NEAR EAST UNIVERSITY

INSTITUTE OF GRADUATE STUDIES

DEPARTMENT OF CIVIL ENGINEERING

EVALUATION OF OPINIONS OF TEACHERS

IMPLEMENTATION OF TOTAL QUALITY MANAGEMENT AND THE INTEGRATION OF BUILDING INFORMATION MODELING IN THE CONSTRUCTION MANAGEMENT SECTOR IN SAUDI ARABIA

PhD THESIS

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Nicosia

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Declaration

I hereby declare that all information, documents, analysis and results in this thesis have been collected and presented according to the academic rules and ethical guidelines of Institute of Graduate Studies, Near East University. I also declare that as required by these rules and conduct, I have fully cited and referenced information and data that are not original to this study.

MOHAMMAD ABAZID

22/04/2022

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Abstract

Implementation of Total Quality Management and The Integration of Building Information Modeling in The Construction Management Sector in Saudi Arabia

Mohammad Abazid

Total Quality Management (TQM) relies on the concepts of managing and enhancing the success of construction projects. When applied, TQM works to improve the implementation of project time management, meet customer demands, reduce costs and increase contractor profit. This research aims to evaluate the effects of employing Building Information Modelling (BIM) in raising the efficiency of applying TQM concepts in construction projects in the Kingdom of Saudi Arabia.

For this research, a case study on applying Building Information Modelling to The Student Housing Building at King Khalid University in Saudi Arabia was analyzed. Furthermore, a comparison was made between the 3D plans generated by the Revit program and the basic 2D plans designed by AutoCAD program. The outcomes revealed the contribution of the BIM application in addressing: the lack of necessary information, orders of alterations caused by errors and oversights, poor perception before reaching the implementation stage, and the automatic management of alterations during the implementation phase. This would raise the efficiency of applying the concepts of total quality management in engineering projects by avoiding an increase in time and cost of the project, as well as focusing on customer satisfaction, and increasing coordination between elements and plans. The results indicated that the construction projects in Saudi Arabia still suffer from setbacks in the application of the concepts of TQM and suffer from a lack of administrative, scientific and technical applications.

The results of the study were obtained through the utilization of a descriptive analytical approach, where 300 questionnaires were distributed to engineering firms and companies with a response rate of 200 questionnaires, hence achieving the study sample for this research. The data gathered was analyzed by applying the Statistical Package for Social Science (SPSS) program and calculating the Relative importance index (RII) and the mean values. From the research conducted, the outcomes showed that the management's ability to commit using TQM while applying BIM obtained relative importance of (0.717), while the relative importance for the management's ability to commit using TQM without the application of BIM is (0.552). The results showed that construction projects in Saudi Arabia still sustain setbacks from applying TQM concepts and suffer from the lack of administrative, scientific and technical applications while the application of BIM in the projects will impact on ensuring project success, customer satisfaction, cost reduction and adhering to the schedule, which achieves the concept of Total Quality Management, which proves the alternative hypothesis that there is a significant relationship in the application of TQM and BIM simultaneously that affects the success of construction project implementation in Saudi Arabia.

Keywords: *Saudi Arabia, construction, projects, quality, Total Quality Management (TQM), Building Information Modeling (BIM)*

To my parental

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CHAPTER I
INTRODUCTION

1.1 Research Background

The application of Building Information Methodology (BIM) in the construction industry can be viewed as a method in employing Information Technology (IT) (Autodesk, 2003), which represents the analyzation, enhancement, structuring, maintenance and processing computer-based data systems. The concept of BIM was initially publicized in 2003 by Autodesk. It was developed as an innovative and sophisticated approach for structure design, building, and management. All over the world, the BIM has been able to transform the method followed by the industrial professionals in anticipating the impact of employing technology for structure design, building and management (Autodesk, 2003).

Ever since BIM has appeared, the modeling and documentation of structure projects have endorsed exploitation of a modern approach (Bentley, 2010). Building Information Modelling (BIM), as a term was originally formulated to disengage the customary Computer Aided Design (CAD) that has been primarily focused on the drawing production of structures from the previous IT and CAD generations. BIM can be identified as the enhancement and processing of structural statistics by an interoperable and viable method. Therefore, BIM is recognized as a systematic process or a set of systematic processes that lets operators to integrate and retrieve structural information and domain data throughout the structure's life cycle (Lee et al, 2006).

Many definitions have been associated to the Building Information Modeling (BIM) approach. The American Institute of Architects (AIA) defined BIM as a “model-based machinery associated with a databank of project statistics” (AIA, 2010). The National Building Information Model Standard (NBIMS) stated that the BIM is viewed as an “automated interpretation of substantial and efficient aspects of a facility” (NBIMS, 2010). They also claimed that BIM is “a communal information source for data on the facility, establishing a dependable foundation for assessments during the facilities life-cycle; or in other terms from the initial origin up to the demolition of the facility” (NBIMS, 2010).

