jidoka automation and Just-In-Time flow. Just-In-Time flow includes the condition of production to demand. Jidoka automation means a single operator runs various machines, and thus, disengages machine and man (Terreno et al., 2019). The philosophy of lean production is based on the idea of continual improvement, such that a basic search strategy is applied for the main source and waste reduction. Some basic types of waste include non-value-added activities, waiting, additional processing and transport, manufacturing of non-ordered goods, rectified mistakes, additional movement, and spare stock (6). Even though lean production is adapted to various industries, the key goals of the overall methodology include enhancement of productivity, waste reduction principle, and enhancement of efficacy (Goh & Goh, 2019). It is adapted in the construction industry through formulation of a new lean production management. This is comprised of three elements: flow, transformation, and value generation (Nascimento et al., 2018).

According to Ansah et al. (2016), construction project teams seek robust methods, models and practical approaches for handling waste issues. This is usually attained through integration of lean production systems into construction projects, which is termed as Lean Construction (LC). This can be supported by the study of Bajjou et al. (2019) who showed that lean construction models are applied in various countries, including UK, Germany, USA, Turkey and Brazil, based on two principles, i.e. management principle and principle of culture and behaviour. In other words, lean implementation can be realised successfully in an organisation if it has support of the top management, a healthy culture, strong leadership, and skilled employees (Al-Najem et al., 2012).

According to Dulaimi & Tanamas (2008), multinational corporations in the construction industry of Singapore are ready to adopt lean construction instruments and principles. However, they hesitate from applying it completely within the local context based on distinct features of the construction industry. On the contrary, Bajjou et al. (2019) showed that US, Germany, Brazil, UK and Malaysia focus on adopting lean construction so that time, materials and efforts-based wastes can be reduced and maximum end-product value can be attained.

According to the findings of Dulaimi & Tanamas (2008), ISO 9000 certified multinational corporations in the construction industry of Singapore implement few distinct features of lean construction only because they face the major obstacle of cultural resistance to this change. This can be supported by the study of Bajjou et al. (2019), who showed that there exists unclear vision of key methods, practices and tools of lean construction. Due to this, each construction company implements lean construction differently as per their own internal features. In other words, the philosophy of lean construction is complex due to lack of an iterative basis for performance enhancement, waste reduction and customer value maximisation (Ansah et al., 2016).

According to Ansah et al. (2016), lean construction offers benefits in terms of better delivery processes and systems, improved financial status and project performance of construction companies, better health and safety as per clients' requirements, and waste elimination. Similarly, Dulaimi & Tanamas (2008) showed that implementation of lean construction offers benefits such as in schematic design duration, higher client satisfaction, reduced construction office times, higher turnover, and lower project costs.

The study by Ansah et al. (2016) gathered qualitative data and adopted a secondary methodology. Similarly, Bajjou et al. (2019) conducted a systematic literature review by gathering data from wide-ranging countries. On the other hand, Dulaimi & Tanamas (2008) conducted interviews by adopting a mono-method, qualitative research approach.

Lean Implementation

According to Wandahl (2014), there exists awareness of the need for lean complementation in the Danish construction industry, so that motivation of site managers can be balanced with standardization

of activities. On the other hand, Bajjou & Chafi (2018) showed that there exists a lack of awareness of lean construction practices among professionals in Morocco. Therefore, they need additional training and support related to VSM, Kanban system, and Poke-Yoke lean practices.

As per the findings of Wandahl (2014), readiness for lean construction requires it to be adapted to the culture of the company and country in a proper manner. This reflects the fact that both organisational and local culture must be respected while planning and applying lean construction. Wandahl (2014) showed that there exists ineffective lean implementation in the Danish construction industry due to its mis-conceptualisation, which in turn is due to lack of education, knowledge and communication. However, on the contrary, Ashghal in Qatar focuses on lean construction implementation within its major pipeline construction projects. Its Roads Projects Department runs several initiatives such as Construction Enhancements and Constructing Excellence in Qatar based on the implementation of lean construction (CIHT Qatar Group, 2019). According to Bajjou & Chafi (2018), implementation of lean construction results in various benefits, such as attainment of non-financial performances. These include enhanced safety, higher project quality, and improved environmental performance.

The study by Wandahl (2014) adopted a quantitative approach and conducted surveys among 500 construction practitioners in Denmark. Similarly, Bajjou & Chafi (2018) also adopted a quantitative approach and conducted a structured questionnaire (survey) among 330 construction practitioners who were selected from Moroccan public and private construction companies.

BIM

According to Mohammed et al. (2019), there exists limited awareness of BIM in the Qatar construction industry, such that engineers are more aware of BIM than contractors, architects, facility managers and quantity surveyors. This can be supported by the findings of Vukovic et al. (2015), who revealed that there exists a lack of clarity of BIM in the Qatar construction industry due to minimal mandate by the national central government, regardless of correct perception of various aspects of BIM, such as real time collaboration, design and coordination, and digital data management. Both of these studies reflect the need for educating professionals about BIM in the Qatar construction industry.

According to Azhar et al. (2015), a bottom-up approach must be used for applying BIM regardless of a top-down approach. Furthermore, an efficient application of BIM requires involvement of people throughout the implementation stage, acceptance of the change by them, learning and development of people skills, and enhancement of their understanding of continual improvement tactics. This can be supported by the study of Edirisinghe et al. (2017), who asserted that a seven-pillar strategy must be used for applying BIM in the construction industry. The strategy includes minimal waste reduction, evaluation of decisions for seeking utmost agreement, integrity-based development, seeking wider perspective, enhancement of the feedback, rapid delivery, and improved knowledge of team members.

A study by Atzl & Eichler (2018) showed that BIM is applied successfully through following inherent procedures, which eventually help in gathering, changing, assessing and reporting construction projects' information. Yet, it must be noted that an efficient application of BIM needs lean methodology in construction management so that sustainable development can be realised (Nascimento et al., 2018). However, as per findings of Mohammed et al. (2019), there exists low implementation of BIM in construction and infrastructure projects. Despite the fact that BIM is being applied in significant ways in US, Singapore, Europe and UK based on its advantages, it is anticipated that the construction industry of Qatar will implement it less comparatively at government level.

In the construction industry, building information modelling (BIM) is a highly effective improvement. BIM technology is comprised of functions that facilitate a highly cooperative construction idea and design, which identify physical issues and allow various domain experts to authorise simultaneously (Hosseini et al., 2018). Thus, BIM technology aims to enhance process and methods related to construction project management. Moreover, it helps in terms of applying lean principles effectively (Terreno et al., 2019).

BIM has been studied by adopting wide-ranging methods such as online questionnaire (Mohammed et al., 2019), semi-structured interviews (Vukovic et al., 2015), case study approach (Azhar et al., 2015), and systematic literature review (Edirisinghe et al., 2017).

BIM dimensions

This section discusses each dimension of BIM in terms of its purpose and functionality, applications and benefits, and level of implementation in developed and developing countries, specifically focusing on Qatar in the Mena Region.

3D dimension of BIM shows the three dimensions of geographical structure of any building. Its purpose is to help stakeholders in terms of visualising three dimensions of any building prior to initiation of the structural project. Stakeholders apply this dimension in order to model and solve usual structural issues at a future stage by effectively collaborating with one another. Some common benefits of 3D BIM include better 3D visualisation of the construction project, enhanced collaboration between various teams, efficient sharing and communication of expected design, and enhanced transparency leading to minimal revisions and rework (Charef et al., 2018).

4D dimension of BIM shows the factor of time during construction planning stage. Its purpose is to provide scheduling data so that overall time required for project completion can be identified. Stakeholders apply 4D BIM for elaborating the time required to operate a project, initiate the installation, and identify the sequence of construction. Its common benefits include better construction site planning, better preparedness throughout the construction process, timeline-based documentation leading to enhanced efficacy and safety, better scheduling optimisation, minimal expensive delays due to sharing of expected timeline, and seamless coordination between contractors, architects and teams on the construction site (Vanhoucke, 2013).

5D dimension of BIM is based on cost estimation and budget analysis. Its purpose is to predict the required budget in an accurate manner in addition to variations in required material, equipment, scope and manpower. 5D BIM is applied by construction project owners and promotes for conducting the financial analysis related to project activities. Its common benefits include real-time visualisation of cost and any changes, simple budgetary and cost analysis, automatic count of project related equipment and parts, and less risk of exceeding the budget due to daily practices of budgeting and cost reporting (Charef et al., 2018).

6D dimension of BIM is based on making an energy efficient and self-sustainable structure. Its core purposes are based on examination of a facility's energy consumption, and estimation of the overall cost of an asset in order to attain cost-efficacy and sustainability. 6D BIM is applied in order to offer support to future operations and facility management. Its common benefits include minimal consumption of energy, thorough examination of effect of a decision on a project's operational and economic aspects, accurate and fast decision-making during the design stage, and improved operational management (Vanhoucke, 2013).

7D dimension of BIM is based on facility management and operations management. Its core purpose is based on tracking key asset data, including maintenance, technical specifications, status, manuals and warranty information of an asset which is needed in the future. 7D BIM is applied in order to collate all required data and other things relative to the facility management process at one section of BIM. Its common benefits include optimised facility and asset management throughout the facility lifecycle, updated maintenance process, and an ease of replacing repairs and part throughout the building lifecycle (Akdag & Maqsood, 2019).

Finally, in terms of implementation, 3D and 4D BIM are more prevalently applied in developed countries in contrast to minimal implementation of 5D, 6D and 7D BIM dimensions (Charef et al., 2018). In the case of developing countries, there exists low implementation of 3D BIM in prefabrication process, 5D BIM in fieldwork and layout, and 6D BIM in operation and maintenance (Akdag & Maqsood, 2019). Considering the Mena region, there exists high awareness of BIM dimensions. Yet, the most prevalent and widely implemented dimensions in Qatar include scheduling function of 4D, cost estimation function of 5D, sustainability function of 6D, and facility management function of 7D BIM (Charef et al., 2018).

Data visualization

According to Leite et al. (2016), data visualization methods have altered the execution of construction processes in a dramatic and fast manner. Consequently, there exists high interest in data visualization. According to the findings of Marasini et al. (n.d.), readiness to adopt data visualisation is not fast in every country, such as in the UK. Due to this, the study suggested development of initiatives for encouraging its use in the construction industry. Moreover, it recommended that developers, researchers and construction industry need to collaborate for delivering affordable and effective solutions.

According to Ivson et al. (2018), data visualization tools such as the 3D-CAD model are used with BIM within mega facilities' construction, design and operations.

Datasets include wide-ranging information related to real-time sensor data and design specifications. Engineers and architects in the construction industry apply data visualization tools for numerous simulations and analysis. Likewise, Fard & Pena-Mora (2007) showed that data visualization methods strengthen communication of crucial information and decisions based on corrective actions.

According to Leite et al. (2016), data visualization methods offer benefits in terms of an ease of identification of temporal and spatial conflicts, better control of quality of construction projects, and monitoring of construction progress. Likewise, Marasini et al. (n.d.) showed that data visualization methods and tools help stakeholders and construction planners in terms of visualising the execution process of projects, and identification of potential issues prior to their occurrence in construction projects. In this way, advanced data visualization methods and tools help to better handle complex models, and alter the construction industry culture (Fard & Pena-Mora, 2007).

Data visualization has been studied by adopting wide-ranging methods such as case study approach (Fard & Pena-Mora, 2007; Marasini et al. (n.d.), systematic review (Ivson et al., 2018), and semi-structured interviews (Leite et al., 2016).

BIM and Lean Construction

According to Sacks et al. (2009), there exists reasonable awareness related to the fact that even though BIM does not depend on Lean Construction, construction projects can be enhanced fully when BIM is integrated with Lean Construction in the form of an Integrated Project Delivery (IPD) approach. As per the findings of Tauriainen et al. (2016), BIM faces issues when applied with Lean Construction due to several reasons. These include lack of BIM instructions, poor communication, vague sharing of responsibilities, and lack of Lean Construction knowledge and BIM experience. Nevertheless, Brathen (n.d.) stressed that collaborative working within the construction design phase can be improved if BIM is implemented with co-location principle of lean construction. This allows key personnel to collaborate while using the latest technologies and working within the organisation. Furthermore, the researcher highlighted that careful implementation and planning can lead to favourable outcomes.

According to Onyango (2016), similarity between BIM and Lean Construction facilitates their mutual implementation, which offers benefits in terms of better elimination of waste and enhanced efficacy. Likewise, Gerber et al. (2010) showed that Lean Construction and BIM integration facilitates lean measures in terms of resource levelling, prefabrication, creation of automated work packages, value planning, and effective coordination. Most importantly, BIM integrates with Lean Construction to better control and manage project schedule, cost and quality besides waste reduction.

Lean Construction and BIM together have been studied by adopting different methods such as case study approach (Gerber et al., 2010; Brathen, n.d.), empirical study (Sacks et al., 2009), interviews (Tauriainen et al., 2016), and systematic literature review (Onyango, 2016).

BIM and Facilities Management

A study by Nascimento et al. (2018) conducted an investigation of ways in which BIM data standards could provide information related to assets within facilities management based on the life-cycle viewpoint. Its findings showed that existing standards in the construction industry do not satisfy the data requirements, and thus, recommended best practices so that the construction stage can transfer to the facility management stage in a smooth manner (Chen, 2017). A study by Oduyemi et al. (2017) showed that there exist challenges related to application of BIM in facilities management. It proposed that there is a need to enhance existing operational processes and management practices. Likewise, the study by Terreno et al. (2019) stressed that existing BIM solutions are inefficient, and thus, must be addressed for meeting the needs and requirements of the facility management.

As per statistical findings by the study of Pilanawithana & Sandanayake (2017), after commissioning, 85% of costs arise from the facility in a project lifecycle. Furthermore, $10 billion of costs are related to maintenance and operations stages, which occur due to poor practices of management and high consumption of time while accessing information. Regardless of this, BIM is implemented to a low extent in facilities management (Toe, 2015). A study by Edirisinghe et al. (2017) conducted a survey among construction professionals, and showed that BIM was applied by 42% of users only during stages of maintenance and operations. Another study by Hosseini et al. (2018) revealed that facilities management is applied most efficiently through 3D-CAD (Computer-aided design), which is comprised of facilitating access to real-time data, keeping a check on maintainability, identifying parts of construction, marketing and visualisation, and managing spaces. Furthermore, Wetzel & Thabet (2015) showed that BIM can enhance facility management's repair and safe maintenance practices in data processing, user interface and interactivity, safety categorisation, and rule-based decision-making. Yet, Nascimento et al. (2018) showed that there exist problems related to the implementation of BIM along with facilities management, because there are challenges posed to integration of required information of BIM models into the system of facilities management.

Both BIM and facilities management have been studied together by adopting wide-ranging methods such as systematic literature review (Edirisinghe et al., 2017), case study approach (Chen, 2017), interviews (Pilanawithana & Sandanayake, 2017), survey (Nascimento et al., 2018), and questionnaire (Oduyemi et al., 2017).

Integrating Lean Construction, BIM and Facilities Management

Lean construction is defined as a methodology that aims to improve project management (McArthur & Bortoluzzi, 2018). Some of the key Lean Construction principles that can be used in Facilities Management are related to leadership, technology and culture of continual improvement. The approach of BIM is related to administration of information, such that it helps in terms of developing and sharing information among stakeholders in a collaborative manner (Edirisinghe et al., 2017). In this way, an integration of lean approaches with BIM results in better and more effective project management. Despite the fact that the principles of BIM are not interlinked with those of lean construction, there does exist some connection throughout the construction project lifecycle (Nascimento et al., 2018). For instance, the study by Nascimento et al. (2018) revealed that implementation of BIM along with Lean Construction can improve Facility Management by better control of the construction projects, and thus, enhancing processes in an incremental and continual manner.

Furthermore, BIM is associated with facilities management. This is so because performance of facilities management, prosperity and business growth can be enhanced by changing construction information and in-use data into tangible knowledge (Hosseini et al., 2018). Yet, there exist barriers related to application of BIM in facilities management. Common barriers include minimal knowledge, non-clarity related to ownership of data, non-existence of methods related to current building, compatibility among software, and reliability of information. These barriers result in limited use of BIM by managers working within new construction projects only (Terreno et al., 2019).

Based on the construction industry setting, lean principles are implemented in facilities management for ensuring a better identification of non-value and value-added activities (Chen, 2017). According to Toe (2015), facilities management is improved by lean through identification of value-creation processes between output and input, and provision of better leaner value creation tools. Likewise, Terreno et al. (2019) revealed that the lean concept needs to be explored in an organised manner within BIM-based Facilities Management because there exists high "waste" and "variability" of construction information available to the facility manager when BIM is used as the source of information. There is, therefore, a need to streamline the large volume of information and extract succinct information that can inform facilities management.

In short, it can be deduced that integrated BIM functions and lean principles offer better value creation tools that help in managing potential challenges, and enhancing and offering support to facilities management process (Nascimento et al., 2018).

Summary of Gaps

The literature review has outlined various studies related to the key themes of this thesis, namely, Lean Construction, BIM, and Facilities Management. The literature review has shown that Lean Construction, BIM, and Facilities Management theories have been extensively investigated by many authors as separate entities. In addition, a relatively large number of authors have investigated the implementation, benefits, barriers, and success factors of integrating Lean Construction and BIM. However, relatively fewer researchers have investigated implementations, benefits, barriers, and success factors in integrating (i) BIM and Facilities Management, (ii) Lean Construction and Facilities Management, and (iii) Lean Construction, BIM, and

Facilities Management. Hence, the impact of these integrations is relatively less well known, particularly in rapidly developing countries like Qatar. Therefore, this thesis will address theoretical gaps at the interface of the proposed integrations mentioned above as well as provide insights on operational gaps related to the said integrations in the Qatar Construction Industry.

More specifically, this thesis will contribute to knowledge by: (a) confirming the impact of implementing an integrated approach to BIM and Facilities Management in the Qatar Construction Industry and comparing it with what has been reported in other parts of world, and (b) further exploration of the impact of implementing an integrated approach to Lean Construction and Facilities Management in a bid to provide insights on how such integrated implementations may improve operating efficiencies in constructed facilities. Although Lean Construction and Facilities Management can be viewed as operating at different levels of the life cycle of a constructed facility, it is often crucial for Facility Managers to understand how Lean Construction principles can be leveraged to inform facilities management as well as help in making decisions on how to optimize facilities operations and maintenance strategies for the whole life cycle of a constructed facility. This consideration is more likely to be beneficial in situations where one organisation is responsible for the construction and management of the constructed facility for its entire life cycle, as is the case with the public works authority in Qatar. Such an integrated approach is expected to improve facilities management, which will in turn improve the built environment of the constructed facility and hence, provide facility users with satisfaction in using the facilities throughout its life cycle. The thesis will also investigate the impact of integrating Lean Construction and BIM for improved Facility Management.

To the best knowledge of the author, no extensive study has been conducted so far to investigate how the associations of Lean Construction and BIM can be integrated into a framework for Facilities Management. Despite the fact that wide-ranging studies have investigated the challenges, benefits, awareness, preparedness and implementation of the key factors, i.e. BIM, Lean Construction and Facilities Management, there is a need to explore interactions between BIM and Lean Construction in Facilities Management. Furthermore, there is no evidence in the publicly available literature related to the use of both Lean Construction and BIM in Facilities Management in the construction industry of Qatar. Therefore, this current study will address the identified gaps in order to strengthen the evidence base and provide insights that can guide the construction industry in developing countries towards excellence in construction.

Chapter Three – Research Methodology

Introduction

Chapters 1 and 2 have outlined the theoretical foundations for this research. The purpose of this chapter is to describe, discuss and explain the research design, methods and techniques that were used for collecting primary data to help in the process of developing a conceptual framework. As noted in the literature review, the body of knowledge about BIM and its interactions with Lean construction and quality-based interventions is still emerging. Hence, this study seeks to identify the challenges, barriers and success factors associated with integrating BIM, facilities management and Lean Construction that would enable the development of a conceptual framework for facilities management to enhance the efficiency and effectiveness of construction practices. Therefore, this research adopts an exploratory approach as highlighted by Saunders et al (2007). The exploratory research helps in investigating emerging and unknown knowledge. This chapter explains the differences between qualitative and quantitative research and provides a detailed overview of the tools used for data collection in developing and validating the conceptual framework. Following the review of the recent literature on this subject, this chapter is based on the synthesis of the different methods applied in this area of research.

Philosophical Approach

Saunders et al (2015) asserted that the assumptions used to develop knowledge are known as a research philosophy. The philosophical approach guides researchers in the development of data collection methods and selecting the appropriate research designs. According to Mkansi & Acheampong (2015), a research philosophy justifies why a researcher selected a particular research design or method for data collection and analysis. There are two widely used research approaches, known as epistemology and ontology. Ontology, as explained by Saunders et al (2015), is associated with how researchers make assumptions about the nature of reality. Ontology is associated with morality, knowledge and trust and focuses on examining the existence of objects and how they are interlinked with the external environment. Bryman (2008) asserted that ontological research seeks to explain what reality and the nature of scientific practice are. Crotty (2003) provided a clear and short definition of ontology where it was defined as "the study of being" (Crotty, 2003, p.10). Hence, it could be understood as the process in which the nature of existing is explained and investigated and also the structure of reality. In other words, ontological research seeks to answer the question of 'what is the nature of reality' (Crotty, 2003). On the other hand, Crotty defines epistemology as a "way of understanding and explaining how we know what we know" (Crotty, 2003, p.3). It could be argued that both ontology and epistemology are interrelated as they provide the basis for how knowledge is understood and how it is explained or created. Researchers, as explained by Creswell (2014), will choose the research approach that provides rich data to answer the research questions which could be obtained through qualitative or quantitative research methods. Obtaining background knowledge and understanding of the research subject was conducted through the literature review to further understand the research subject and its components. This indicates that an ontological approach was used, geared towards understanding what existing knowledge had been established, whereas an epistemological approach would be utilized for understanding how this knowledge is created and impacted by existing contextual and organisational factors. As shown in Figure 3.1, the diagram provides a better view of the terms and how they correlate to each other (Patel, 2015).

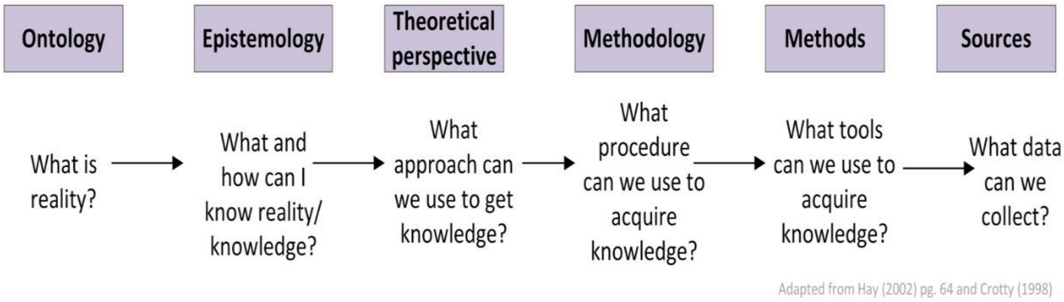

Figure 1. Flow of the Research Philosophy. (Patel, 2015)

Research Methodology and Approaches

To be able to explore how knowledge is created, it is important that a researcher follows a methodological approach for data collection and analysis. A methodology is defined by Crotty (2003) as the "*the strategy, plan of action, process or design lying behind the choice and use of particular methods and linking the choice and use of the methods to the desired outcomes."* (Crotty, 2003, p.3). This indicates that a systematic plan has to be created for the collection of data that would enable researchers to answer their research questions. The research methodology as highlighted by Saunders et al (2007) should explain the philosophical assumptions, research approach and design as well as the data collection techniques. As noted above, this research adopts an ontological and epistemological philosophy that aims to explain and describe what is known about facilities management and how it can be examined and understood.

Quantitative and Qualitative Research Approaches

The distinction between qualitative and quantitative research approaches lies with the methods applied for data collection and the type of data collected as noted by

Creswell (2014). Quantitative research is associated with the collection of numerical data that aims to test hypotheses and provide explanations on causations or correlations. According to Davies (2007), quantitative research can be linked to positivism as positivism claims that there is a single reality which can be measured and tested. There are different tools used for collecting numerical data such as tests, experiments and survey questionnaires which require statistical and mathematical tools for conducting data analysis. Biggam (2015) pointed out that quantitative research is associated with answering the questions of 'how many' and 'how much'. Saunders et al. (2007) pointed out that quantitative research can be cost-effective as it enables the collection of large samples of data.

Qualitative research is linked with the collection of textual data that can provide rich and deeper insights and understandings about people’s perceptions, views and opinions. Thomas (2003) stated that exploratory research utilizes qualitative methods as it helps in discovering underpinning factors. Neuman (2006) asserted that qualitative research can be helpful in generating theories and exploring hidden and unknown knowledge through direct interaction or observation of events. Similarly, it was pointed out by Bryman (2008) that qualitative research provides an opportunity to challenge existing knowledge by interacting directly with the research subjects to clarify any misunderstandings. De Vaus (2014) claimed that abundant data about real life situations and people can be collected through qualitative approaches which will help in gaining rich understandings. Similarly, qualitative research has been linked to the ability of collecting factual and description information by interacting directly with the research subjects (Johnson & Christensen, 2012). However, Johnson and Christensen (2012) indicated that generalising findings from qualitative approaches can be of limited use, as they are based on a particular group or setting. Hence, scholars such as Saunders et al (2007) recommend the use of a mixed method approach to overcome the limitations of using a single method in data collection.

Mixed methods research

Following the review of the literature and examining the body of knowledge in this area, it was noted that researchers have utilised multiple and mixed methods to explore and answer the research questions, providing rich insights from different perspectives. This was also highlighted by Liu (2014) who stated that researchers can benefit from the advantages of both approaches when applying a mixed method approach. In other words, qualitative and quantitative methods can be used for collecting data to help gain deeper insights. The application of a mixed method approach as noted by Saunders et al (2007) can yield more valid and reliable findings.

Jankowics (2000) pointed out that researchers face challenges in regard to the selection of a suitable research approach that could answer their research questions. Hence, the objectives and the overall purpose of the study play a vital role in selecting the research approach. For example, a qualitative approach has been described as a more useful approach for research studies that seek to develop frameworks or theories (Saunders et al., 2007). As discussed earlier, quantitative research tends to provide answers to questions about 'how many' whereas qualitative research can help in answering questions related to 'why' and 'how' (Biggam, 2015). Evaluating existing theories can be conducted through the application of quantitative methods whereas qualitative research can be beneficial in developing new knowledge and insights about a research problem (Saunders et al., 2007).

The objectives of this research are to critically review the current theories on lean construction, BIM and Facilities Management. The research also seeks to identify the challenges, barriers and success factors associated with integrating BIM, facilities management and Lean Construction and develop and validate a conceptual framework for facilities management. This would be based on a case-study design approach as discussed later in this chapter. Hence, it is vital to explore the existing knowledge on the subject as well as collecting primary data that would provide better insights and understandings of the barriers, challenges and solutions. The benefits of such an integrated approach would be also examined to provide new knowledge that would be beneficial not only to the academic arena, but also to policy and practice. The research addresses important questions that would yield better outcomes for construction companies through the utilization of resources and enhancement of production and performance. This would influence many other aspects such as finance, customer satisfaction and company growth and survival in today's highly complex and competitive business environment. This cannot be achieved without the collection of primary data from construction industry in Qatar to help understand the current barriers and challenges and explore how such barriers can be overcome.

The development of a conceptual framework requires multiple sources of data and the use of a mixed-method approach provides an opportunity to collect such data so that the reliability and validity of the developed framework can be enhanced. This also involves a process of validating the framework through communicating and interacting directly with stakeholders in the construction sector. A case study of the construction industry in Qatar will be conducted. To be able to develop a framework that reflects the knowledge, perceptions, and views of the construction stakeholders in Qatar, it is important to ensure that such stakeholders are involved at both stages through cost-effective methods for data collection. There is currently a research gap in this research subject. Furthermore, there are operational gaps in the context of Qatar and this study provides a starting point for future research in this area in Qatar.

Research Design and Data Collection Techniques

Fellows and Liu (2008) pointed out that data collection and analysis requires a well-defined research design that provides researchers with the tools to answer their research questions. A research design should not just focus on the approach to be utilized for data collection but also on selecting the right tools and methods for collecting and analysing the data (Bryman, 2008). There are five common research design types that are widely used and described by scholars:

According to Saunders et al (2007), ethnographic researchers are required to explain and interpret why a behaviour occurs and not just record what behaviours occur among the research subjects. Ethnographic research, as noted by Fellows and Liu (2008), is about the examination of culture and has its roots in anthropology. The principles of ethnographic research do not match the requirements of this study as behaviours and why such behaviours occur is not the sole purpose of this study. Moreover, ethnographic research requires significant amount of time and resources to conduct, which is a limitation of this study.

Solving a particular problem in the researcher's own environment is usually conducted by an action research design. According to Biggam (2015), when adopting an action research design, researchers will not act as independent observers but also as key participants in the research. It is widely used in solving social problems that require direct observation and participation from the researchers (Fellows & Liu, 2008). A key limitation of this design is the inability to be fully objective in the research. This study does not seek to solve a social problem or one which concerns the researcher's own environment. Therefore, action research design is not convenient for this study.

Experiments are widely used as part of a quantitative approach to test a hypothesis or invent new materials, particularly in laboratories. Fellows and Liu (2008) pointed out that experiments are very helpful in identifying correlations and causations. Saunders et al (2007) pointed out that experiments can also be applied in social research but can be very difficult to implement due to the ethical concerns and considerations. The overall purpose of this research is to develop a conceptual model for Lean Construction and hence, experiments as a research design is not suitable for this study.

Yin (1981) defines a case study design as *"an empirical inquiry which must examine a contemporary phenomenon in its real-life context, especially when the boundaries between phenomenon and context are not clearly evident"*. Similarly, a case study design is defined as a "*strategy for doing research which involves an empirical investigation of a particular contemporary phenomenon within its real-life context using multiple sources of evidence"* (Robson, 2002). Both definitions put great emphasis on the need for using the real-life context to investigate the research problem. Researchers can study either a single case study or multiple cases. It was pointed out by Morris and Wood (1991) that a rich understanding of the research context can be obtained through case study design to enable researchers to put forward new ideas.

Saunders et al (2007) pointed out that surveys are widely used as part of a cross-sectional design to collect qualitative and quantitative data. The use of a survey enables researchers to collect data that can support either descriptive or exploratory research as pointed out by Bryman (2008). Survey research has been widely adopted in the field of construction management, quality improvement and organisational change as it provides rich data that would help in answering complex research questions. Fellows and Liu (2008) pointed out that a survey can be a cost-effective tool for researchers, which makes it a common research design. They also pointed out that survey research can use observations, interviews and questionnaires for data collection and can help in answering questions related to why, how and what in management related research.

Case Study and Survey Designs

Based on the above discussions, it is evident that action research is not applicable to the overall aim of this study, which seeks to explore views, perceptions and barriers associated with integrating BIM, Facilities and Lean Construction. Ethnographic research is also not applicable as this study does not aim to examine any cultural or roots specific areas but rather focuses on organisational improvement and management sciences. A case study design and a survey design are the most convenient designs for this study as it enables the examination and exploration of the research problem in its natural settings and also enables the interaction and communication with the key stakeholders needed to provide insights on the research topic. It was highlighted by Tan (2002) that a survey strategy helps in gaining insights directly from the research participants. It was also noted in the literature that surveys can be used to collect both quantitative and qualitative data depending on the overall purpose of the study.

Selecting the appropriate research design is influenced by the overall purpose of the study and its objectives as noted by Creswell (2014). Therefore, considering that this study is aimed at developing a conceptual framework for facilities management, it is vital that a case-study design is adopted to examine the problem in its natural settings and also to be able to communicate with the key stakeholders. This research is positioned strongly with both principles of quantitative and qualitative research as explained in section 3.4 above, as the data collected would be both quantitative and qualitative to help explore the underpinning problems, barriers, challenges and also identify new ideas and solutions to enhance the effectiveness and efficiency of construction practices. Case study design is commonly used in construction management research as pointed out by Fellows & Liu (2008). They stated that case study research can help in providing new insights and ideas and also to describe phenomena. Moreover, case study design in construction management can help researchers observe the problem in its natural settings. For example, similar studies in the field have utilised the case study design to discuss and explore quality-related research subjects in the field of construction industry including (Hamdi & Lite, 2012; Liu & Shi, 2017; Hatmannet al., 2012; Di Giuda et al., 2020; Pikas et al., 2020).

The case-study design approach provides the opportunity to answer the key research questions in this study by exploring the research problem in its real-life context. The questions related to what barriers and challenges hinder the integration of BIM and Lean Construction to inform facilities management can only be explored through a case-study design and a survey design to collect mixed data which can be statistically analysed (questionnaire responses) and thematised (interview responses) to help gain a better understanding for the development of the conceptual framework. Bryman (2008) and Saunders et al (2007) pointed out that case study design can help in gaining rich understanding of the research context as well as answering the questions of 'why' and 'how', which are critical to this research. However, some of the limitations associated with case study design as noted by Fellows & Liu (2008) include difficulty in setting out the context for the case being studied as well as the huge quantities of data collected which could hinder the researcher's ability to analyse.

Construction Industry in Qatar

The construction industry in Qatar runs various construction projects that are related to residential construction, infrastructure, utility construction, commercial construction, industrial construction, road construction, and energy (Consulting Haus, 2020). The report titled ‘Qatar Construction Market’ was published by Mordor Intelligence (2020), which anticipated that a Compound Annual Growth Rate (CGAR) of 8% will be registered during 2020 – 2025. The government is focusing on attaining key infrastructure goals, which will make Qatar one of the fastest developing and progressing construction market worldwide. The construction industry will most probably attain benefits by continuing to invest in mega-scale projects related to the upcoming 2022 FIFA World Cup sports event and Qatar National Vision (QNV) 2030.

The key trends in the construction industry of Qatar include development of transport infrastructure, creation of wide-ranging top-rated sporting venues, and development of an up-to-date hospitality and residential environment so that the anticipated rise in population can be supported successfully (Consulting Haus, 2020). There exist various regional and local players in the industry, such as Golf Contracting, AL Jaber Engineering, QD – SBG, and HBK Contracting (Mordor Intelligence, 2020). The top 10 clients as per value of awarded projects include Ashghal (1st), HIA (2nd), QDREIC (3rd), QP (4th), Kahramaa (5th), Ariane Real Estate (6th), NBK & Sons Group (7th), MoQ (8th), QAF (9th), and SCDL (10th) (Consulting Haus, 2020, p. 5). Besides these, various facility management companies also offer services in the industry by establishing partnerships with construction developers. It is anticipated that the facility management market will grow in Qatar exponentially in upcoming years because low-rise buildings, malls, towers and stadiums will continue to be built and completed in the near future.

Data Collection Tools for Framework Development

The development of the conceptual framework for this study has utilized the following tools:

Literature Review: A systematic literature review using online databases was carried out to explore the Lean Construction approach and BIM approaches. The literature review helped in identifying facilities management improvement requirements through a comprehensive review of Lean Construction and BIM. Challenges and barriers associated with integrating such approaches were explored to help establish a strong theoretical basis for the study and provide better insights on the approach adopted for collecting primary data.

Case study Design and Survey Strategy**:** A cross-sectional survey design was adopted for the collection of data from the target 275 research participants. 275 sample size was targeted with confidence interval 95% and maximum variability of p = 0.5 (Israel, 2003). The population of the survey were practitioners in the field of construction in Qatar which include and not limited to project managers, surveyors, consultants, suppliers, and quality managers. As a result, a sample size of 163 was included in the study for precision of +-5% (Israel, 2003). In other words, 163 participants conducted the online questionnaire, whereas 6 took part in the interview. The online questionnaire was designed and conducted via Google Form survey, whereas interviews were conducted through online platform of Zoom. The rationale for choosing an online platform for both questionnaire and survey was that it facilitated the researcher in terms of gathering data with no cost and rapidly. Furthermore, all participants were selected as per the convenience sampling method. Therefore, whoever was able to attend on time as per their work schedule, took part in the questionnaire and interview.

The purpose of the survey was to understand current awareness and preparedness levels as well as the extent of implementations of BIM and Lean Construction. The survey also aimed at exploring the challenges or barriers and success factors of integrating Lean Construction and BIM as perceived by the participants. Moreover, expert opinion on how the integration of Lean Construction and BIM can inform Facilities Management will be elicited from case study findings. The survey was distributed in various construction companies in Qatar that were mainly undertaking construction projects as part of the FIFA World Cup 2022 preparations. The survey strategy utilized a structured online questionnaire and semi-structured interviews for collecting both numerical and textual data, respectively. Questionnaires provided the opportunity to understand the underlying meanings, factors, and insights on the research problem by gaining the viewpoints of the research subjects. To ensure the framework meets the expectations of the users, structured interviews were used to test the appropriateness and feasibility of adopting the framework.

Interviews: Besides conduction of online questionnaires, the survey strategy in this study also utilized interviews for the collection of primary data. Interviews have been commonly used to collect verbal and textual data using a systematic approach as explained by Evans (2007). The advantages of the case-study design can be maximized using a qualitative approach as these interviews can be more fluid than rigid as described by Yin (2009). Interviews provide rich insights and understandings once structured in an interactive manner. Semi-structured interviews are most commonly used in management and improvement research as they provide the opportunity for the researchers to expand on the questions being asked as well as develop a rapport with the research participants. Thomas (2003) indicated that structured interviews tend to use structured and closed questions that could limit the participants' ability to expand and provide more insights about their experience and knowledge. Hence, having a semi-structured approach to interviews would not limit the options available for the participants as noted by Moore (2006) and will lead to a more interactive session. Similarly, it was argued by Evans that structured interviews are perceived to be less flexible compared to semi-structured interviews.

Strategic Level Framework Development Process: A systematic approach was used to develop the conceptual framework for Facilities Management, taking into account the findings of the different phases of the study. The process can be summarised as follows:

Following the synthesis of the comprehensive literature review into BIM, Facilities Management, Lean Construction and quality-related improvement interventions in the construction field, it was important to conduct a thorough synthesis of the literature review to identify the main themes and patterns that were explored in other contexts rather than the Qatari context. The findings of the literature review enabled the development of the research methodology and the data collection tools so that the problem can be investigated in its real-life context.

A case-study design was utilised where the construction industry in Qatar was used as a case-study to help identify the barriers and challenges associated with integrating Lean Construction, BIM and Facilities Management. The case study design, along with survey strategy, enabled the researcher to observe and obtain first-hand information through conduction of online questionnaires that helped in shaping and developing the conceptual framework. Figure 2 is the flowchart of the survey process according to which the questionnaire was conducted.

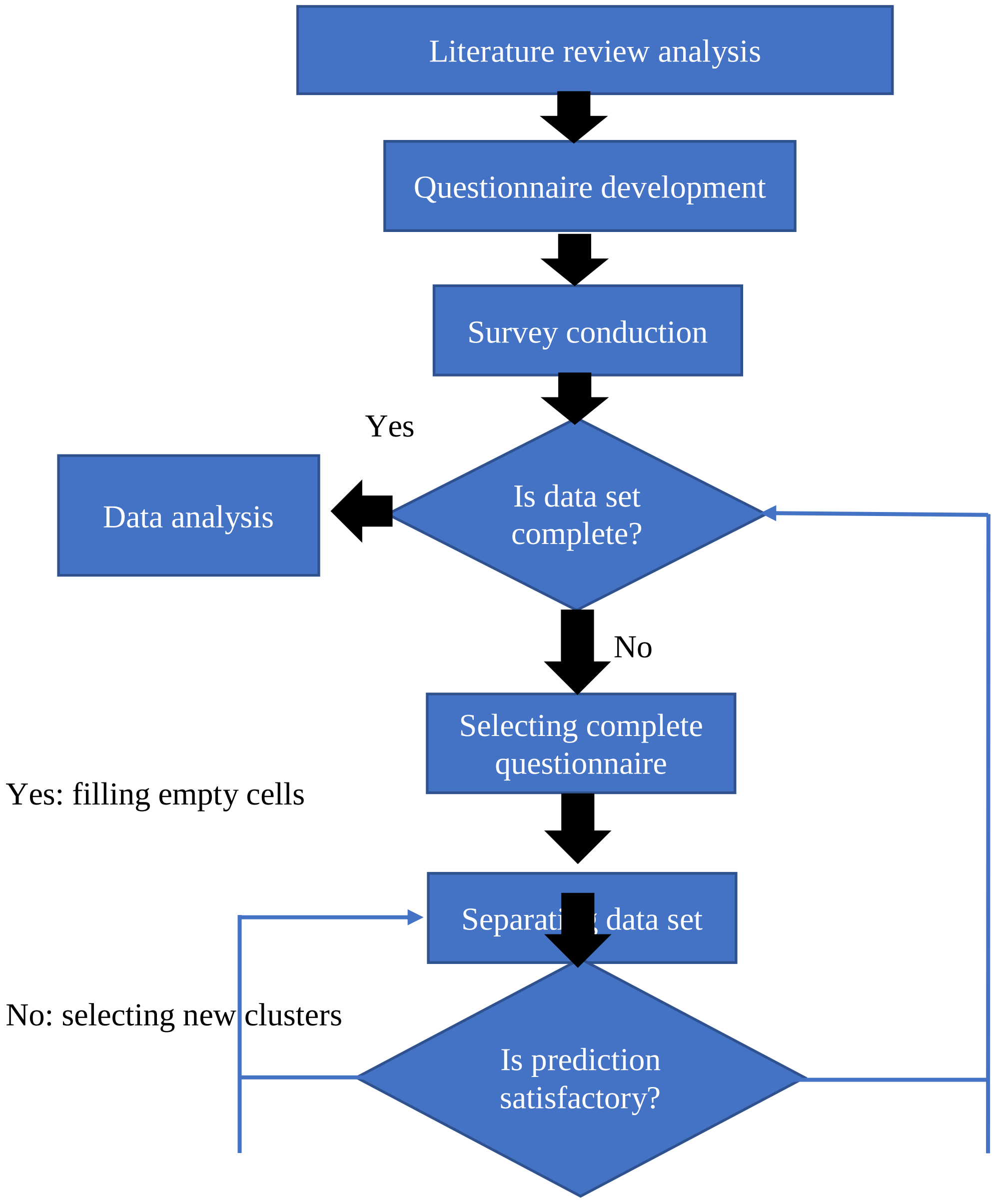

Figure 2. Flowchart for the Survey Process

Strategic Level Framework Validation Process**:** This body of research in Qatar is limited due to lack of experts' viewpoints in the country. Therefore, using a questionnaire survey for the validation of the conceptual framework was not possible due to the scarcity of experts so that a good response rate could be achieved. Therefore, it was vital to adopt a more flexible approach that could be utilised easily and will provide expert's comments on the framework and its appropriateness. Hence, in-depth structured interviews were carried out to validate the framework. Validation requires the collection of real-world comments as noted by Pidd (2009). Validation in research is crucial to ensure that the findings of the research make a positive impact as noted by Patton (2002). However, validation in qualitative research can be challenging as tests or experiments cannot be used to measure the effectiveness of the developed framework. Therefore, validation in this context of the research refers to the fitness, appropriateness and practicability of the development framework based on the views and opinions of experts in the field of construction management in Qatar. This provides real-life data based on the key stakeholders in the field. Further details on the validation process are included in Chapter Five. In short, semi-structured interviews were conducted for the collection of verbal and textual data. This was carried out using an interview protocol (copy in the appendices) to guide the interviews. Thematic analysis was used to analyse the data and develop themes for validation of the conceptual framework along with the findings of the literature review. Figure 3 is the flowchart of the interview process according to which interviews were conducted.

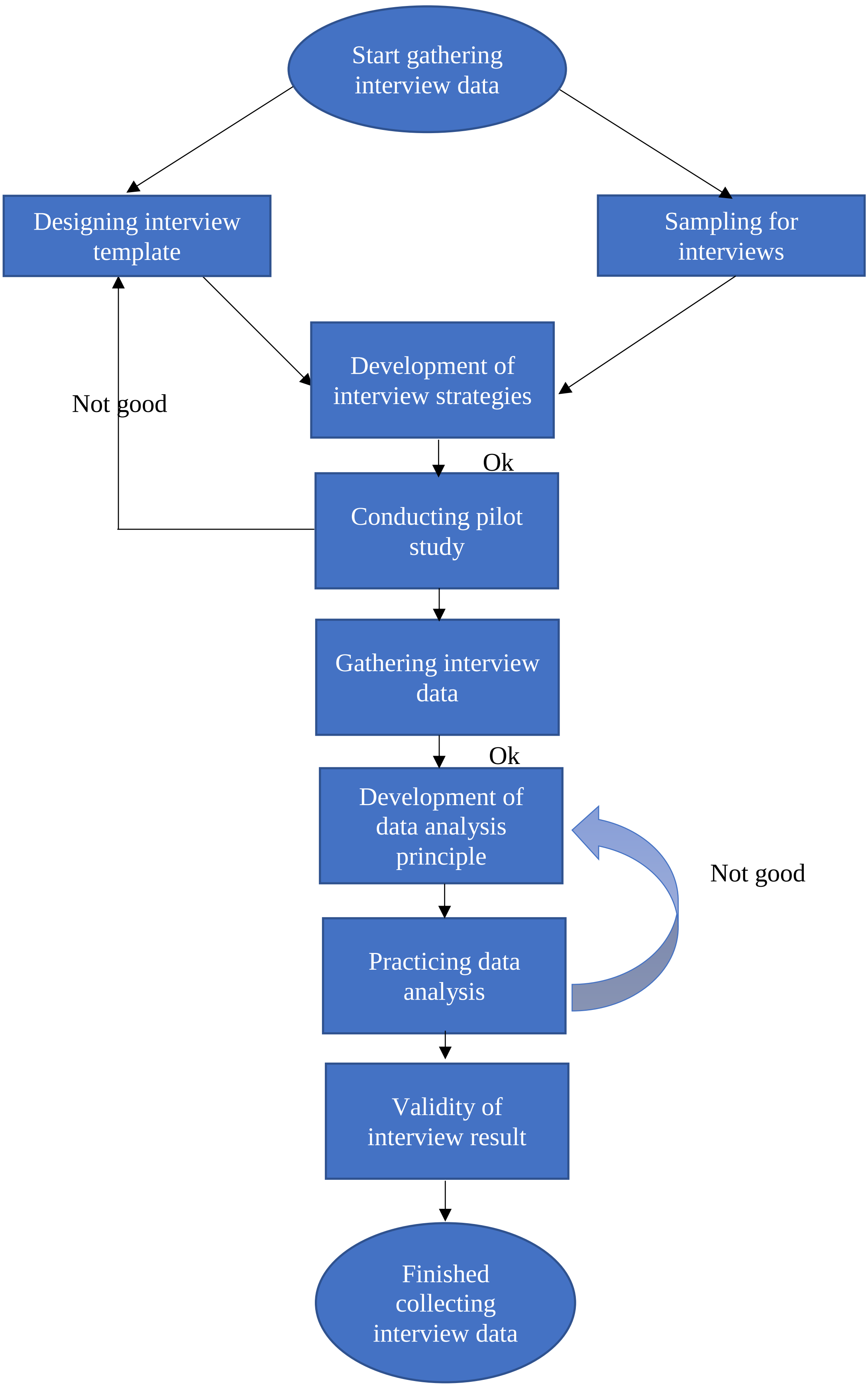

Figure 3. Flowchart for the Interview Process

Development of Implementation Level Framework: An implementation level framework was developed based on strategic level framework. The implementation matrix was developed based on quality-based BIM applications and Lean Construction principles. Particularly, the implementation level focused on facilities operations and maintenance.

Ethical Considerations

This research was carried out ethically and professionally in accordance with the rules of the University of Qatar. This involved the need to obtain informed consent from all the participants prior the data collection process (see appendix I). The participants were informed about their rights and responsibilities and they can withdraw from the study at any stage. The participants were assured that personal identifiable information was not collected and their participation is solely used for academic purposes. There were no hazards or risks imposed on the participants. The participation was based on voluntary basis and hence, no incentives were offered to the participants.

Chapter Summary

The purpose of this chapter was to discuss in great detail the methodological approach that was utilized for the collection of primary and secondary data for this research. The chapter discussed the philosophical research foundations along with explaining the difference between the qualitative and quantitative research approaches and the rationale for their application in this research. The chapter provided an overview of the data collection tools that were used for the development of the conceptual framework along with the ethical considerations and how these were managed throughout this research. The following chapter presents the key results and discussions.

Chapter Four – Case Study: Questionnaire Results

Chapter Introduction

The previous chapter discussed and critically analyzed the methodological approach adopted by this study. The purpose of this case study chapter is to present the findings of this empirical study by explaining questionnaire findings in theoretical, tabular and graphical forms. SPSS version 20 is used to conduct statistical analysis, and present results in the form of frequency distributions and descriptive statistics (mean). It also presents a discussion on the findings and their links with the literature review evidence.

Reliability Analysis and Response Rate

The online questionnaire was completed by 163 participants from the construction industry of Qatar; however, only 122 practitioners were able to fill all questions of the questionnaire. The remaining 41 attempted the survey, yet did not give responses for a few questions. Based on this, 122 valid responses were yielded, which led to a response rate of 75% (see table 1). Furthermore, a reliability test was run to ensure internal consistency of the scales used in the questionnaire design. The value of Cronbach's alpha was calculated to be 0.967 (see table 2), which shows exceptionally high reliability of the questionnaire.

Table 1. Case Processing Summary

		N	%
Cases	Valid	122	74.8
	Excluded[a]	41	25.2
	Total	163	100.0

a. Listwise deletion based on all variables in the procedure.

Table 2. Reliability Statistics for all scales

Cronbach's Alpha	N of Items
.959	97

Questionnaire Results

Demographics: The first section of the questionnaire asked questions related to demographics of participants, such as their job roles and duration of job experience. Overall, 163 responses were gathered and thus, there was no missing data (see table 3). The statistical results showed that there were 42% project managers, 33% subcontractors, 8% owner-private sectors, 6% owner-government, 5.5% suppliers, 2.5% general contractors and 1.8% consultants for site supervision (see table 4). In other words, the majority of participants were project managers followed by subcontractors. Furthermore, when questioned about the duration of their experience, the results showed that 60.7% had experience of more than 12 years, 14.7% had experience of 8-11 years, 12.9% had experience of 4-7 years, and 11.7% had experience of less than 3 years (see table 5). In other words, a majority of participants had wide experience of more than 12 years, followed by reasonable experience of 8-11 years. This reflects that the majority of participants who took part in the survey were experienced, and thus, provided valuable information based on their extensive experiences and viewpoints.

Table 3. Statistics for Demographics

		Please indicate your role?	What is the length of your experience please?
N	Valid	163	163
	Missing	0	0

Table 4. Frequency distribution for Job roles of Participants

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Academic or Researcher	1	.6	.6	.6
	Owner – government	10	6.1	6.1	6.7
	Owner – private sector	13	8.0	8.0	14.7
	Subcontractor	54	33.1	33.1	47.9
	Consultant - Site Supervision	3	1.8	1.8	49.7
	General Contractor	4	2.5	2.5	52.1
	Project Manager	69	42.3	42.3	94.5
	Supplier	9	5.5	5.5	100.0
	Total	163	100.0	100.0	

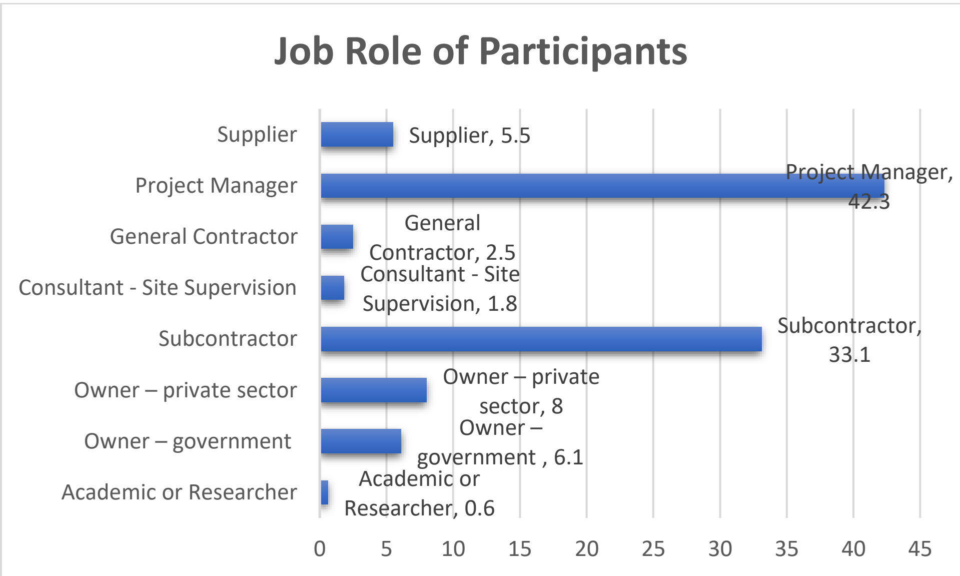

Figure 4. Graph for Frequency distribution of Participants as per their job roles.

Table 5. Length of experience of research participants

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	4-7 year	21	12.9	12.9	12.9
	8-11 years	24	14.7	14.7	27.6
	Less than 3 years	19	11.7	11.7	39.3
	More than 12 years	99	60.7	60.7	100.0
	Total	163	100.0	100.0	

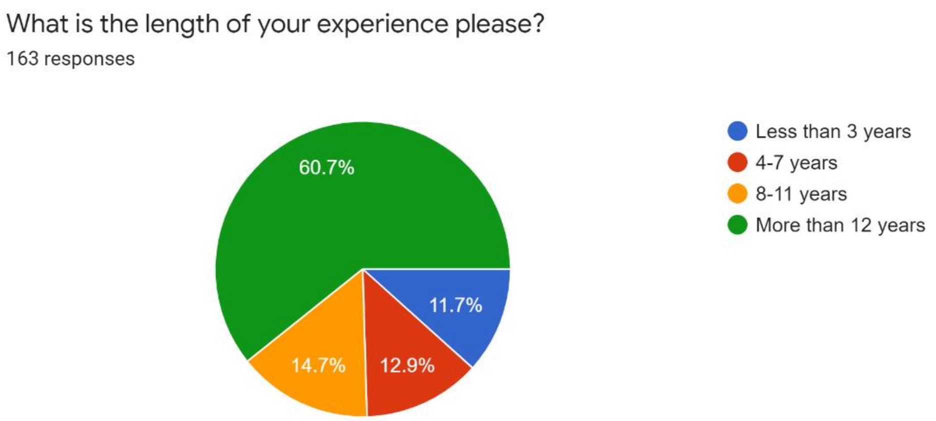

Figure 5. Graph for Frequency distribution of Participants as per their job experiences.

Lean Construction: The second section of the questionnaire asked questions related to the main study variable, i.e. Lean Construction. Initially, participants were questioned about the extent of use of Lean Construction in their organisation. It was found that 32.5% reported usage to some extent, 31.9% reported no use at all, and 23% reported usage to a moderate extent (see table 6). Based on the responses of majority of participants, it can be seen that there exists moderate to slight use of Lean Construction in the construction industry of Qatar.

Table 6. Participants' responses related to the extent of use of Lean Construction

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	not at all	52	31.9	31.9	31.9
	to some extent	53	32.5	32.5	64.4
	to a moderate extent	38	23.3	23.3	87.7
	to a great extent	20	12.3	12.3	100.0
	Total	163	100.0	100.0	

Next, results were gathered from participants in the form of mean values, where a mean value of 1 showed response value 'strongly agree' – 5 showed response value 'strongly disagree'. When participants were questioned about awareness of Lean Construction in their organisation, it was found that a majority of them agreed to having awareness of Lean Construction, because they agreed that waste reduction is conducted in construction projects by incorporating lean production systems. Yet, most of them showed neutral response to applicability of lean construction models in their organisation (see table 7). In other words, it can be seen that there exists limited awareness of Lean Construction in the industry.

Table 7. Participants' responses related to the extent of agreement or disagreement with the Awareness of Lean Construction

	N	Mean

Waste reduction is handled through integration of lean production systems in construction projects	163	2.67
Lean construction models are applied in your construction company	163	2.97
Valid N (listwise)	163	

When participants were questioned about preparedness for Lean Construction in the organisation, it was found that a majority of them agreed to the adoption of Lean Construction for waste reduction and attainment of maximum end-product. Yet, most of them showed neutral response to readiness for adoption of Lean Construction instruments and principles (see table 8). In other words, it can be seen that there exists limited preparedness for Lean Construction in the industry.

Table 8. Participants' responses related to the extent of agreement or disagreement with the Preparedness for Lean Construction

	N	Mean
Your company is ready to adopt lean construction instruments and principles	163	2.37
Your company focuses on adopting lean construction so that wastes can be reduced and maximum end-product value can be attained	163	2.77
Valid N (listwise)	163	

When participants were questioned about implementation of Lean Construction in their organisation, it was found that a majority of them agreed to implementation of a few main features of Lean Construction due to cultural resistance to change. Yet, most of them showed neutral response to different implementations of Lean Construction due to no clarity of main practices, methods and tools (see table 9). In other words, it can be seen that there exists limited implementation of Lean Construction in the industry mainly due to the factor of cultural resistance to change.

Table 9. Participants' responses related to the extent of agreement or disagreement with the Implementation of Lean Construction

	N	Mean
Your company implements few distinct features of lean construction due to cultural resistance to this change	163	2.70
Your company implements lean construction differently since there exists unclear vision of key methods, practices and tools of lean construction	163	2.98
Valid N (listwise)	163	

When participants were questioned about benefits of Lean Construction in the organisation, it was found that a majority of them strongly agreed to all the listed benefits. The top three benefits of Lean Construction include waste elimination, higher client satisfaction, and better delivery processes and systems (see table 10).

Table 10. Participants' responses related to the extent of agreement or disagreement with the Benefits of implementing Lean Construction

	N	Mean
a. Better delivery processes and systems	163	2.09
b. Improved financial status and project performance of company	163	2.21
c. Better health and safety as per clients' requirements	163	2.36
d. Waste elimination	163	2.07
e. Higher client satisfaction	163	2.13
f. Reduced construction office times	163	2.60
g. Higher turnover	163	2.44
h. Lower project costs	163	2.38

Valid N (listwise)	163

When participants were asked about key success factors for Lean Construction in the organisation, it was found that a majority of them strongly agreed to all mentioned critical success factors. The top three success factors for Lean Construction include the role of senior management, appropriate training, and process-focused efforts (see table 11).

Table 11. Participants' responses related to the extent of agreement or disagreement with the Key Success Factors for implementing Lean Construction

	N	Mean
a. Role of Senior Management	163	2.04
b. Process-focused efforts	163	2.14
c. Improvement goals	163	2.16
d. Involvement of Stakeholders	163	2.28
e. Appropriate Training	163	2.10
f. Flexible time to be spent on improvements	163	2.20
g. High level of Communication between Suppliers	163	2.19
h. Assessment of Barriers to change and formation of an Action Plan	48	2.42
Valid N (listwise)	48	

When participants were asked about the main challenges and barriers associated with implementing Lean Construction in their organisation, it was found that a majority of them either gave neutral responses, or mentioned significant challenges. The top three challenges included lack of lean knowledge, changing employees' working culture, lack of long-term forecast and investment, and lack of cooperation from employees (see table 12). In other words, it can be seen that there exist limited barriers and challenges in terms of mismanagement of time, less knowledge and cooperation from employees, scarce finances, varying work culture, and poor forecast.

Table 12. Participants' responses related to the extent of agreement or disagreement with the main barriers and challenges associated with implementing Lean Construction

		N	Mean
a.	Changing Employees Working Culture	160	3.71
b.	Cost of Implementation	161	3.35
c.	Lack of Lean Knowledge	161	3.78
d.	Long Implementation Time	160	3.61
e.	Complexity	161	3.34
f.	Lack of Cooperation from Employees	161	3.61
g.	Lack of Incentives	161	3.67
h.	Lack of long-term Forecast and Investment	163	3.70
Valid N (listwise)		157	

BIM**:** The third section of the questionnaire asked questions related to another study variable, i.e. BIM. Initially, participants were asked about the extent of use of BIM in their organisation. It was found that 33.7% reported moderate use, 26% reported usage to some extent, and 22% reported no use at all (see table 13). In other words, it can be seen that there exists moderate use of BIM in the industry.

Table 13. Participants' responses related to the extent of use of BIM

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	not at all	36	22.1	22.8	22.8
	to some extent	43	26.4	27.2	50.0
	to a moderate extent	55	33.7	34.8	84.8
	to a great extent	24	14.7	15.2	100.0
	Total	158	96.9	100.0	

Missing	System	5	3.1	
Total		48	163	100.0

When participants were asked about awareness of BIM in their organisation, it was found that a majority of them agreed to having limited awareness and lack of clarity of BIM (see table 14). This reflects that there exists limited awareness of BIM in the industry.

Table 14. Participants' responses related to the extent of agreement or disagreement with the Awareness of BIM

	N	Mean
a. Limited awareness of BIM among contractors, architects, facility managers and quantity surveyors	159	2.66
b. Lack of clarity of BIM	159	2.97
Valid N (listwise)	159	

When participants were asked about preparedness for BIM in their organisation, it was found that a majority of them agreed to preparedness for BIM in their respective companies in the construction industry of Qatar, since it uses a bottom-up approach and involves people in the implementation stage for applying BIM (see table 15). In other words, it can be seen that there exists reasonable preparedness for BIM in the industry.

Table 15. Participants' responses related to the extent of agreement or disagreement with the Preparedness for BIM

	N	Mean

a.	BIM application requires a Bottom-up approach	159	2.72
b.	BIM application requires involvement of people in implementation stage	157	2.26
Valid N (listwise)		157	

When participants were asked about implementation of BIM in their organisation, it was found that a majority of them agreed there had been successful implementation of BIM. Yet, most of them also agreed to the fact that there exists implementation to only a low extent of BIM in infrastructure and construction projects (see table 16). In other words, even though there exists low implementation of BIM in the industry, most projects in which BIM is implemented are found to be successful.

Table 16. Participants' responses related to the extent of agreement or disagreement with the Implementation of BIM

		N	Mean
a.	Successful application of BIM	160	2.29
b.	Low implementation of BIM in construction and infrastructure projects	160	2.96
Valid N (listwise)		160	

When participants were asked about the benefits of BIM in their organisation, it was found that a majority of them agreed to all stated benefits. The benefits of BIM are ranked as: enhanced construction project management methods and process (1st benefit), highly cooperative construction design and idea (2nd benefit) and effective application of lean principle (3rd benefit) (see table 17).

Table 17. Participants' responses related to the extent of agreement or disagreement with the Benefits of implementing BIM

	N	Mean
a. Highly cooperative construction idea and design	162	2.24
b. Enhance construction project management process and methods	162	2.14
c. Effective application of lean principles	162	2.30
Valid N (listwise)	162	

When participants were asked about key success factors for BIM in their organisation, it was found that a majority of them agreed to all stated critical success factors. The top-rated success factors for BIM include BIM training programs, organisational structure to support BIM system, competent technical support, and professional BIM design teams (see table 18).

Table 18. Participants' responses related to the extent of agreement or disagreement with the Key Success Factors for implementing BIM

	N	Mean
a. Clients acceptance with BIM projects	160	2.41
b. Organisational Structure to support BIM system	161	2.22
c. Financial Support from the Government to set up BIM system	162	2.37
d. BIM Standards for the Industry	161	2.36
e. BIM Training programmes	161	2.17
f. Information-sharing protocols	159	2.33
g. Competent technical support team	162	2.23
h. Professional BIM Design team	162	2.24
Valid N (listwise)	159	

When participants were asked about the main challenges and barriers associated with implementing BIM in the organisation, it was found that some of them either gave neutral responses, yet a majority mentioned moderate challenges. The top three moderate challenges include lack of awareness about benefits of BIM, lack of commitment from top management and lack of training and expertise (see table 19). In other words, it can be seen that there exist limited barriers and challenges in terms of minimal awareness, non-supportive top management and less expert staff.

Table 19. Participants' responses related to the extent of agreement or disagreement with the main barriers and challenges associated with implementing BIM

	N	Mean
a. High operational costs	161	3.36
b. Lack of training and expertise	162	3.54
c. Lack of commitment from top management	160	3.56
d. Not widely adopted in Qatar	158	3.27
e. Resistance to change	160	3.34
f. Lack of awareness about benefits	160	3.63
Valid N (listwise)	158	

Integration of Lean Construction and BIM in Facilities Management**:** The third section of the questionnaire asked questions related to association between all study variables, i.e. Lean Construction, Facilities' Management, and BIM. Initially, participants were inquired about integration of all these variables for enhancement of performance and data visualization. It was found that 46% strongly agreed to it, 25% showed neutral response to it, and 12% agreed to it (see table 20). In other words, it can be seen that there exists strong agreement to integration of Lean Construction, Facilities' Management and BIM for improving performance and data visualization.

Table 20. Participants' responses related to the integration of Facilities Management, BIM and Lean Construction for enhancing data visualisation and performance

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	strongly agree	75	46.0	46.9	46.9
	agree	20	12.3	12.5	59.4
	neutral	41	25.2	25.6	85.0
	disagree	12	7.4	7.5	92.5
	strongly disagree	12	7.4	7.5	100.0
	Total	163	100	100.0	

When participants were asked about benefits of integration of Facilities management and BIM, it was found that a majority of them agreed to all stated benefits. The benefits of integration of Facilities management and BIM are ranked as better tracking and maintenance of assets (1st benefit), an ease of data transfer (2nd benefit), improved issuing of work orders (3rd benefit) (see table 21).

Table 21. Participants' responses related to the extent of agreement or disagreement with the benefits that can be achieved from integrating BIM and Facilities Management

	N	Mean
a. Ease of data transfer	160	2.31
b. Better tracking and maintenance of assets	159	2.33
c. Improved issuing of work orders	160	2.44
Valid N (listwise)	159	

When participants were asked about benefits of integration of Facilities management and Lean Construction, it was found that a majority of them agreed to all stated benefits. The benefits of integration of Facilities management and Lean Construction are ranked as reduced inefficiencies (1st benefit), increased value for customers (2nd benefit), and increased productivity level (3rd benefit) (see table 22).

Table 22. Participants' responses related to the extent of agreement or disagreement with the benefits that can be achieved from integrating Lean Construction and Facilities Management

		N	Mean
a.	Increased value for customers	160	2.45
b.	Reduced inefficiencies	153	2.38
c.	Increased productivity level	159	2.51
Valid N (listwise)		153	

When participants were asked about benefits of integration of BIM and Lean Construction, it was found that a majority of them agreed to all stated benefits. The benefits of integration of BIM and Lean Construction are ranked as effective coordination (1st benefit), waste reduction (2nd benefit) and better management and control of project cost, schedule and quality (3rd benefit) (see table 23).

Table 23. Participants' responses related to the extent of agreement or disagreement with the benefits that can be achieved from integrating Lean Construction and BIM

		N	Mean
a.	Creation of automated work package	157	2.51
b.	Effective coordination	160	2.35
c.	Better control and management of project schedule, cost and quality	159	2.37
d.	Waste reduction	158	2.39
Valid N (listwise)		157	

When participants were asked about the main challenges and barriers associated with integration Facilities management and BIM, it was found that some of them either gave neutral responses, yet majority mentioned moderate challenges. The top three moderate challenges include lack of collaboration between project stakeholders and end user, lack of training and lack of BIM skills (see table 24). In other words, it can be seen that there exists limited barriers and challenges in terms of minimal training and skills, and lack of collaboration between end user (customer) and project stakeholders.

Table 24. Participants' responses related to the existing barriers and challenges for integrating BIM and Facilities Management

	N	Mean
a. Hard data entry in Facilities Management Software	160	3.12
b. Scattered and unorganised data	160	3.20
c. Outdated model	160	3.15
d. Lack of BIM skills	160	3.28
e. Lack of communication	158	3.23
f. Lack of training	160	3.29
g. Lack of collaboration between end user and project stakeholders	157	3.41
Valid N (listwise)	157	

When participants were asked about the main challenges and barriers associated with integration Facilities management and Lean Construction, it was found that a majority of them gave neutral response related to challenges of insufficient resources and high expectations of customers. However, most of them identified moderate challenges such as culture and language barriers (see table 25). In other words, it can be seen that there exist challenges in terms of language and cultural barriers.

Table 25. Participants' responses related to the existing barriers and challenges for integrating Lean Construction and Facilities Management

		N	Mean
a.	Insufficient resources	160	3.24
b.	Language barrier	155	2.99
c.	Culture barrier	155	3.09
d.	High expectations of customers	160	3.23
Valid N (listwise)		155	

When participants were asked about the main challenges and barriers associated with integration BIM and Lean Construction, it was found that a majority of them gave neutral response related to challenges of uneven sharing of risk, resistance to change, lack of BIM standard and lack of government incentives. However, most of them identified moderate challenges such as cost of implementation, lack of employee skills, lack of organisational infrastructure, and lack of education and training (see table 26). In other words, it can be seen that there exist challenges in terms of high implementation cost, inadequate organisational infrastructure, and less trained, skilled and educated staff.

Table 26. Participants' responses related to the existing barriers and challenges for integrating Lean Construction and BIM for Facilities Management

		N	Mean
a.	Cost of implementation	160	3.38
b.	Lack of government incentives	153	3.31
c.	Lack of employee skills	157	3.43
d.	Lack of BIM standard	159	3.32
e.	Lack of organisational infrastructure	155	3.35
f.	Uneven risk sharing	154	3.31
g.	Lack of training and education	157	3.35
h.	Resistance to change	156	3.28

Valid N (listwise)	153	

When participants were asked about key success factors for integrating Lean Construction and Facilities Management, it was found that a majority of them agreed to all stated critical success factors. The top three success factors for integrating Lean Construction and Facilities Management include training for employee development, continuous improvement and leadership (see table 27).

Table 27. Participants' responses related to the success factors for integrating Lean Construction and Facilities Management

	N	Mean
a. Use of reliable tested technology	159	2.60
b. Leadership	154	2.51
c. Continuous improvement	158	2.46
d. Training for employee development	159	2.45
e. Sharing of crucial data and information	155	2.54
Valid N (listwise)	154	

Finally, when participants were asked about key success factors for integrating Lean Construction and BIM for Facilities Management, it was found that a majority of them agreed to all stated critical success factors. The top three success factors for integrating Lean Construction and BIM for Facilities Management include organisation continuous improvement, collaboration in the design and construction, and information maintenance and model integrity (see table 28).

Table 28. Participants’ responses related to the success factors for integrating Lean Construction and BIM for Facilities Management

	N	Mean
a. Standardization	160	2.57
b. Organisation continuous improvement	160	2.39
c. Visual management use	156	2.44
d. Information maintenance and model integrity	158	2.43
e. Rapid assessment and generation of alternative construction plans	159	2.46
f. Selection of an appropriate method of production control	158	2.51
g. Collaboration in the design and construction	158	2.40
Valid N (listwise)	156	

Discussion

Regarding Lean Construction, the questionnaire responses from practitioners within the construction industry in Qatar showed there exists moderate to slight use of Lean Construction. Moreover, it showed that there exists limited awareness, implementation and preparedness of Lean Construction because it is used for waste reduction only. Its other models, principles, and instruments are not ready to be applied in the industry. The lack of awareness and preparedness for Lean Construction can be supported by the study of Bajjou et al. (2019) who showed that lean construction models are widely known in various countries, including the UK, Germany, USA, Turkey and Brazil, but not Middle East. Likewise, Bajjou et al. (2019), showed that there exists unclear vision of key methods, practices and tools of lean construction. Its lack of implementation in Qatar can be supported by the study of Dulaimi & Tanamas (2008) who revealed that construction companies hesitate from applying it completely within the local context because they face the major obstacle of cultural resistance to this change.

The questionnaire results further identified the top three benefits of Lean Construction as waste elimination, higher client satisfaction, and better delivery processes and systems. The top three success factors for Lean Construction are identified to be: role of senior management, appropriate training, and process-focused efforts. These success factors and benefits can be supported by the literature review findings of Ansah et al. (2016) and Dulaimi & Tanamas (2008). The questionnaire findings further identified four moderate challenges including lack of lean knowledge, changing employees' working culture, lack of long-term forecast and investment, and lack of cooperation from employees. This can be supported by the findings of Tauriainen et al. (2016), who found that issues faced while applying Lean Construction include poor communication leading to lack of cooperation, and lack of Lean Construction knowledge.

Regarding BIM, the questionnaire responses from practitioners within the construction industry in Qatar showed there exists moderate use of BIM, despite its limited awareness, its low yet successful implementation, and reasonable preparedness in the industry. The lack of awareness is also identified as the major barrier facing those working towards BIM application. This can be supported by the study of Mohammed et al. (2019) who showed that there exists limited awareness related to BIM in the Qatar construction industry, such that engineers are more aware of BIM in contrast to contractors, architects, facility managers and quantity surveyors. Likewise, Vukovic et al. (2015) revealed that there exists lack of clarity about BIM in the Qatar construction industry due to minimal mandate by the national central government. Furthermore, the reasonable preparedness of BIM can be supported by the literature review findings of Azhar et al. (2015), which stressed that a bottom-up approach is applied for BIM regardless of a top-down approach.

The successful implementation of BIM in the industry can be supported by the study of Atzl & Eichler (2018) who showed that BIM is applied successfully through following inherent procedures, which eventually help in gathering, changing, assessing and reporting construction projects' information. However, low implementation of BIM is reflected by the identified barrier of lack of training and expertise, which can be supported by the literature review findings of Mohammed et al. (2019), who anticipated that construction industry of Qatar will implement BIM less at government level.

The benefits of BIM are ranked as: enhanced construction project management methods and process (1st benefit), highly cooperative construction design and idea (2nd benefit) and effective application of lean principle (3rd benefit). These benefits can be supported by the findings of Hosseini et al. (2018) and Terreno et al. (2019) who showed that BIM technology is comprised of functions that facilitate a highly cooperative construction idea and design. Furthermore, it must be noted that the identified benefits can be attained through focusing on the top-rated success factors. For instance, BIM training programmes and supportive organisational structure are crucial for successful application of BIM. Likewise, the success factors of competent technical support team and professional BIM design team within the industry can lead to benefit of highly cooperative construction design and idea.

Afterwards, the most important survey findings showed that there exists strong agreement to integration of Lean Construction, Facilities' Management and BIM for improving performance and data visualization. This can be supported by the study of Nascimento et al. (2018) who found that an implementation of BIM along with Lean Construction can improve Facility Management by better controlling the construction projects, and thus, enhancing processes in an incremental and continual manner.

The questionnaire results showed benefits of integration of Facilities management and BIM, which are ranked as: better tracking and maintenance of assets (1^{st} benefit), an ease of data transfer (2^{nd} benefit), and improved issuing of work orders (3^{rd} benefit). This can be supported by the literature review finding of Edirisinghe et al. (2017), who found that BIM is related to administration of information, such that it helps in terms of developing and sharing information among stakeholders in a collaborative manner. The questionnaire showed benefits of integration of BIM and Lean Construction, which are ranked as: effective coordination (1^{st} benefit), waste reduction (2^{nd} benefit) and better management and control of project cost, schedule and quality (3^{rd} benefit). These benefits can be attained through success factors such as standardization, organisation continuous improvement and use of visual management This can be supported by the study of Nascimento et al. (2018) who found that an integration of lean approaches with BIM results into a better and effective project management.

The top three success factors for integrating Lean Construction and Facilities Management include sharing of training for employee development, continuous improvement and leadership. This can be supported by the findings of McArthur & Bortoluzzi (2018) who found that the key Lean Construction principles for Facilities Management are related to leadership and kaizen (continual improvement). Therefore, the focus on these success factors can help to attain certain benefits. For instance, success factor of employee development can increase productivity. Likewise, success factor of leadership can increase value for customers, and success factor of continuous improvement can offer benefit in terms of reduced inefficiencies. Finally, the moderate challenges identified through the survey included culture and language barriers, high implementation cost, inadequate organisational infrastructure, and less trained, skilled and educated staff. These barriers were also identified by literature review study by Terreno et al. (2019).

Chapter Summary

This chapter has presented and explained the questionnaire findings in theoretical, tabular and graphical forms. Both frequency distributions and descriptive statistics in terms of mean values were used to present important findings, which were then linked with the literature review evidence to draw sound judgements and conclusions. The main findings were used to develop a conceptual framework for Facilities Management, which is presented and explained in the next chapter.

Chapter Five – Development of Facilities Management Conceptual Framework

Introduction

This chapter aims to develop a conceptual framework based on the questionnaire findings of the research. It has been validated through conduction of a mixture of structured and semi-structured interviews with professionals in the field. The thematic content analysis has been used for the development of themes underlying the proposed facilities management framework. The purpose of the framework is to provide an integrated approach to enhance efficiency, effectiveness, and value in facilities management in developing countries.

Strategic Level Conceptual Framework Development

The questionnaire's main findings led to the identification of various benefits and critical success factors for integrating Lean Construction and BIM for Facilities Management. The survey findings also identified potential barriers and challenges for this integration. Therefore, the following is the proposed conceptual model of the

Facilities Management conceptual framework, which is suitable for the construction industry in Qatar. The model shows applications of BIM functions and tools (stage 1) along with implementation of Lean Construction principles and Kaizen (stage 2) which can achieve the desired targets of an effective Facilities Management system, a holistic usage of Lean Construction and BIM for better construction quality, and consequently, maximized value for customers. Here, it must be noted that the model assumes that the companies have already implemented BIM and Lean Construction, and the companies aware of the benefits for integrating Lean Construction and BIM. In case of such companies, all outcomes at stage 3 can be attained. However, in the case of companies that have limited awareness and readiness level of Lean Construction, only one 1 out of 3 outcomes can be attained at stage 3 as shown in the figure 6. Besides these, companies which are still at awareness and readiness levels of both BIM and Lean Construction are not in a position to apply this model. This means that such companies have to first improve the levels of BIM usage and Lean Construction implementation in order to qualify for stage 1 of the conceptual model. In addition, such companies need to appreciate the benefits of integrating Lean Construction and BIM.

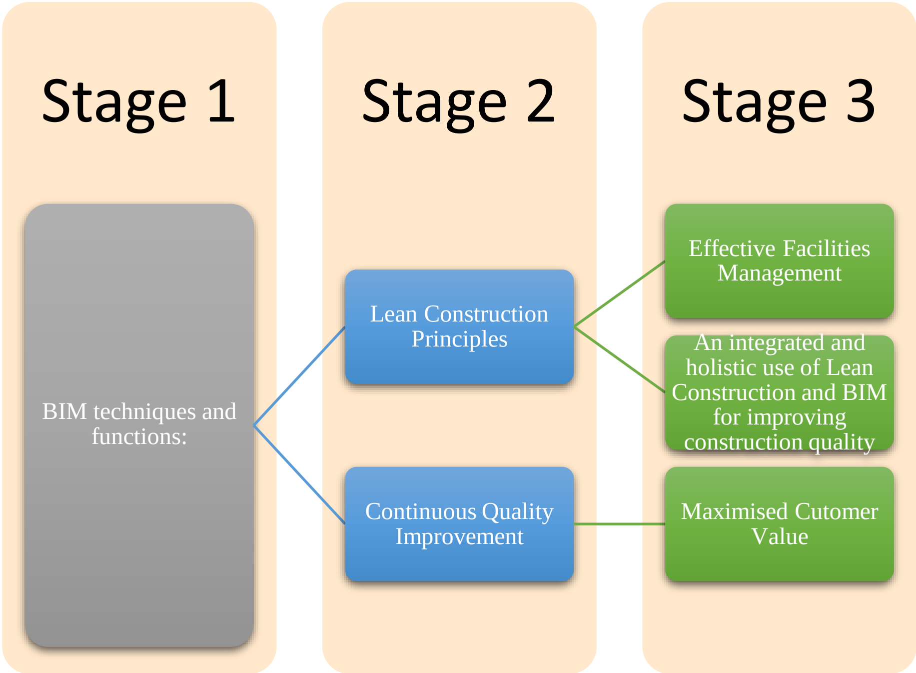

Figure 6. Conceptual Model for Facilities Management framework for developing countries.

Based on the conceptual model shown in Figure 6, a 4-level strategic conceptual model was developed. The conceptual model derived inspiration from a research framework proposed in Sacks et al. (2010). The conceptual model was developed in the form of interaction matrices that provides an array mapping of key success factors, key functions, and benefits that can be accrued if a pairwise combination of the key elements of this research, i.e. BIM functions, Lean Construction principles and Facilities Management principles. The aforementioned conceptual framework has led to four matrices within a strategic level framework. The construction industry in Qatar can use all four strategic interaction frameworks for enhancing Facilities Management through integrating BIM and Lean Construction. Overall, the questionnaire results and literature review findings were used to design these frameworks.

In the strategic level frameworks shown in Tables 29, 31, 33 and 35, BIM functions and Lean Construction principles are arranged in the form of a matrix. In table

29, Lean Construction principles are stated along rows and BIM functions are stated across columns. The strategic interactions between both BIM and Lean Construction are shown with the sign of 'x' in the matrix cells. All cells are briefly explained in Table 30. Table 29 shows the strategic level conceptual framework for BIM versus Lean Construction. Table 31 shows the strategic level conceptual framework for Lean Construction versus Facilities Management and the cells are explained in Table 32. Table 33 shows the strategic level conceptual framework for BIM versus Facilities Management, and the cells are explained in Table 34. Finally, Table 35 shows the strategic level conceptual framework for BIM and Lean Construction versus Facilities Management, and the cells are explained in Table 36. All frameworks were validated through a mixture of structured and semi-structured interviews with project managers, facilities managers and professionals in the field of quality improvement, lean construction and project management.

Table 29. Interaction Matrix of BIM functionality and Lean Construction principles for Facilities Management

		Lean Construction Principles as per its Benefits					
		Better management and control of project cost, quality, and schedule	Waste reduction	Effective coordination	Leadership	Continuous improvement (kaizen)	Training for employee development
BIM functionality as per Key Success Factors		A	B	C	D	E	F
Organisation continuous improvement	1	X					
Collaboration in Design and Construction	2			X		X	
Information maintenance and model integrity	3	X					
Organisation structure to support BIM system	4	X				X	
Competent technical support	5	X		X			X
BIM Training	6					X	X
Minimal cultural and language barriers	7			X	X		X
Professional BIM design team	8		X				
Top Management Support	9				X		X

Table 30. Strategic Interaction Matrix that explains contents of cells

Index	Explanation
1-A	Principle of kaizen, i.e. continual improvement while applying BIM leading to better facility management through enhanced control and management of project schedule, operational costs, and quality of projects.
3-A	Model integrity along with better maintenance of information can help in better scheduling, minimise misinformation and avoid unnecessary work for staff
4-A	Organisational structure to support application of BIM can also improve success rate of projects through better control and management of time, finances and quality.
4-E	Supportive organisational structure for BIM can help in seeking continual improvement, i.e. Kaizen which is the main principle of Lean Construction.
2-C	Collaboration in BIM design and construction along with effective coordination in Lean Construction can result in favourable outcomes for facilities management in the industry.
2-E	Collaboration in BIM design and construction can speed up the continuous improvement process in construction companies.
7-C	Removal of language and cultural barriers during implementation of BIM can facilitate Lean Construction through more effective coordination in facility management.
7-F	Minimal cultural and language barriers allow trainers and leaders to better guide and lead subordinates and trainees.
7-D	Minimal cultural and language barriers during BIM application can strengthen leadership in Lean Construction, which can lead to better training and guidance of key personnel for facility management.
6-E	Provision of BIM training allows staff to better execute methods and job roles which are relative to Lean Construction in construction companies.
6-F	BIM training along with employee development training can enhance skills, professional personality, expertise and knowledge of staff, so they can use reliable and tested technology for Lean Construction.
5-A	Competent technical support improves control and management of project schedule, operational costs, and quality of technical parts of the project.
5-C	Competent technical support for BIM applications reflects effective coordination, which can facilitate the industry in Lean Construction and Facility Management.
5-F	Competent technical support for BIM along with training for employee development regarding Lean Construction can produce the required manpower for successful Facilities Management.
8-B	Professional BIM design team within the industry can reduce waste to the desired extent.

9-D	Top management support for BIM and leadership in Lean Construction ensures a satisfied, more aware, and committed workforce.
9-F	Top management support for development of employees in required fields can produce desired results.

Table 31. Interaction Matrix of Lean Construction and Facilities Management

		Facilities Management			
		High value for customers	Lower inefficiencies	Higher productivity level	Sharing of crucial information and data
Lean Construction		A	B	C	D
Minimal language barrier	1				X
Minimal cultural barrier	2			X	
Sufficient resources	3		X		
Use of reliable tested technology	4	X			
Leadership	5			X	
Kaizen	6		X		
Training	7		X		

Table 32. Strategic Interaction Matrix that explains contents of cells

Index	Explanation
1-D	Removal of language barrier during implementation of Lean Construction can facilitate better sharing of important information and data, and thus, consequently effective coordination in facility management.
2-C	Removal of language and cultural barriers during implementation of BIM can facilitate Lean Construction through more effective coordination in facility management.
3-B	Availability of required and adequate resources can enhance quality of business processes, and thus, lower inefficacies.
4-A	Use of reliable tested technology of Lean Construction can reduce waste, streamline business processes, and thus, provide high value for customers.
5-C	Leadership can result into strong human resources and effective coordination in Lean Construction, which in turn can result into favorable outcome of higher productivity for facilities management in the industry.
6-B	Principle of kaizen, i.e. continual improvement while applying Lean Construction leads to better facility management through improved operations and thus lower inefficiencies.
7-B	Training of staff related to Lean Construction can also reduce inefficiencies by improving skills, knowledge and expertise of workforce.

Table 33. Interaction Matrix of BIM functionality and Facilities Management

		Facilities Management								
		Ease of data transfer	Latest model	Organized data	Better tracking and maintenance of assets	Improved space management	Historical trends for maintenance and service history	Environmental impacts and operating cost	Appropriate maintenance system	Productivity
BIM functionality		A	B	C	D	E	F	G	H	I
BIM skills	1				X					
Communication	2	X		X						
Training	3		X							

Data visualization	4					X				
Digitalization	5								X	
Life cycle of facility	6									X
Information platform	7						X			
Workflow efficiencies	8							X		
Facilitate data accessibility	9			X						

Table 34. Strategic Interaction Matrix that explains contents of cells

Index	Explanation
1-D	Attainment or improvement of BIM skills can result into better facility management through improved maintenance and tracking of assets.
2-A	Communication within the staff, and between management, top authorities and employees (all key stakeholders) can facilitate data transfer and sharing.
2-C	Strong communication skills can strengthen facility management through better organizing crucial data.
3-B	Training of employees related to BIM can facilities facility management by making them capable of using latest tools and models.
4-E	BIM-based data visualization enhances space management in facilities by integrating real-time data into BIM
5-H	BIM-based Facility Maintenance System helps the maintenance staff members in terms of accessing and examining 3D-BIM models, so that maintenance records can be updated digitally in the construction facility.
6-I	The use of advanced BIM technology for facility management not only enhances the effectiveness of building lifecycle, but also leads to higher productivity.
7-F	BIM information platform helps in maintenance of the facility by allowing the maintenance team to use prior maintenance operations for tracking the history of the building element and relevant factors, in addition to learning from past experiences.

8-G	BIM enhances workflow efficiencies by (i) Environmental Impact Assessment (EIA) that gives the environmental impact score for making effective decisions in the design stage, and (ii) reduces operating costs by extending the use of information modelling in the construction facility.
9-C	BIM offers various opportunities and helps Facilities Management practices based on its analysis, visualization and controlling functions, which in turn fulfills information requirements of Facilities Management activities.

Table 35. Interaction Matrix of BIM + Lean Construction versus Facilities Management

		Facilities Management							
		Organisation continuous improvement	Virtual management use	Alternative construction plans	Collaboration in design and construction	Information maintenance and model integrity	Lean Maintenance Management	Optimized build environment	Operations and Maintenance decisions
BIM + Lean Construction		A	B	C	D	E	F	G	H
Implementation costs	1			X					
Government incentives	2			X					
Employee skills	3	X							
BIM standards	4				X				
Organisational infrastructure	5		X						
Even risk sharing	6	X							
Training and education	7					X			

Adaptation to change	8	X							
Lean accurate information	9						X		
Information and knowledge of building operations	10								X
Information and knowledge of building maintenance	11							X	

Table 36. Strategic Interaction Matrix that explains contents of cells

Index	Explanation
1-C	Lower and better controlled implementation costs related to BIM and Lean Construction functions can result in more savings, which facilities can use to design and manage alternative construction plans.
2-C	Government funds and incentives for BIM and Lean Construction processes can also facilitate facility management through designing and management of alternative construction plans.
3-A	Employees skills of BIM and Lean Construction can improve construction facilities’ processes and functions continuously.
4-D	Collaboration in BIM design and construction along with latest BIM standards can result into favorable outcomes for facilities management in the industry.
5-B	Organisational infrastructure can be designed, improved and adjusted for running virtual management successfully within facilities.
6-A	Even sharing of risks by all departments in the facility can also successfully implement Kaizen principle in the industry.
7-E	Training and education of employees regarding BIM and Lean Construction can help in ensuring model integrity and better maintaining information, as a result of which misinformation can be avoided and there can be no unnecessary work for staff.

8-A	Adaptation of organisations to changes in Lean Construction and BIM ensures continual improvement in construction facilities.
9-F	Accurate and complete lean information and data facilitate Lean Maintenance Management by proactively maintaining operations that are used in planning and scheduling maintenance activities throughout a construction facility.
10-H	Capturing and using information and knowledge of building operations help in making effective operations and maintenance decisions, and thus, avoiding high costs.
11-G	Information and knowledge of building maintenance activities results into effective planning, better performance, and reduced risks, thereby resulting into an optimized built environment.

Implementation Level Framework Development

Facilities Management for the lifecycle of an infrastructure usually encompasses operations and maintenance, energy management, and commissioning. For the implementation framework the discussions are based on operations and maintenance. The key factor in the implementation framework is that decisions made at the design and construction stage of a facility affect operations and maintenance. Thus, at the design and construction phases a facility manager can provide post occupancy evaluation of facilities for optimal operations and maintenance. On the other hand, facilities management functions can be considered at the design and construction stage to avoid redesigns, major repairs, alterations as well as reduce maintenance effort and costs.

In the implementation level framework shown in Tables 37, Operations and maintenance functions of Facilities Management are stated along rows and relevant BIM functions are stated across columns. The strategic interactions between both BIM and Operations and maintenance functions of Facilities Management are shown with the sign of ‘x’ in the matrix cells. All cells are briefly explained in Table 38. This framework was also validated through a mixture of structured and semi-structured interviews with project managers, facilities managers and professionals in the field of quality improvement, lean construction and project management. The implementation level framework specifically focuses on facilities operations and management. It offers implementation guidelines and shows ways of enhancing quality of facilities management through integration of BIM applications with Operations and maintenance functions of Facilities Management.

Table 37. Implementation Interaction Matrix of BIM functionality and Operations and Maintenance Functions

		Operations and Maintenance (O & M) Principles									
		Lean facilities operations and management planning	Waste reduction	Financial Transparency	Leadership and capability of owners	Continuous improvement (kaizen)	Training and Education for employees	Corrective maintenance	Effectiveness of cost and time control to repair	Preventive maintenance service (workflow)	Resource optimization in OM
BIM functionality		A	B	C	D	E	F	G	H	I	J
Organisation continuous improvement	1	X									
Collaboration in Design and Construction	2					X					
Information maintenance and model integrity	3	X									
Organisation structure to support	4					X					

BIM system								
Competent technical support	5	X					X	
BIM Training	6					X	X	
Minimal cultural and language barriers	7				X		X	
Professional BIM design team	8		X					
Top Management Support	9	X		X	X		X	
Computerized facility maintenance management system	10							X

Root cause of failure	1 1		
Visualization	1	X	X
Integration and storage of design and construction information	2 1 3		

Table 38. Implementation Interaction Matrix that explains contents of cells

Index	Explanation
1-A	Principle of kaizen, i.e. continual improvement while integrating lean operations and maintenance throughout the facility lifecycle of a building aids in getting desired outcomes.
3-A	Model integrity along with better maintenance of information can help in better lean operations and maintenance planning, which would deliver on-time, on-budget, and on-demand projects.
5-A	Competent technical support improves implementation of lean processes while operations and maintenance planning.
9-A	Top management support during lean facilities operations and management planning helps in terms of effective execution of lean processes, accessibility to required resources, and setting performance metrics and KPIs for monitoring success.
8-B	Professional BIM design team within the industry helps in waste reduction up to the desired extent.
9-C	Supportive top management in financial matters helps in meeting the set budget, reducing costs, and thus, maintaining a transparency with all key stakeholders for gaining their trust and loyalty.
7-D	Minimal cultural and language barriers during BIM application can strengthen leadership in Lean Construction, which can lead to better training and guidance of key personnel for facility management.
9-D	Top management support by capable leaders and owners in terms of appropriate choice of leadership style helps in better lean operations and maintenance planning and execution.
4-E	Supportive organisational structure for BIM can help in seeking continual improvement, i.e. Kaizen which is the main principle of Lean Construction.
2-E	Collaboration in BIM design and construction can speed up the continuous improvement process in construction companies.
6-E	Provision of BIM training allows staff to better execute methods and job roles which are relative to Lean Construction in construction companies.
7-F	Minimal cultural and language barriers allow trainers and leaders to better guide and lead subordinates and trainees.
5-F	Competent technical support for BIM along with training for employee development regarding Lean Construction can produce the required manpower for successful Facilities Management.
6-F	BIM training along with employee education and development training can enhance skills, professional personality, expertise and knowledge of staff, so they can perform better throughout the facility life-cycle management.
9-F	Top management support in terms of their ongoing training and education is important for development of lean operations and maintenance employees. This in turn allows them to interact with the key stakeholders effectively.

10-G	A facility's computerized maintenance management system (BIM) offers wide-ranging maintenance functionalities, such as corrective and preventive maintenance, work order system, vendor management, labour, scheduling, inventory control, and budgeting.
13-H	Integration of design and storage information can be used in Operations and Maintenance for meeting requirements, such as sharing information of life-cycle cost among the kye stakeholders of the facility, related to all stages of the lifecycle. This helps in effective controlling of repairing cost and time required to do so.
11-J	A knowledge-based BIM visual analytics approach helps in detection of root cause of failure in the facility management. This in turn allows an integration between BIM and asset management so that resource optimisation can be done effective in operations and maintenance.
12-I	BIM allows visualisation that provides important data, which can be integrated for enhancing preventive maintenance service of a facility. For example, a facility can use BIM for a 3-D visualisation that offers both textual information and 3D drawings of the facility. This can help facility management by generating a long-term schedule and notifications for the facility's preventive maintenance.

Framework Validation – Interview Responses and Thematic Analysis

The BIM and Lean Construction interaction framework needed to be validated so that its effectiveness, appropriateness, understanding and clarity could be ensured and identified. This was achieved through the conduction of a mixture of structured and semi-structured interviews among 6 participants, who included project managers, facilities managers and professionals in the field of quality improvement, lean construction and project management. These six experts were chosen because their valuable insights into the conceptual Facilities Management framework via integration of BIM and Lean Construction helped in verifying and testing the research outcome. The general profile of each participant is shown in the following table 31:

Table 39. Demographics of Interviewees

Sr. No.	Job title	Job experience (in years)	Type of Company
1	Project manager	8 years	Contractor
2	Project manager	More than 10 years	Developer
3	Technical director	15 years	Developer
4	Facilities manager	10 years	Contractor
5	Construction consulter	12 years	Developer
6	Facilities manager	7 years	Contractor

Below are their summarised responses divided into themes, which were deduced from thematic analysis.

Theme 1: Perception about the BIM-Lean Construction (BIM-LC, LC-Facilities Management, BIM- Facilities Management, and (BIM + LC)-Facilities Management Frameworks for a Facility Management**.** All 6 interviewees appreciated the conceptual framework and subsequent four matrices (strategic level frameworks), and considered them as a stepping stone which can help to attain desired facility management and enhanced quality in construction projects of Qatar. When asked about interaction between Lean Construction Facilities Management and BIM, all of them agreed that integration between BIM functions and lean principles can offer better value creation tools, which can assist companies in terms of managing potential challenges and barriers, enhancing management of projects, and offering support to the facilities management process.

Theme 2: Appropriateness of the BIM-Lean Construction Framework for Facilities Management within the context of Qatar**.** All 6 interviewees agreed to the fact that there is low to limited understanding of BIM and Lean Construction in a large number of companies. Due to this, so far, no company in the construction industry of Qatar has implemented this proposed model for facilities management. The majority of firms either apply Lean Construction or BIM, and the implementation is also to a low extent due to low awareness, training and education. Hence, all of them agreed that the framework is reasonable enough to be tested and applied in the construction companies of Qatar.

Theme 3: Clarity of the BIM-Lean Construction Framework for its adoption in Qatar and subsequent implementation for Facilities Management in its construction companies. All interviewees showed agreement towards clarity of structure of the interaction framework. They highlighted the need for an intuitive and simple presentation of all four-interaction matrix. According to them, all arrangements and explanation of cells were easy to follow and understand.

Theme 4: Limitations of the BIM-Lean Construction Framework. A majority of the interviewees identified one flaw within the framework. They stressed that some of the frameworks lacked an implementation level, which otherwise would have shown possible associations between Lean Construction and Facilities Management, BIM and Facilities Management, and (BIM + Lean Construction) and Facilities Management functions. Therefore, the absence of an implementation level within these proposed frameworks makes them less effective in guiding professionals about how to apply them in the construction industry.

Theme 5: Contribution of the BIM-Lean Construction Framework to enhancement of Quality Management practices in Qatar construction sector. A majority of the interviewees agreed that the proposed strategic level Facilities management framework as per interaction between Lean Construction and BIM, Lean Construction and Facilities Management, BIM and Facilities Management, and (BIM + Lean Construction) and Facilities Management could contribute usefully to improvement of quality management in the construction sector of Qatar. They stressed that the framework could lead to better quality management practices through better managing and controlling the construction projects, and thus, enhancing processes in an incremental and continual manner.

Framework Implementation Tips

With changes made to the flaw identified by a majority of the interviewees, the proposed strategic frameworks can be implemented by interlinking Lean Construction with Facilities Management functions, BIM and Facilities Management functions, and (BIM + Lean Construction) and Facilities Management functions. When BIM applications are combined with current methods and tools of Lean Construction, this will facilitate Facilities Management through enhancement of the quality of buildings and infrastructure in Qatar. Addition of emerging technologies such as digitalization, smart sensors, personal devices and the Internet of Things (IoTs) can prove to be critical in terms of achieving high levels of effectiveness and efficiencies in Facilities Management that is supported by the synergies in the integration of BIM and Lean Construction.

Chapter Summary

Overall, this chapter has developed four versions of the strategic-level conceptual framework based on the questionnaire findings of the research. It was validated through conduction of a mixture of structured and semi-structured interviews with project managers, facilities managers and professionals in the field of quality improvement, lean construction and project management, and subsequent generation of useful themes.

Chapter Six – Results and Discussion

Chapter Introduction

This chapter presents the findings of the structured and semi-structured interviews aimed at verifying and validating the proposed facilities management conceptual framework. A generic strategic-level model of the Facilities Management conceptual framework suitable for developing countries is discussed. A comparative analysis of such a model with models that have been implemented in developed countries has been provided. Perspectives on the merits, demerits and implementation of such a framework in developing countries are also outlined.

Case Study Competence

The level of competences in the Case study can be seen by considering following graphs which show the following for LC and BIM: awareness levels, preparedness levels, extent of use, and implementation status.

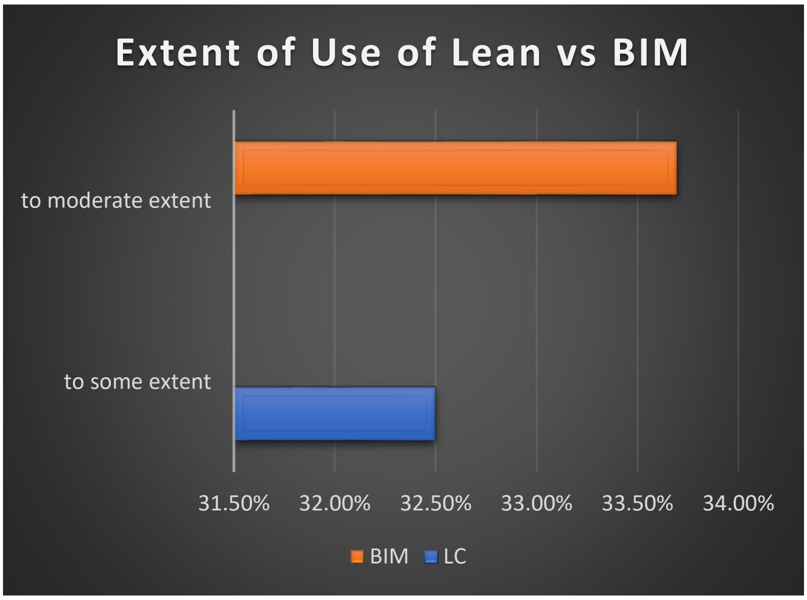

Figure 7. Graph between extent of use of Lean versus BIM

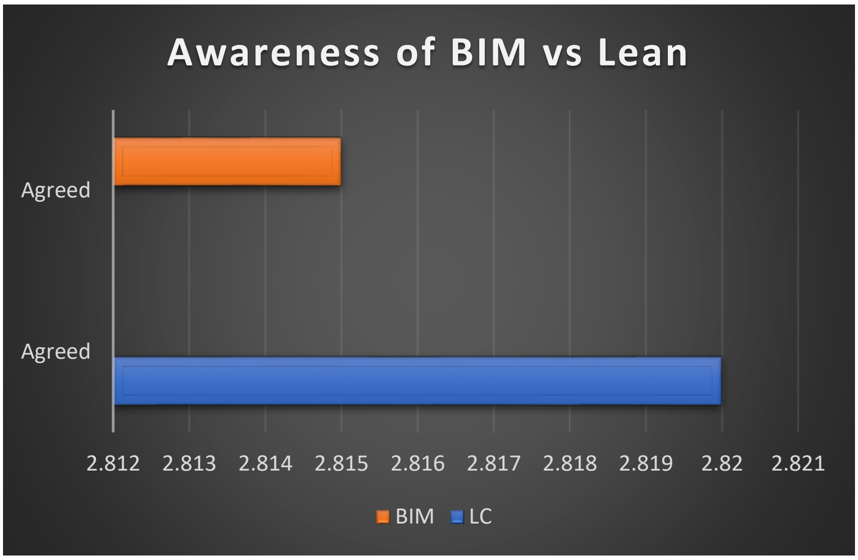

Figure 8. Graph between Awareness of Lean versus BIM

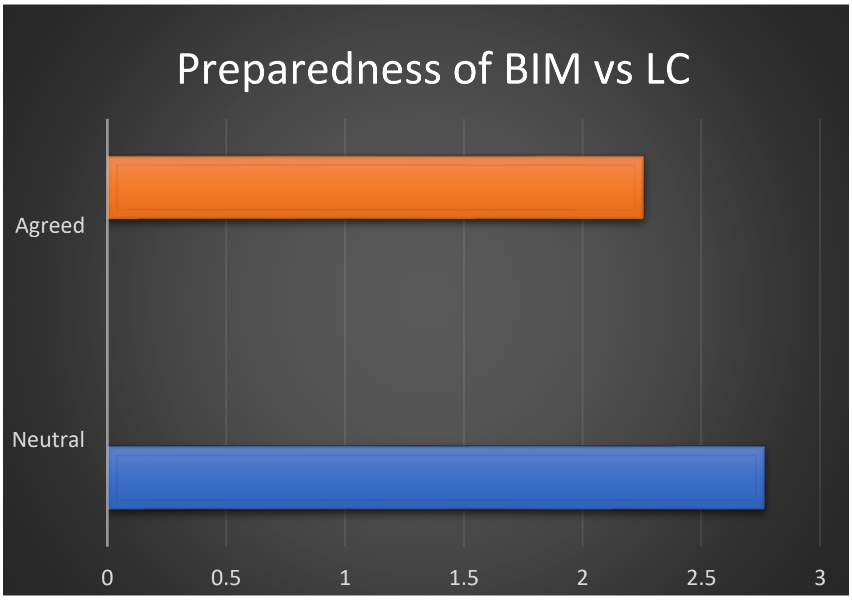

Figure 9. Graph between Preparedness for Lean versus BIM

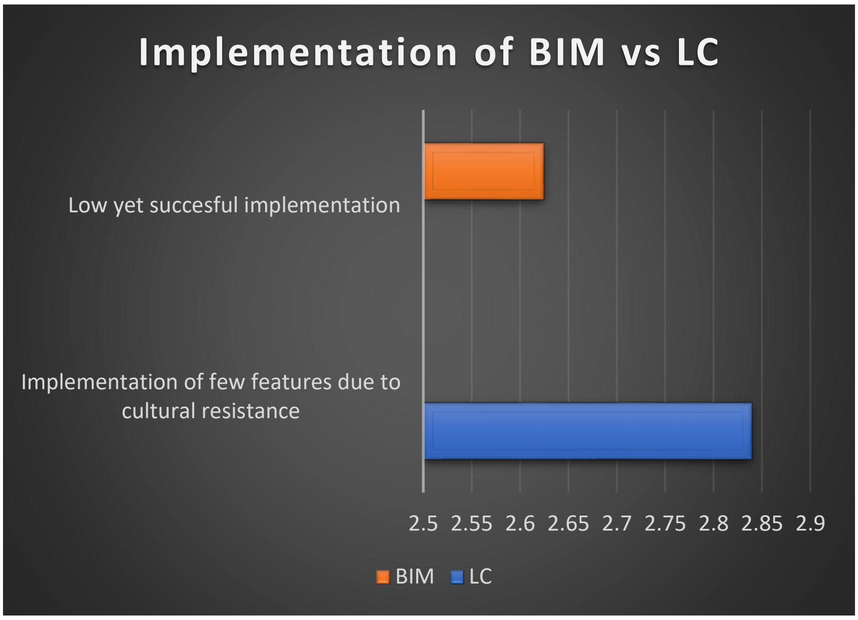

Figure 10. Graph between Implementation of Lean versus BIM

The 1st graph shows that in terms of extent of use, BIM is used to a moderate extent, whereas, LC is used to some extent only. In other words, there is comparatively wider extent of use of BIM. The 2nd graph shows that most of participants agreed to lack to awareness of lean construction models, and lack of awareness and clarity of BIM. Yet, the comparison showed that there was more lack of awareness of LC comparatively, which can be supported by its less extent of use.

The 3rd graph shows that majority of participants gave neutral response to preparedness for adopting LC. On the contrary, most of them agreed to preparedness for BIM. In other words, there is more readiness for BIM comparatively at present. The 4th graph shows that majority of participant agreed to low yet successful implementation of BIM, whereas, most of them neutrally responded to implementation of few features of LC in organisation due to cultural resistance to change. Hence, it can be deduced that there is confirmation related to low yet successful implementation of BIM, yet, unclear responses were generated related to lack of implementation of LC.

BIM Functionality and Dimensions in the Construction industry of Qatar

The following table 40 shows functions and dimensions of BIM currently being used in the local construction industry, global regions, and especially Qatar. This is a checklist to show how far the case study companies in Qatar are utilizing complete BIM functions in contrast to the local and global industries.

Table 40. BIM functionality and dimensions in Qatar vs local industry vs global industry

	BIM Functions and Dimensions	Construction Industry		
Functions		Qatar	Mena-Region	Global
1	Lean Construction	✓	✓	✓
2	Project scheduling	✓	✓	✓
3	Project visualisation		✓	✓
4	Supply chain management	✓	✓	✓
5	Real time analysis		✓	✓
6	Budget visualisation			✓
7	Optimisation of construction costs	✓	✓	✓
8	Energy consumption tracking			✓
9	Conceptual energy analysis			✓
10	Maintenance and operation manuals	✓	✓	✓
11	Life cycle assessment	✓	✓	✓
12	Project specifications	✓	✓	✓
13	Optimisation of asset management			✓
14	Procurement management			✓
Dimensions				
3D		✓	✓	✓
4D		✓	✓	✓
5D		✓	✓	✓
6D				✓
7D				✓

The table 40 shows only implementation of 3D, 4D and 5D dimensions of BIM in Qatar. This can be supported with the literature review findings, which showed that only few functions of these dimensions are implemented in Qatar, such as scheduling function of 4D, and cost estimation function of 5D (Charef et al., 2018). However, sustainability function of 6D and facility management function of 7D BIM are seldom or rarely used in Qatar and the Mena region. This reflects that the construction industry in Qatar may be disadvantaged by not using the complete functions and dimensions of BIM. This limited functionality would affect facilities management post occupation of constructed facilities in terms of poor construction site planning, poor preparedness throughout the construction process, challenging budgetary analysis, high consumption of energy, inefficient operational management, and weak asset management throughout the facility lifecycle.

Main Findings and Discussion

Drawing on the interview responses, the conceptual strategic-level frameworks were appreciated and considered as a stepping stone, which can help to attain desired facility management and enhanced quality in construction projects of Qatar. All interviewees agreed that the integration between BIM functions and Lean Construction principles, Lean Construction and Facilities Management, BIM and Facilities Management, and (BIM + Lean Construction) and Facilities Management can offer better value creation tools, which can assist companies in terms of managing potential challenges and barriers, thus enhancing management of projects, and offering support to the facilities management process. Moreover, appropriateness, clarity of structure and reasonableness of the model was highlighted, so that it can be tested and applied in construction companies of Qatar. Nevertheless, all interviewees agreed that the proposed strategic-level facilities management frameworks as per interaction between Lean Construction and BIM, Lean Construction and Facilities Management, BIM and Facilities Management, and (BIM + Lean Construction) and Facilities Management can contribute to improvement of quality management in the construction sector in Qatar. It has been postulated that the strategic-level frameworks can lead to better quality management practices through better managing and controlling the construction projects, thus enhancing processes in an incremental and continual manner for the lifecycle of a facility. Therefore, Figure 7 is a generic strategic-level model for Facilities Management, suitable for developing countries. The model shows that applications of BIM functions and tools (stage 1) along with how implementation of Lean Construction principles and Kaizen (stage 2) can offer; desired targets of an effective facilities management program, a holistic usage of Lean Construction and BIM for better construction quality, and, consequently, maximized value for customers.

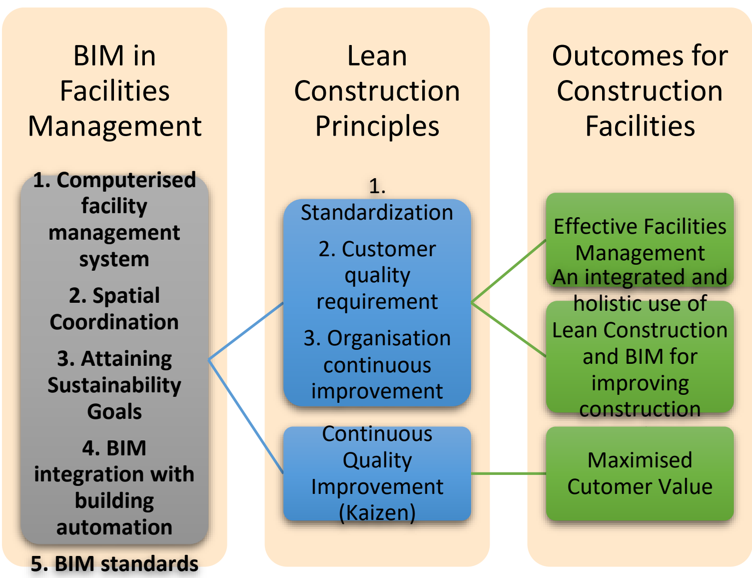

Figure 11. Generic Model for Facilities Management framework for developing countries.

The aforementioned proposed generic strategic-level assumes that similar BIM standards and Lean Construction principles are followed across different construction companies. This model can be compared with a LC-BIM quality house model, which was proposed for implementation in developed countries, such as China. The study by Zhang (2019) provided a visual description of a Lean Construction – BIM quality improvement house, which showed how BIM can be integrated with Lean Construction. This integrated model was then used to enhance construction quality in the Chinese construction sector. The generic model proposed in Figure 7 is not as detailed and holistic as that provided by Zhang (2019). This is due the demerit of the matrices, such that the four strategic-level frameworks lack an implementation level, which otherwise would have shown possible associations between BIM applications and Lean Construction tools and methods, Lean Construction and Facilities Management, BIM and Facilities Management, and (BIM + Lean Construction) and Facilities Management. Even though, the model proposed in this thesis is strong in terms of offering a thorough understanding on how to use interactions between BIM and Lean Construction for Facilities Management and why the integration is important. The generic model in figure 4 can be expanded and developed further into an implementation level framework but further explorations and pilot implementations in several case studies. This will make it more effective and a more detailed as well as more specific guide for professionals and practicing engineers in terms of its application in companies in developing countries.

Chapter Summary

This chapter has summarized the main findings of interviews, and proposed a generic strategic-level model of the Facilities Management conceptual framework that is suitable for developing countries. The proposed model has been compared with another model that was implemented in developed countries, so that perspectives on the merits, demerits and implementation of such a strategic-level framework in developing countries can be outlined.

Chapter Seven – Conclusions and Recommendations

Introduction

This chapter presents the key conclusions of the study as well as providing some practical recommendations to help organisations implement the conceptual strategic-level framework to enhance their performance. The chapter also discusses the study's implications and provides some ideas that could be further researched in the future.

Key Conclusions

The overarching aim of this study was to develop a conceptual strategic-level framework for facilities management through exploring the benefits, barriers and success factors associated with the synergy between Lean Construction and BIM. This aim was addressed by conducting an empirical study on the construction industry in Qatar. Data obtained through this empirical study was used to synthesize a strategic-level framework for facilities management. The study unfolded by addressing three main objectives and two research questions.

The first objective (*To explore the extent of adoption of practices of Lean Construction by the construction industry in Qatar*) was fulfilled by studying the dynamics of the operations of construction companies in Qatar through surveys and interviews. The literature review also showed that in the past decades, there were unclear visions on key methods, practices, and tools in the public literature on lean construction. In most developing countries including Qatar, the lean journey started recently and was consolidated by the development of a Lean Construction Institute chapter in Qatar. Due to this observation, each construction company has been implementing lean construction principles differently as per their own internal features. Therefore, the philosophy of lean construction in the past was unclear and complex to implement and pursue due to lack of an iterative basis for performance enhancement, waste reduction and customer value maximisation. This was supported by this study findings which showed limited awareness and preparedness for Lean Construction in some of the construction companies in Qatar. Extensive lean implementations are expected to rise in the near future since a lot of awareness, preparations for lean implementations have been initiated by leading construction companies in Qatar.

The 2rd objective (*To identify the challenges, barriers and success factors associated with integrating BIM, Facilities Management and Lean Construction*) was attained by gathering survey responses, which revealed success factors such as sharing of training for employee development, continuous improvement, and leadership. This is also supported by the findings of McArthur & Bortoluzzi (2018) elsewhere. The study further identified several moderate challenges such as culture and language barriers, high implementation cost, inadequate organisational infrastructure, and less trained, skilled, and educated staff, which were also identified by literature review study by Terreno et al. (2019). One of the research questions in this study (*What are the contextual and organisational factors that may hinder the effective integration of Lean Construction, BIM and Facilities Management?)* was answered the 2nd research to a moderate extent by the findings of the conducted survey. In answering this question, the study identified a number of organisational challenges. However, a smaller number of contextual factors have been identified that may hinder the effective integration of Lean Construction, BIM and Facilities Management.

The 3rd objective (*To develop and validate a conceptual framework for Facilities Management based on inputs from integrating Lean Construction and BIM*) was achieved by designing four interactive matrices between: (i) Lean Construction and BIM, (ii) Lean Construction and Facilities Management, (iii) BIM and Facilities

Management, and (iv) {BIM + Lean Construction} and Facilities Management. These interactive matrices were validated through a mix of structured and semi-structured interviews with professionals in the construction industry in Qatar. The interaction matrices were developed based on a generic model for knowledge-informed facilities management at strategic level. The development of the generic model and the 4-level strategic Facilities Management framework helped in answering one of the research questions (*How can Lean Construction, BIM and Facilities Management be integrated in a collective model for the continued benefits of lean construction management*?). The study findings have answered this question to a great extent by designing four interactive matrices related to the proposed strategic generic model. This question has been answered comprehensively since four possible forms of interactions between BIM, Lean Construction and Facilities Management have been illustrated and thoroughly explained. The matrix illustrations provided and insight into the interconnections, and synergies among the three key research components. The resulting matrices show that integrating Lean Construction, BIM and Facilities Management has potential benefits generally related to optimization of the built environment to the satisfaction of facility owners, managers, and users. Although there are several non-technical and technical challenges and barriers in integrating Lean Construction, BIM and Facilities Management, successful integration may impact life cycle facilities operational and maintenance costs. An implementation level framework was developed between BIM and Facilities Operations and Maintenance. It provided implementation guidelines and showed ways of enhancing quality of facilities through integration of BIM functionality with Facilities Operations and Maintenance principles.

Research Contribution

This research has contributed to the existing literature by developing an interaction framework between BIM, Lean Construction, and Facilities Management for the construction industry in Qatar. The framework comprised of four sets of interactive matrices, hence is termed as a four-level interactive framework. Research findings provide an attempt at closing the theoretical gap related to associations between BIM and Lean Construction for improving Facilities Management within construction companies. Therefore, the developed framework provides a new perspective on how Lean Construction, BIM, and Facilities Management can be integrated to perpetuate the benefits of lean principles in the construction industry. Unlike the common reactive approach in which Facilities Management requirements information is collected at project closeout, the proposed approach is proactive in the sense that Facilities Management information requirements are collected continuously from facilities design throughout the construction project life cycle. This study has also expanded the current knowledge base of BIM and Lean Construction approaches by pointing out how and why a proactive Facilities Management approach is necessary. In addition, the proposed approach is also different from the usual attempt on introducing lean in facilities management as a reaction to low performance and/or low operating levels of a constructed facility.

Recommendation

Although BIM was adopted in Qatar for more than a decade now in many mega projects such as Lusail city, Qatar Metro, and recent infrastructure projects by Ashghal, BIM adoption was fairly limited to applications during the design and construction phases. In Qatar, BIM is mainly adopted in applications such as: design coordination and verification, quantity take-offs, bill of quantity creation, project cost estimations, design analysis, shop drawings design generation and verification, constructability analysis and clash detection, accessibility analysis, schedule simulation and verification, progress monitoring and dispute resolution.

The growth of the construction industry in Qatar is expected to continue until 2030; therefore, the need for proper facilities and robust operational and management process will be required. Based on this research findings, it is recommended that BIM should be adopted at early stages with a main focus and consideration on successful FM integration. Similarly, it is recommended that BIM adoptions in Qatar with focus on facilities management takes into considerations the following BIM applications during the early stages of the tendering process:

- The interoperability of the as built integrated BIM model with BMS and FM platforms based on typical BIM standards.
- The ability of integrating the BIM model with BMS for energy consumption tracking.
- The integration of maintenance and operation manuals within the BIM model for future time saving and assets management
- The integration of warranty information within the BIM model
- The detailed elements, systems and facility specifications for future FM processes

It is recommended that future research based on this study should measure and quantify the current level of BIM adoption into facilities management within the construction industry in Qatar. Similarly, based on the presented framework, it is recommended to measure and quantify how proper lean concepts adoption during design and construction phases may contribute to enhancing facilities and operational management processes in construction projects in Qatar.

Furthermore, it is suggested that professionals in BIM, Lean construction, quality improvement, Facilities Management must focus on BIM applications and functions along with current methods, principles, and tools of Lean Construction, which will facilitate Facilities Management through enhancement of quality of buildings and infrastructure in Qatar. It is also necessary to point out that BIM is not just another modelling tool which is required during the design and construction phase of a facility. It should be viewed as a tool that collects data and information from design until end of life of a facility. While most facilities managers do not consider BIM to be a useful tool in facilities management this is just a misconception that requires more case studies and evidence to resolve. Construction companies should therefore dig deeper into BIM functionality to leverage on the potential strength of BIM as an information tool throughout the life cycle of a facility. Integrating BIM and Lean construction can resolve the usual problems of being overwhelmed by data and information collated in BIM. In addition, it is recommended that BIM functionality and value can be unlocked by linking it with other software packages that are commonly used by facility managers. This can prove to be critical in removing the barriers due to misconceptions on the capabilities and usefulness of BIM in sustainable management of facilities.

Study Implications

The thesis has examined the interactions between BIM, Lean Construction and Facility Management. Both quantitative and qualitative approaches were used for the development of the four-level interaction framework. The existing literature was validated by gathering theoretical viewpoints from the construction industry, and conducting a survey (questionnaire and interviews) within the case study, i.e. Qatar construction industry. Overall, the interaction between Lean Construction principles and approaches and BIM quality-based functions implies that this synergy can enhance the quality of construction in developing countries based on an integrated and holistic use of Lean Construction and BIM. The integration between Lean Construction, BIM and Facilities Management implies that integrated BIM functions and Lean principles offer better value creation tools that help in managing potential challenges, and enhancing and offering support to the Facilities Management process. Moreover, the developed 4-level interactive model implies that such an integration model can offer help to government and construction companies in terms of identifying the direction of BIM and Lean Construction approaches, which are based on a general improvement in quality of construction works.

Study Limitations and Future Directions

The scope of the study was limited to the construction sector in Qatar. The lack of time and resources resulted in the conduction of a survey within a limited number of construction companies in Qatar. The prevalence of COVID-19 also limited the number of face-to-face interviews with professionals in Qatar construction industry. The interviews were conducted in Qatar. Therefore, the results cannot be generalized for construction companies in developing countries. Therefore, future researchers can expand this research by investigating the proposed interaction models in other companies in Qatar as well as conduct surveys in other developing countries. Future studies can also focus on developing facility management models at implementation levels. This is expected to reveal possible latent associations between Lean Construction and Facilities Management, BIM and Facilities Management, as well as BIM and Lean Construction versus Facilities Management.

References

Ahmed, M., & Wong, L. (2018). Assessment of Lean Construction Practice at Selected Construction Sites in Klang Valley. *International Journal of Engineering & Technology*, *7*(4.35), 125. doi: 10.14419/ijet.v7i4.35.22340

Akdag, S., & Maqsood, U. (2019). A roadmap for BIM adoption and implementation in developing countries: the Pakistan case. *Journal Of Architectural Research*, 1-22. doi: 10.1108/ARCH-04-2019-0081

Al-Najem, M., Dhakal, H., & Bennett, N. (2012). The role of culture and leadership in lean transformation: a review and assessment model. *International Journal Of Lean Thinking*, *3*(1), 1-21.

Al Mohannadi, F., Arif, M., Aziz, Z., & Richardson, P. A. (2013). Adopting BIM standards for managing vision 2030 infrastructure development in Qatar. *International Journal of 3-D Information Modeling (IJ3DIM)*, *2*(3), 64-73.

Al-Buenain, A., Al-Muhanadi, S., & Falamarzi, M. (2020). The New Construction Approach Adapted by Ashghal for the Public Projects in Qatar.

Ansah, R., Sorooshian, S., & Mustafa, S. (2016). LEAN CONSTRUCTION: AN EFFECTIVE APPROACH FOR PROJECT MANAGEMENT. *ARPN Journal Of Engineering And Applied Sciences*, *11*(3), 1607-1612.

Asdrubali, F., Baldassarri, C., & Fthenakis, V. (2013). Life cycle analysis in the construction optimization sector: Guiding the of conventional Italian buildings. *Energy And Buildings*, *64*, 73-89.

Attallah, S., Senouci, A., Kandil, A., & Al-Derham, H. (2013). Utilization of life-cycle analysis to evaluate sustainability rating systems for construction projects with a case study on Qatar Sustainability Assessment System (QSAS). *Smart And*

Sustainable Built Environment, *2*(3), 272-287. doi: 10.1108/sasbe-03-2013-0017

Atzl, G., & Eichler, C. (2018). BIM - Application for tunnel projects. *Geomechanics And Tunnelling*, *11*(4), 310-311. doi: 10.1002/geot.201870403

Azhar, S. (2011). Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry. *Leadership and management in engineering*, *11*(3), 241-252.

Azhar, S., Khalfan, M., & Maqsood, T. (2015). Building information modelling (BIM): now and beyond. *Construction Economics And Building*, *12*(4), 15-28. doi: 10.5130/ajceb.v12i4.3032

Bajjou, M., & Chafi, A. (2018). Lean construction implementation in the Moroccan construction industry Awareness, benefits and barriers. *Journal Of Engineering, Design And Technology*, *16*(4), 533-556.

Bajjou, M., Chafi, A., & Ennadi, A. (2019). Development of a Conceptual Framework of Lean Construction Principles: An Input–Output Model. *Journal Of Advanced Manufacturing Systems*, *18*(01), 1-34. doi: 10.1142/s021968671950001x

Barker, I.(n.d.). *A practical introduction to facilities management*.

Bilec, M., Ries, R., & Matthews, S. (2010). Life-Cycle Assessment Modelling of Construction Processes for Buildings. *Journal Of Infrastructure Systems*, 199-205.

Biggam, J., (2015). *Succeeding with your master's dissertation: a step-by-step handbook*. London: Open University Press (McGraw-Hill Education

Börner, K., Bueckle, A., & Ginda, M. (2019). Data Visualization Literacy: Definitions, conceptual Frameworks, Exercises, and Assessments. *Proceedings of The National Academy Of Sciences, 116*(6), 1857-1864. doi: 10.1073/pnas.1807180116

Bråthen, K. *Combining BIM and Lean Construction: Towards enhanced collaborative working?* Fafo & Norwegian University of Science and Technology

Buyle, M., Braet, J., & Audenaert, A. (2013). Life cycle assessment in the construction sector: A review. *Renewable and Sustainable Energy Reviews*, *26*, 379-388. doi: 10.1016/j.rser.2013.05.001

Brioso, X., & Humero, A. (2016). Incorporating Lean Construction Agent Into the Building Standards Act: The Spanish Case Study. *Organisation, Technology & Management in Construction, 8*(1), 1511-1517. doi: http://dx.doi.org.library.wlac.edu/10.1515/otmcj-2016-0010

Bryman, A. (2008). Social Research Methods. (3rd ed). New York: Oxford University Press.

Charef, R., Alaka, H., & Emmitt, S. (2018). Beyond the Third Dimension of BIM: A Systematic Review of Literature and Assessment of Professional Views. *Journal Of Building Engineering*, 1-35.

Chen, Z. (2017). *THE PRINCIPLES OF FACILITIES MANAGEMENT AND CASE STUDIES*. Glasgow, UK.

CIHT Qatar Group. (2019). *Implementing Lean Construction in Ashghal* (pp. 1-2). Qatar: CIHT.

Creswell, J. W. (2011). Controversies in mixed methods research. *The Sage handbook of qualitative research, 4*, 269-284.

Creswell, J., (2014). *Research design: qualitative, quantitative, and mixed method*. London: Sage Publications Ltd.

Crotty, M. (2003): *The Foundations of Social Research: Meaning and Perspectives in the Research Process*, London: Sage Publications, 3rd edition, 10.

Dang, Y., Han, J., & Li, Y. (2015). Analysis of the Seismic Performance of Isolated Buildings According to Life-Cycle Cost. *Computational Intelligence and Neuroscience*, *2015*, 1-7. doi: 10.1155/2015/495042

Daniel Luiz de, M. N., Osvaldo Luiz Gonçalves Quelhas, Meiriño, M. J., Rodrigo Goyannes Gusmão Caiado, Barbosa, S. D. J., & Ivson, P. (2018). Facility Management Using Digital Room by Integrating BIM-Lean Approaches – An Empirical Study. *Journal of Civil Engineering and Management*, *24*(8), 581-591. doi:http://dx.doi.org.library.wlac.edu/10.3846/jcem.2018.5609

Davies, M., (2007). *Doing a successful research project: Using qualitative or quantitative methods*. New York: Palgrave Macmillan.

De Vaus, D. A. (2014). Surveys in Social Research. (6th ed). Australia: UCL Press.

Dehdasht, G., Ferwati, M., Zin, R., & Abidin, N. (2020). A Hybrid Approach Using Entropy and TOPSIS to Select Key Drivers for a Successful and Sustainable Lean Construction Implementation. *PLOS ONE*, *15*(2), e0228746. doi: 10.1371/journal.pone.0228746

Di Giuda, G. M., Giana, P. E., Paleari, F., Schievano, M., Seghezzi, E., & Villa, V. (2020). A BIM-Based Process from Building Design to Construction: A Case Study, the School of Melzo. In *Buildings for Education* (pp. 163-173). Springer, Cham.

Dixit, M. K., Culp, C. H., Fernandez-Solis, J., & Lavy, S. (2016). Reducing Carbon Footprint of Facilities using a Facility Management Approach. *Facilities*, *34*(3), 247-259. doi:http://dx.doi.org.library.wlac.edu/10.1108/F-11-2014-0091.

Dulaimi, M., & Tanamas, C. (2008). THE PRINCIPLES AND APPLICATIONS OF

LEAN CONSTRUCTION IN SINGAPORE, 1-15.

Edirisinghe, R., London, K. A., Kalutara, P., & Aranda-Mena, G. (2017). Building Information Modeling for Facility Management: Are we there yet? *Engineering, Construction, and Architectural Management, 24*(6), 1119-1154.

Emuze A, F., & Saurin A, T. (2016). *Value and Waste in Lean Construction*. London: Routledge, Taylor & Francis Group.

Evens, J., (2007). *Your psychology project the essential guide*. London: Sage Publications Ltd.

Fadli, F., Dacanay, T., Moen, C., & Guest, J. (2016). Life Cycle Assessment of Tall Buildings in Qatar, A focus on Construction Materials Use and Techniques. In *Qatar Foundation Annual Research Conference ARC'14*.

Fard, M., & Peña-Mora, F. (2007). *Application of Visualization Techniques for Construction Progress Monitoring*. University of Illinois.

Fellows, R. and Liu, A., (2008). *Research Method for Construction*. Oxford: Blackwell Publishing Ltd.

Gao, S., Pheng, L., & Tay, W. (2020). Lean facilities management: preliminary findings from Singapore's international schools. *Facilities*, *38*(7/8), 539-558. doi: 10.1108/f-07-2019-0076

Gerber, D., Becerik-Gerber, B., & Kunz, A. (2010). BUILDING INFORMATION MODELING AND LEAN CONSTRUCTION: TECHNOLOGY, METHODOLOGY AND ADVANCES FROM PRACTICE. In *18th Annual Conference, International Group for Lean Construction,* (pp. 1-12). Haifa, Israel.

Goh, M., & Goh, Y. (2019). Lean production theory-based simulation of modular construction processes. *Automation In Construction*, *101*, 227-244. doi: 10.1016/j.autcon.2018.12.017

Hamdi, O. and Leite, F., (2012). BIM and Lean interactions from the BIM capability maturity model perspective: a case study. *Proceedings of the 20th annual conference of the international group for lean construction,* July 2012 San Diego. California: Montezuma Publishing.

Hao, J., Cheng, B., Lu, W., Xu, J., Wang, J., Bu, W., & Guo, Z. (2020). Carbon Emission Reduction in Prefabrication Construction during the Materialization Stage: A BIM-Based Life-Cycle Assessment Approach. *Science of The Total Environment*, *723*, 137870. doi: 10.1016/j.scitotenv.2020.137870

Hartmann, T., Meerveld, H., Vossebeld, N. and Adriaanse, A., (2012). Aligning building information model tools and construction management methods. *Automation in construction,* 22, pp.605-61

Heralova, R. (2017). Life Cycle Costing as an Important Contribution to Feasibility Study in Construction Projects. *Procedia Engineering*, *196*, 565-570. doi: 10.1016/j.proeng.2017.08.031

Hosseini, M. R., Roelvink, R., Papadonikolaki, E., Edwards, D. J., & Pärn, E. (2018). Integrating BIM into Facility Management. *International Journal of Building Pathology and Adaptation,* *36*(1), 2-14. doi:http://dx.doi.org.library.wlac.edu/10.1108/IJBPA-08-2017-0034

Inomata, T., Triadan, D., Pinzón, F., & Aoyama, K. (2019). Artificial Plateau Construction During the Preclassic Period at the Maya Site of Ceibal, Guatemala. *PLOS ONE*, *14*(8), e0221943. doi: 10.1371/journal.pone.0221943

Ivson, P., Moreira, A., Queiroz, F., Santos, W., & Celes, W. (2018). A Systematic

Review of Visualization in Building Information Modeling. *IEEE Transactions On Visualization And Computer Graphics*, *26*(10), 3109-3127. doi: 10.1109/tvcg.2019.2907583

Jankowicz, A., (2000). *Business research project for students*. London: Chapman and Hall.

Jawdeh, H. (2013). *IMPROVING THE INTEGRATION OF BUILDING DESIGN AND FACILITIES MANAGEMENT* (Doctor of Philosophy). University of Salford, Salford, UK.

Johnson, B. & Christensen, L. (2012). Educational Research, Qualitative, Quantitative and Mixed Approach. (4th ed). California: SAGE Publication.

Koseoglu, O., Sakin, M., & Arayici, Y. (2018). Exploring the BIM and Lean Synergies in the Istanbul Grand Airport Construction Project. *Engineering, Construction, and Architectural Management*, *25*(10), 1339-1354. doi:http://dx.doi.org.library.wlac.edu/10.1108/ECAM-08-2017-0186

Laine, E., Alhava, O., & Kiviniemi, A. (2014). Improving built-in quality by BIM based visual management. *Proceedings of IGLC22*, 945-956.

Lee, W., Tsai, M., Yang, C., Juang, J., & Su, J. (2016). V3DM+: BIM Interactive Collaboration System for Facility Management. *Visualization in Engineering*, *4*(1), 1-15. doi:http://dx.doi.org.library.wlac.edu/10.1186/s40327-016-0035-9

Leite, F., Cho, Y., Behzadan, A., Lee, S., Choe, S., & Fang, Y. et al. (2016). Visualization, Information Modeling, and Simulation: Grand Challenges in the Construction Industry. *Journal Of Computing In Civil Engineering*, *30*(6), 04016035. doi: 10.1061/(asce)cp.1943-5487.0000604

Lin, Z., Xie, Q., Feng, Y., Zhang, P., & Yao, P. (2020). Towards a Robust Facility

Location Model for Construction and Demolition Waste Transfer Stations Under Uncertain Environment: The Case of Chongqing. *Waste Management*, *105*, 73-83. doi: 10.1016/j.wasman.2020.01.037 doi:http://dx.doi.org.library.wlac.edu/10.1108/ECAM-06-2016-0139

Liu, J. and Shi, G., (2017). Quality control of a complex lean construction project based on KanBIM technology. *EURASIA Journal of mathematics, science and technology education*, 13(8), pp.5905-5919.

Marsini, R., Dean, J., & Dawood, N. Application of visualisation tools in project management in construction industry: innovation and challenges, 791-801.

Mazur, L., Johnson, K., Pooya, P., Chadwick, J., & McCreery, J. (2016). Integrating Lean Exploration Loops into Healthcare Facility Design. *HERD: Health Environments Research & Design Journal*, *10*(3), 116-130. doi: 10.1177/1937586716680063

McArthur, J., & Bortoluzzi, B. (2018). Lean-Agile FM-BIM: a demonstrated approach. *Facilities*, *36*(13/14), 676-695. doi: 10.1108/f-04-2017-0045

Mkansi, M., & Acheampong, E. A. (2012). Research philosophy debates and classifications: students' dilemma. *Electronic Journal of Business Research Methods*, *10*(2), 132-140.

Mohammed, A., Hasnain, S., & Quadir, A. (2019). Implementation of Building Information Modelling (BIM) Practices and Challenges in Construction Industry in Qatar. *Journal Of Engineering Research And Reports*, *9*(1), 1-9. doi: 10.9734/jerr/2019/v9i117008

Mohamed, S. B., & Chafi, A. (2018). Lean Construction Implementation in the

Moroccan Construction Industry. *Journal of Engineering, Design, and Technology, 16*(4), 533-556. doi:http://dx.doi.org.library.wlac.edu/10.1108/JEDT-02-2018-0031

Moore, N., (2006). *How to do research a practical guide to designing and managing research projects*. London: Facer publishing.

Morder, M. (2020). Six Ways for Construction Professionals to Lean into Lean Construction. Retrieved 21 April 2020, from https://www.constructionexec.com/article/six-ways-for-construction-professionals-to-lean-in-to-lean-construction

Morris, T. and Wood, S., (1991). Testing the survey method: continuity and change in British industrial relations. *Work employment and society*, 5(2), pp.259-282.

Nascimento, D., Quelhas, O., Meiriño, M., Caiado, R., Barbosa, S., & Ivson, P. (2018). Facility management using digital Obeya room by integrating BIM-lean approaches – an empirical study. *Journal of Civil Engineering And Management*, *24*(8), 581-591. doi: 10.3846/jcem.2018.5609

Neuman, W., (2006). *Social research methods: qualitative and quantitative approaches*, Boston: Pearson Education.

Nguyen, P., & Akhavian, R. (2019). Synergistic effect of Integrated Project Delivery, Lean Construction, and Building Information Modeling on Project Performance Measures: A Quantitative and Qualitative Analysis. *Advances in Civil Engineering, 2019*, 9. doi:http://dx.doi.org.library.wlac.edu/10.1155/2019/1267048

Oduyemi, O., Okoroh, M., & Fajana, O. (2017). The application and barriers of BIM in sustainable building design. *Journal Of Facilities Management*, *15*(1), 15-34. doi: 10.1108/jfm-03-2016-0008

Olesen, P., Powell, D., Hvolby, H., & Fraser, K. (2015). Using lean principles to drive operational improvements in intermodal container facilities. *Journal Of Facilities Management*, *13*(3), 266-281. doi: 10.1108/jfm-09-2014-0030

Onyango, A. (2016). *Interaction between Lean Construction and BIM* (Master of Science). KTH.

Patel, S. (2015). The research paradigm–methodology, epistemology and ontology–explained in simple language. *Retrieved June*, *28*, 2017.

Patton, M., (2002). *Qualitative research and evaluation methods.* Thousand Oaks: Sage Publications Ltd.

Pidd, M., (2009). *Tools for thinking: modelling in management science,* Chichester: John Wiley and Son.

Pikas, E., Koskela, L., & Seppänen, O. (2020). Improving building design processes and design management practices: a case study. *Sustainability*, *12*(3), 911.

Pilanawithana, N., & Sandanayake, Y. (2017). Positioning the facilities manager's role throughout the building lifecycle. *Journal Of Facilities Management*, *15*(4), 376-392. doi: 10.1108/jfm-06-2016-0024

Robson, C., (2002). *Real world research*. Oxford: Blackwell.

Roh, S., Tae, S., & Kim, R. (2018). Development of a Streamlined Environmental Life Cycle Costing Model for Buildings in South Korea. *Sustainability, 10*(6), 1733. doi:http://dx.doi.org.library.wlac.edu/10.3390/su10061733

Saad, S., Perera, T., Achanga, P., Shehab, E., Roy, R., & Nelder, G. (2006). Critical success factors for lean implementation within SMEs. *Journal of manufacturing technology management*.

Sacks, R., Radosavljevic, M., & Barak, R. (2009). Requirements for building information modelling based lean production management systems for construction. *Automation In Construction*, *19*(5), 641-655. doi: 10.1016/j.autcon.2010.02.010.

Safa, M., & Hill, L. (2019). Necessity of Big Data Analysis in Construction Management. *Strategic Direction, 36*(1), 3-5. doi:http://dx.doi.org.library.wlac.edu/10.1108/SD-09-2018-0181

Sánchez-Rivera, O. G., Galvis-Guerra, J., Porras-Díaz, H., Ardila-Chacón, Y. D., & Martínez-Martínez, C. A. (2017). Brim 5D Models and Lean Construction for Planning Work Activities in Reinforced Concrete Bridges. *Revista Facultad De Ingenieria, 26*(46), 39-50. doi:http://dx.doi.org.library.wlac.edu/10.19053/01211129.v26.n46.2017.7314

Saunders, M., Lewis, P. and Thornhill, A., (2007). *Research methods for business students*. London: Prentice Hall.

Saunders, M., Lewis, P., Adrian, T. and Bristow, A., (2015). Understanding research philosophy and approaches to theory development. *Research methods for business students*, pp. 122-161.

Silvestre, J., Pargana, N., de Brito, J., Pinheiro, M., & Durão, V. (2016). Insulation Cork Boards—Environmental Life Cycle Assessment of an Organic Construction Material. *Materials*, *9*(5), 394. doi: 10.3390/ma9050394

Tan, W., (2002), *Practical research methods,* Singapore: Pearson Education Asia Pte Ltd.

Tauriainen, M., Marttinen, P., Dave, B., & Koskela, L. (2016). The Effects of BIM and Lean Construction on Design Management Practices. *Procedia Engineering*, *164*, 567-574. doi: 10.1016/j.proeng.2016.11.659

Terreno, S., Asadi, S., & Anumba, C. (2019). An Exploration of Synergies between

Lean Concepts and BIM in FM: A Review and Directions for Future Research. *Buildings*, *9*(6), 147. doi: 10.3390/buildings9060147

Thomas, H. R., Horman, M. J., Minchin Jr, R. E., & Chen, D. (2003). Improving labor flow reliability for better productivity as lean construction principle. *Journal of construction engineering and management*, *129*(3), 251-261.

Thomas, R., (2003). *Blending qualitative and quantitative research methods in thesis and dissertations*. Thousand Oaks: Sage Publication Ltd.

Toe, D. (2015). *An overview of facilities management strategies Employed in shopping centres in Johannesburg, South Africa* (Master of Science in Building (Property Development and Management).). University of Witwatersrand.

Tucker, M., & Masuri, M. (2016). The rationale to integrate facilities management into the development process. *Property Management*, *34*(4), 332-344. doi: 10.1108/pm-08-2015-0040

Vanhoucke, M. (2013). *Project management with dynamic scheduling*. Berlin, Heidelberg: Springer Berlin Heidelberg.

Vilventhan, A., Ram, V., & Sugumaran, S. (2019). Value Stream Mapping for identification and Assessment of Material Waste in Construction: A Case Study. *Waste Management & Research*, *37*(8), 815-825. doi: 10.1177/0734242x19855429.

Vukovic, V., Hafeez, A., Kassem, M., & Chahrour, R. (2015). BIM adoption in Qatar: capturing high level requirements for lifecycle information flow. In *Conference Paper* (pp. 1-12).

Wandahl, S. (2014). Lean construction with or without lean –

Challenges of implementing lean construction. *Conference Paper*, 97-108.

Wang, D., Fan, J., Fu, H., & Zhang, B. (2018). Research on Optimization of Big Data Construction Engineering Quality Management Based On RNN-LSTM. *Complexity*, *2018*, 16. doi:http://dx.doi.org.library.wlac.edu/10.1155/2018/9691868

Wang, H., Meng, X., & McGetrick, P. J. (2018). Early Contractor and Facility Management Team Involved in the BIM Environment. *Periodica Polytechnica.Architecture,* *49*(1), 47-58. doi:http://dx.doi.org.library.wlac.edu/10.3311/PPar.12693

Wong, L. S., & Mohammed Elhaj Alsoufi, M. A. (2018). A Critical Review of Lean Construction for Cost Reduction in Complex Projects. *Jordan Journal of Civil Engineering,* *12*(4) Retrieved from http://library.wlac.edu/login?url=https://search-proquest-com.library.wlac.edu/docview/2127776181?accountid=38212

Wu, X., Yuan, H., Wang, G., Li, S., & Wu, G. (2019). Impacts of Lean Construction on Safety Systems: A System Dynamics Approach. *International Journal Of Environmental Research And Public Health*, *16*(2), 221. doi: 10.3390/ijerph16020221

Wyton, P., & Payne, R. (2014). Exploring the development of competence in Lean management through action learning groups: a study of the introduction of Lean to a facilities management function. *Action Learning: Research And Practice*, *11*(1), 42-61. doi: 10.1080/14767333.2013.873015

Yang, S. (2019). Application of Bim During Lean Construction of High-Rise Buildings. *Civil Engineering Journal,* (3) doi:http://dx.doi.org.library.wlac.edu/10.14311/CEJ.2019.03.0027

Yassin, A., & Razali, M. (2020). Facilities management practice in Construction Management: A Case Study of Construction Companies in Malaysia. Retrieved 18 April 2020, from https://www.researchgate.net/publication/259973383_FACILITIES_MANAGEMENT_PRACTICE_IN_CONSTRUCTION_MANAGEMENT_A_Case_Study_of_Construction_Companies_in_Malaysia

Yin, R. K. (1981). The case study crisis: Some answers. *Administrative science quarterly*, *26*(1), 58-65.

Yin, R., (2009). *Case Study Research: Design and Methods*. London: Sage Publishing Ltd.

Yusuf, S., Lumbi, W., Umar, I., Loko, Z., & Mundi, A. (2020). Structural Shielding Evaluation: A Case Study of the Radiography Room of a Rural Hospital in Jos, Nigeria. *Journal of Medical Imaging And Radiation Sciences*. doi: 10.1016/j.jmir.2020.02.002

Zoghi, M., & Kim, S. (2020). Dynamic Modeling for Life Cycle Cost Analysis Of BIM-Based Construction Waste Management. *Sustainability, 12*(6), 2483. doi:http://dx.doi.org.library.wlac.edu/10.3390/su12062483

Appendix A: Copy of Consent Form sent via Email

Dear Participant,

My name is …, and I am a postgraduate student at the University of Qatar. I am currently conducting an independent research study as part of my Master's degree and I am kindly requesting your help and contribution in this research. My research aims to develop a conceptual framework for Lean Construction Management through exploring the barriers associated with linking BIM and Facilities Management.

To achieve this aim, the following objectives have been identified:

To critically review the current theories on lean construction, BIM and Facilities Management

To explore the widely adopted practices of Lean Construction

To identify the challenges, barriers and success factors associated with integrating BIM, facilities management and Lean Construction

To develop and validate a conceptual framework for integrated Lean Construction

To provide practicable recommendations for the implementation of the integrated model.

I am seeking your input by completing a short survey that aims to explore your views and perceptions on the current practices so that better understanding of the challenges associated with BIM, Facilities Management integration into Lean Construction.

This study is part of an academic programmeme and the results are only used for academic purposes. Your participation is on a voluntary basis and the study does not seek to collect any personal details from you. You have the right to withdraw from the study at any stage and any data provided by you will be destroyed and not used. The data is only accessed by the researcher and the supervisor and will be saved in highly secured computer networks. This study does not pose any health and safety hazards and the estimated time to compete the survey would be around 30 minutes which will be highly appreciated.

Should you have any questions about the study and its objectives, please feel free to contact me at any time. If you would like to receive a copy of the final findings of the study, I would be more than happy to share with you once the degree is awarded.

I would be very grateful for your participation in this study.

Kind regards

Appendix B: Copy of Survey Protocols

Initial Questionnaire for Framework Development

Dear participant,

Thank you for agreeing to take part in this survey that aims to understand the challenges and success factors associated with Lean construction, Facilities Management, and BIM practices in Qatar and how they can be integrated to enhance the effectiveness of the construction sector in Qatar.

Section A: Demographics

1. Please indicate your role?

a. Owner – government
b. Owner – private sector
c. Consultant – site supervision
d. General contractor
e. Subcontractor
f. Project manager
g. Supplier
h. Academic or Researcher

2. What is the length of your experience please?

a. Less than 3 years
b. 4 – 7 years
c. 8 – 11 years
d. More than 12 yours

Section B: Lean Construction

3. To what extent does your organisation use Lean Construction for projects?

a. Not at all
b. To some extent
c. To a moderate extent
d. To a great extent

4. Kindly rate the extent of your agreement or disagreement with the Awareness of Lean Construction in your organisation. (1: Strongly agree – 5: strongly disagree)

a. Waste reduction is handled through integration of lean production systems in construction projects (1 – 2 – 3 – 4 – 5)

b. Lean construction models are applied in your construction company (1 – 2 – 3 – 4 – 5)

5. Kindly rate the extent of your agreement or disagreement with the Preparedness for Lean Construction implementation. (1: Strongly agree – 5: strongly disagree)

a. Your company is ready to adopt lean construction instruments and principles (1 – 2 – 3 – 4 – 5)

b. Your company focuses on adopting lean construction so that wastes can be reduced and maximum end-product value can be attained (1 – 2 – 3 – 4 – 5)

6. Kindly rate the extent of your agreement or disagreement with the Implementation of Lean Construction. (1: Strongly agree – 5: strongly disagree)

a. Your company implements few distinct features of lean construction due to cultural resistance to this change. (1 – 2 – 3 – 4 – 5)

b. Your company implements lean construction differently since there exists unclear vision of key methods, practices and tools of lean construction. (1 – 2 – 3 – 4 – 5)

7. Kindly rate the extent of your agreement or disagreement with the Benefits of implementing Lean Construction. (1: Strongly agree – 5: strongly disagree)

a. Better delivery processes and systems (1 – 2 – 3 – 4 – 5)

b. Improved financial status and project performance of company (1 – 2 – 3 – 4 – 5)

c. Better health and safety as per clients' requirements (1 – 2 – 3 – 4 – 5)

d. Waste elimination (1 – 2 – 3 – 4 – 5)

e. Higher client satisfaction (1 – 2 – 3 – 4 – 5)

f. Reduced construction office times (1 – 2 – 3 – 4 – 5)

g. Higher turnover (1 – 2 – 3 – 4 – 5)

h. Lower project costs (1 – 2 – 3 – 4 – 5)

8. In your view, what are the critical success factors for implementing Lean Construction in your organisation? (1: Strongly agree – 5: strongly disagree)

a. Role of Senior Management (1 – 2 – 3 – 4 – 5)

b. Process-focused efforts (1 – 2 – 3 – 4 – 5)

c. Improvement goals (1 – 2 – 3 – 4 – 5)

d. Involvement of Stakeholders (1 – 2 – 3 – 4 – 5)

e. Appropriate Training (1 – 2 – 3 – 4 – 5)

f. Flexible time to be spent on improvements (1 – 2 – 3 – 4 – 5)

g. High level of Communication between Suppliers (1 – 2 – 3 – 4 – 5)

h. Assessment of Barriers to change and formation of an Action Plan (1 – 2 – 3 – 4 – 5)

9. In your view, what are the main barriers and challenges associated with implementing Lean Construction in your organisation? (1: low challenge – 5: high challenge)

a. Changing Employees' Working Culture (1 – 2 – 3 – 4 – 5)

b. Cost of Implementation (1 – 2 – 3 – 4 – 5)

c. Lack of Lean Knowledge (1 – 2 – 3 – 4 – 5)

d. Long Implementation Time (1 – 2 – 3 – 4 – 5)

e. Complexity (1 – 2 – 3 – 4 – 5)

f. Lack of Cooperation from Employees (1 – 2 – 3 – 4 – 5)

g. Lack of Incentives (1 – 2 – 3 – 4 – 5)

h. Lack of long-term Forecast and Investment (1 – 2 – 3 – 4 – 5)

Section C: BIM

10. To what extent does your organisation use Building Information Modelling (BIM) for projects?

a. Not at all

b. To some extent

c. To a moderate extent

d. To a great extent

11. Kindly rate the extent of your agreement or disagreement with the Awareness of BIM. (1: Strongly agree – 5: strongly disagree)

a. Limited awareness of BIM among contractors, architects, facility managers and quantity surveyors (1 – 2 – 3 – 4 – 5)

b. Lack of clarity of BIM (1 – 2 – 3 – 4 – 5)

12. Kindly rate the extent of your agreement or disagreement with the Preparedness for using BIM. (1: Strongly agree – 5: strongly disagree)

a. BIM application requires a Bottom-up approach (1 – 2 – 3 – 4 – 5)

b. BIM application requires involvement of people in implementation stage (1 – 2 – 3 – 4 – 5)

13. Kindly rate the extent of your agreement or disagreement with the Implementation of BIM in construction projects. (1: Strongly agree – 5: strongly disagree)

a. Successful application of BIM. (1 – 2 – 3 – 4 – 5)

b. Low implementation of BIM in construction and infrastructure projects. (1 – 2 – 3 – 4 – 5)

14. Kindly rate the extent of your agreement or disagreement with the Benefits of BIM. (1: Strongly agree – 5: strongly disagree)

a. Highly cooperative construction idea and design (1 – 2 – 3 – 4 – 5)

b. Enhance construction project management process and methods (1 – 2 – 3 – 4 – 5)

c. Effective application of lean principles (1 – 2 – 3 – 4 – 5)

15. In your view, what are the critical success factors for implementing BIM? (1: Strongly agree – 5: strongly disagree)

a. Client’s acceptance with BIM projects (1 – 2 – 3 – 4 – 5)

b. Organisational Structure to support BIM system within company (1 – 2 – 3 – 4 – 5)

c. Financial Support from the Government to set up BIM system (1 – 2 – 3 – 4 – 5)

d. BIM Standards for the Industry (1 – 2 – 3 – 4 – 5)

e. BIM Training programmes (1 – 2 – 3 – 4 – 5)

f. Information-sharing protocols (1 – 2 – 3 – 4 – 5)

g. Competent technical support team within company (1 – 2 – 3 – 4 – 5)

h. Professional BIM Design team within company (1 – 2 – 3 – 4 – 5)

16. In your view, what are the main barriers and challenges associated with implementing BIM? (1: low challenge – 5: high challenge)

a. High operational costs (1 – 2 – 3 – 4 – 5)

b. Lack of training and expertise (1 – 2 – 3 – 4 – 5)

c. Lack of commitment from top management (1 – 2 – 3 – 4 – 5)

d. Not widely adopted in Qatar (1 – 2 – 3 – 4 – 5)

e. Resistance to change (1 – 2 – 3 – 4 – 5)

f. Lack of awareness about benefits (1 – 2 – 3 – 4 – 5)

Section D: Integration of Lean Construction, BIM and Facilities Management

17. Do you think BIM, Facilities Management and Lean Construction can be integrated to enhance data visualisation and enhance performance?

a. Strongly agree

b. Agree

c. Neutral

d. Disagree

e. Strongly disagree

18. What do you think are the benefits that can be achieved from integrating BIM and Facilities Management? (1: Strongly agree – 5: strongly disagree)

a. Ease of data transfer (1 – 2 – 3 – 4 – 5)

b. Better tracking and maintenance of assets (1 – 2 – 3 – 4 – 5)

c. Improved issuing of work orders (1 – 2 – 3 – 4 – 5)

19. What do you think are the benefits that can be achieved from integrating Facilities Management and Lean Construction? (1: Strongly agree – 5: strongly disagree)

a. Increased value for customers (1 – 2 – 3 – 4 – 5)

b. Reduced inefficiencies (1 – 2 – 3 – 4 – 5)

c. Increased productivity level (1 – 2 – 3 – 4 – 5)

20. What do you think are the benefits that can be achieved from integrating BIM and Lean Construction? (1: Strongly agree – 5: strongly disagree)

a. Creation of automated work package (1 – 2 – 3 – 4 – 5)

b. Effective coordination (1 – 2 – 3 – 4 – 5)

c. Better control and management of project schedule, cost and quality (1 – 2 – 3 – 4 – 5)

d. Waste reduction (1 – 2 – 3 – 4 – 5)

21. What barriers and challenges exist for integrating BIM and Facilities Management? (1: low challenge – 5: high challenge)

a. Hard data entry in Facilities Management Software (1 – 2 – 3 – 4 – 5)
b. Scattered and unorganised data (1 – 2 – 3 – 4 – 5)
c. Outdated model (1 – 2 – 3 – 4 – 5)
d. Lack of BIM skills (1 – 2 – 3 – 4 – 5)
e. Lack of communication (1 – 2 – 3 – 4 – 5)
f. Lack of training (1 – 2 – 3 – 4 – 5)
g. Lack of collaboration between end user and project stakeholders (1 – 2 – 3 – 4 – 5)

22. What barriers and challenges exist for integrating Lean Construction and Facilities Management? (1: low challenge – 5: high challenge)
a. Insufficient resources (1 – 2 – 3 – 4 – 5)
b. Language barrier (1 – 2 – 3 – 4 – 5)
c. Culture barrier (1 – 2 – 3 – 4 – 5)
d. High expectations of customers (1 – 2 – 3 – 4 – 5)

23. What are the main barriers for integrating lean construction and BIM for Facilities Management? (1: low challenge – 5: high challenge)
a. Cost of implementation (1 – 2 – 3 – 4 – 5)
b. Lack of government incentives (1 – 2 – 3 – 4 – 5)
c. Lack of employee skills (1 – 2 – 3 – 4 – 5)
d. Lack of BIM standard (1 – 2 – 3 – 4 – 5)
e. Lack of organisational infrastructure (1 – 2 – 3 – 4 – 5)
f. Uneven risk sharing (1 – 2 – 3 – 4 – 5)
g. Lack of training and education (1 – 2 – 3 – 4 – 5)
h. Resistance to change (1 – 2 – 3 – 4 – 5)

24. What are the success factors for integrating Lean Construction and Facilities Management? (1: Strongly agree – 5: strongly disagree)
a. Use of reliable tested technology (1 – 2 – 3 – 4 – 5)
b. Leadership (1 – 2 – 3 – 4 – 5)
c. Continuous improvement (1 – 2 – 3 – 4 – 5)
d. Training for employee development (1 – 2 – 3 – 4 – 5)
e. Sharing of crucial data and information (1 – 2 – 3 – 4 – 5)

25. What are the success factors for integrating Lean Construction and BIM for Facilities management? (1: Strongly agree – 5: strongly disagree)

a. Standardization (1 – 2 – 3 – 4 – 5)

b. Organisation continuous improvement (1 – 2 – 3 – 4 – 5)

c. Visual management use (1 – 2 – 3 – 4 – 5)

d. Information maintenance and model integrity (1 – 2 – 3 – 4 – 5)

e. Rapid assessment and generation of alternative construction plans (1 – 2 – 3 – 4 – 5)

f. Selection of an appropriate method of production control (1 – 2 – 3 – 4 – 5)

g. Collaboration in the design and construction (1 – 2 – 3 – 4 – 5)

Interview for Framework Validation

Dear Participant,

Thank you for agreeing to take part in this interview to validate the developed conceptual framework for Lean Construction. This interview aims to improve and assess the accuracy and suitability of the four-level interaction framework

Q1	*Based on your experience in the field of construction, what do you think about the overall framework and interaction between its different components?*
Q2	Do you agree or disagree that this framework is Qatari-context oriented? Why?
Q3	Based on your experience, do you think this framework is clear enough to be implemented for Facilities Management in Qatar if adopted?
Q4	Based on your experience, what are the limitations of this framework?
Q5	Based on your experience, can this framework contribute to the improvement of quality management practices in the construction sector in Qatar and how?

Table 1(a). Interaction Matrix of BIM functionality and Lean Construction principles for Facilities Management

		Lean Construction Principles as per its Benefits					
		Better management and control of project cost, quality, and schedule	Waste reduction	Effective coordination	Leadership	Continuous improvement (kaizen)	Training for employee development
BIM functionality as per Key Success Factors		A	B	C	D	E	F
Organisation continuous improvement	1	X					
Collaboration in Design and Construction	2			X		X	
Information maintenance and model integrity	3	X					
Organisation structure to support BIM system	4	X				X	
Competent technical support	5	X		X			X
BIM Training	6					X	X
Minimal cultural and language barriers	7			X	X		X
Professional BIM design team	8		X				
Top Management Support	9				X		X

Table 1(b). Strategic Interaction Matrix that explains contents of cells

Index	Explanation
1-A	Principle of kaizen, i.e. continual improvement while applying BIM leading to better facility management through enhanced control and management of project schedule, operational costs, and quality of projects.
3-A	Model integrity along with better maintenance of information can help in better scheduling, minimise misinformation and avoid unnecessary work for staff
4-A	Organisational structure to support application of BIM can also improve success rate of projects through better control and management of time, finances and quality.
4-E	Supportive organisational structure for BIM can help in seeking continual improvement, i.e. Kaizen which is the main principle of Lean Construction.
2-C	Collaboration in BIM design and construction along with effective coordination in Lean Construction can result in favourable outcomes for facilities management in the industry.
2-E	Collaboration in BIM design and construction can speed up the continuous improvement process in construction companies.
7-C	Removal of language and cultural barriers during implementation of BIM can facilitate Lean Construction through more effective coordination in facility management.
7-F	Minimal cultural and language barriers allow trainers and leaders to better guide and lead subordinates and trainees.
7-D	Minimal cultural and language barriers during BIM application can strengthen leadership in Lean Construction, which can lead to better training and guidance of key personnel for facility management.
6-E	Provision of BIM training allows staff to better execute methods and job roles which are relative to Lean Construction in construction companies.
6-F	BIM training along with employee development training can enhance skills, professional personality, expertise and knowledge of staff, so they can use reliable and tested technology for Lean Construction.
5-A	Competent technical support improves control and management of project schedule, operational costs, and quality of technical parts of the project.
5-C	Competent technical support for BIM applications reflects effective coordination, which can facilitate the industry in Lean Construction and Facility Management.
5-F	Competent technical support for BIM along with training for employee development regarding Lean Construction can produce the required manpower for successful Facilities Management.
8-B	Professional BIM design team within the industry can reduce waste to the desired extent.

9-D	Top management support for BIM and leadership in Lean Construction ensures a satisfied, more aware, and committed workforce.
9-F	Top management support for development of employees in required fields can produce desired results.

Table 2(a). Interaction Matrix of Lean Construction and Facilities Management

		Facilities Management			
		High value for customers	Lower inefficiencies	Higher productivity level	Sharing of crucial information and data
Lean Construction		A	B	C	D
Minimal language barrier	1				X
Minimal cultural barrier	2			X	
Sufficient resources	3		X		
Use of reliable tested technology	4	X			
Leadership	5			X	
Kaizen	6		X		
Training	7		X		

Table 2(b). Strategic Interaction Matrix that explains contents of cells

Index	Explanation
1-D	Removal of language barrier during implementation of Lean Construction can facilitate better sharing of important information and data, and thus, consequently effective coordination in facility management.
2-C	Removal of language and cultural barriers during implementation of BIM can facilitate Lean Construction through more effective coordination in facility management.
3-B	Availability of required and adequate resources can enhance quality of business processes, and thus, lower inefficacies.
4-A	Use of reliable tested technology of Lean Construction can reduce waste, streamline business processes, and thus, provide high value for customers.
5-C	Leadership can result into strong human resources and effective coordination in Lean Construction, which in turn can result into favorable outcome of higher productivity for facilities management in the industry.
6-B	Principle of kaizen, i.e. continual improvement while applying Lean Construction leads to better facility management through improved operations and thus lower inefficiencies.
7-B	Training of staff related to Lean Construction can also reduce inefficiencies by improving skills, knowledge and expertise of workforce.

Table 3(a). Interaction Matrix of BIM functionality and Facilities Management

		Facilities Management								
		Ease of data transfer	Latest model	Organized data	Better tracking and maintenance of assets	Improved space management	Historical trends for maintenance and service history	Environmental impacts and operating cost	Appropriate maintenance system	Productivity
BIM functionality		A	B	C	D	E	F	G	H	I
BIM skills	1				X					
Communication	2	X		X						
Training	3		X							

Data visualization	4					X				
Digitalization	5								X	
Life cycle of facility	6									X
Information platform	7						X			
Workflow efficiencies	8							X		
Facilitate data accessibility	9			X						

Table 3(b). Strategic Interaction Matrix that explains contents of cells

Index	Explanation
1-D	Attainment or improvement of BIM skills can result into better facility management through improved maintenance and tracking of assets.
2-A	Communication within the staff, and between management, top authorities and employees (all key stakeholders) can facilitate data transfer and sharing.
2-C	Strong communication skills can strengthen facility management through better organizing crucial data.
3-B	Training of employees related to BIM can facilities facility management by making them capable of using latest tools and models.
4-E	BIM-based data visualization enhances space management in facilities by integrating real-time data into BIM
5-H	BIM-based Facility Maintenance System helps the maintenance staff members in terms of accessing and examining 3D-BIM models, so that maintenance records can be updated digitally in the construction facility.
6-I	The use of advanced BIM technology for facility management not only enhances the effectiveness of building lifecycle, but also leads to higher productivity.
7-F	BIM information platform helps in maintenance of the facility by allowing the maintenance team to use prior maintenance operations for tracking the history of the building element and relevant factors, in addition to learning from past experiences.

8-G	BIM enhances workflow efficiencies by (i) Environmental Impact Assessment (EIA) that gives the environmental impact score for making effective decisions in the design stage, and (ii) reduces operating costs by extending the use of information modelling in the construction facility.
9-C	BIM offers various opportunities and helps Facilities Management practices based on its analysis, visualization and controlling functions, which in turn fulfills information requirements of Facilities Management activities.

Table 4(a). Interaction Matrix of BIM + Lean Construction versus Facilities Management

		Facilities Management							
		Organisation continuous improvement	Virtual management use	Alternative construction plans	Collaboration in design and construction	Information maintenance and model integrity	Lean Maintenance Management	Optimized build environment	Operations and Maintenance decisions
BIM + Lean Construction		A	B	C	D	E	F	G	H
Implementation costs	1			X					
Government incentives	2			X					
Employee skills	3	X							
BIM standards	4				X				
Organisational infrastructure	5		X						
Even risk sharing	6	X							
Training and education	7					X			

Adaptation to change	8	X							
Lean accurate information	9						X		
Information and knowledge of building operations	10								X
Information and knowledge of building maintenance	11							X	

Table 4(b). Strategic Interaction Matrix that explains contents of cells

Index	Explanation
1-C	Lower and better controlled implementation costs related to BIM and Lean Construction functions can result in more savings, which facilities can use to design and manage alternative construction plans.
2-C	Government funds and incentives for BIM and Lean Construction processes can also facilitate facility management through designing and management of alternative construction plans.
3-A	Employees skills of BIM and Lean Construction can improve construction facilities' processes and functions continuously.
4-D	Collaboration in BIM design and construction along with latest BIM standards can result into favorable outcomes for facilities management in the industry.
5-B	Organisational infrastructure can be designed, improved and adjusted for running virtual management successfully within facilities.
6-A	Even sharing of risks by all departments in the facility can also successfully implement Kaizen principle in the industry.
7-E	Training and education of employees regarding BIM and Lean Construction can help in ensuring model integrity and better maintaining information, as a result of which misinformation can be avoided and there can be no unnecessary work for staff.

8-A	Adaptation of organisations to changes in Lean Construction and BIM ensures continual improvement in construction facilities.
9-F	Accurate and complete lean information and data facilitate Lean Maintenance Management by proactively maintaining operations that are used in planning and scheduling maintenance activities throughout a construction facility.
10-H	Capturing and using information and knowledge of building operations help in making effective operations and maintenance decisions, and thus, avoiding high costs.
11-G	Information and knowledge of building maintenance activities results into effective planning, better performance, and reduced risks, thereby resulting into an optimized built environment.

Table 5(a) Implementation Interaction Matrix of BIM functionality and Lean Construction principles for Facilities Management

		Lean Construction Operations and Maintenance Principles					
		Lean facilities operations and management planning	Waste reduction	Financial Transparency	Leadership and capability of owners	Continuous improvement (kaizen)	Training and Education for employees
BIM functionality		A	B	C	D	E	F
Organisation continuous improvement	1	X					
Collaboration in Design and Construction	2					X	
Information maintenance and model integrity	3	X					
Organisation structure to support BIM system	4					X	
Competent technical support	5	X					X
BIM Training	6					X	X
Minimal cultural and language barriers	7				X		X
Professional BIM design team	8		X				
Top Management Support	9	X		X	X		X

Table 5(b). Implementation Interaction Matrix that explains contents of cells

Index	Explanation
1-A	Principle of kaizen, i.e. continual improvement while integrating lean operations and maintenance throughout the facility lifecycle of a building aids in getting desired outcomes.
3-A	Model integrity along with better maintenance of information can help in better lean operations and maintenance planning, which would deliver on-time, on-budget, and on-demand projects.
5-A	Competent technical support improves implementation of lean processes while operations and maintenance planning.
9-A	Top management support during lean facilities operations and management planning helps in terms of effective execution of lean processes, accessibility to required resources, and setting performance metrics and KPIs for monitoring success.
8-B	Professional BIM design team within the industry helps in waste reduction up to the desired extent.
9-C	Supportive top management in financial matters helps in meeting the set budget, reducing costs, and thus, maintaining a transparency with all key stakeholders for gaining their trust and loyalty.
7-D	Minimal cultural and language barriers during BIM application can strengthen leadership in Lean Construction, which can lead to better training and guidance of key personnel for facility management.
9-D	Top management support by capable leaders and owners in terms of appropriate choice of leadership style helps in better lean operations and maintenance planning and execution.
4-E	Supportive organisational structure for BIM can help in seeking continual improvement, i.e. Kaizen which is the main principle of Lean Construction.
2-E	Collaboration in BIM design and construction can speed up the continuous improvement process in construction companies.
6-E	Provision of BIM training allows staff to better execute methods and job roles which are relative to Lean Construction in construction companies.
7-F	Minimal cultural and language barriers allow trainers and leaders to better guide and lead subordinates and trainees.
5-F	Competent technical support for BIM along with training for employee development regarding Lean Construction can produce the required manpower for successful Facilities Management.
6-F	BIM training along with employee education and development training can enhance skills, professional personality, expertise and knowledge of staff, so they can perform better throughout the facility life-cycle management.
9-F	Top management support in terms of their ongoing training and education is important for development of lean operations and maintenance employees. This in turn allows them to interact with the key stakeholders effectively.