BIM has been implemented in the execution of large and high-scale projects. An example of such projects includes the recently constructed London 2010 Olympic, 6,000 seating, Velodrome cycle track and the 225 meters high, 48 floors, Leadenhall Building “The cheese grater". BIM is not only implemented within massive projects; it also is processed in smaller scale projects on particular components throughout the project. One example of smaller scale projects with BIM application is the new bus post located in Slough, UK. It was opened in 2011 of June, in which BIM was utilized to model and install the modular stairs (Build offsite, 2011). Due to the anticipated compensations from BIM employment, with respect to the cutbacks of operation costs and smaller chances of error, the UK government declared that all contracts as of 2014 will compel source chain partners to work jointly by utilizing the "fully collaborative 3D" BIM (Cabinet Office, 2011). The three-dimensional BIM insinuates all resource information, data and records of all projects in a programmed method. In the United States, both the public and private sectors are collaborating to validate the application of the BIM method (Underwood and Isikdag, 2011).

On the contrary, there have been several evaluations that claim that the application of BIM has not yet proven or justified it to be completely effective (Jung and Joo, 2010). Succar provided a definition on BIM that emphasizes its entire aspect, which consists of a software that involves arithmetical Modeling and input of information, as well as the utensils and procedures coupled with Project Management (PM). Hence, observing BIM in its complete complexion undeniably classifies it within the structure of the Project Management domain. Structural project managers are capable of employing BIM to develop the involvement among investors, in which the duration needed for documentation is reduced resulting in profitable project results. From previous literature works on BIM features, some incorporated the detailed record of BIM application on specific project conditions such as the Heathrow Terminal 5(BSI, 2010) and the Walt Disney Concert Hall (Haymaker and Fisher, 2001).

Accordingly, to determine whether the implementation of TQM concepts within the construction projects in Saudi Arabia can be accomplished, this research will study the evaluation of tangible BIM application. A comparison of the TQM will also be made regarding the outcomes of the project when BIM is applied or disregarded. The results will be obtained by conducting researches, applying evaluation/assessment utilities and the method used to comprehend the outcomes while acknowledging the primary features of the project that is represented by time and cost and are incorporated to acquire the vital quality.

1.2 Research Problem

Each construction project has its own unique environment and as a result, each project has its own quality management plan. The quality management plan is aimed at determining the quality targets, identifying the required operation procedures and indicating the resources needed to reach the quality targets. Generally, the quality of any construction project is associated with proper quality management throughout all stages of the project life cycle.

The growing complications of projects have resulted in many developments within the construction industry. The development of a Total Quality Management (TQM) method can be integrated with modern planning methods to enhance the implementation of construction projects. Taking into consideration that the TQM system is relatively a concept and directing system, it requires the presence of other utilities to apply the concepts associated, so that the quality of a project is constantly enhanced. In light of the recent global advancement in information technology (IT), along with the extensive utilization of Building Information Modeling (BIM). Hence, it is necessary to assess TQM approaches as an essential strategy for application in the construction industry of Saudi Arabia.

The complications can be summarized as follows:

- Pre-construction Phase Complications
  1- The project owner’s poor perception leads to difficulty in understanding or imagining the final form of the project. Also, the lack of a full understanding of the project requirements and desires in the early stages. Hence, alteration orders will be issued randomly and unintentionally to add or remove part of the project resulting in an increase or decrease in the materials used in addition to the layout changes. This leads to delay and/or increase the time and cost set for the project.
  2- The low efficiency of the costing process for various reasons, including the semi-manual counting of construction quantities. This results in inaccuracies and high error rates.
  3- Inaccuracy in determining the total time of the project because the design process takes place separately from the timeline stage.
  4- Lack of an efficient mechanism that guarantees coordination between the plans in case of design changes.

- Construction Phase Complications
    1- The contractor is considered the last party to be included in the construction projects, which results in the issuance of a large number of requests for inquiries during the implementation phase.
    2- The design lacks all the information the contractor needs to implement the project.
    3- The contractor's poor experience in implementing some parts of the project, especially modern, large, complex and high-tech projects.
    4- Poor coordination between the various functions and services of the project, and weak communication channels between the project parties. Consequently, collision and overlap points between functions are often not discovered except at the implementation stage, which results in an increase in processing time that can be avoided in advance, which in turn affects the duration and the total cost of the project.

As a result, this research will express the importance of integrating Building Information Modeling tool (BIM) with the TQM system and analyze its effects on the construction management sector in Saudi Arabia. This research will contribute to not only understanding TQM and the impact of BIM technology on the engineering facilities, but it will also develop a theoretical model to identify the numerous factors that hinder the application of such practices in construction projects, specifically in Saudi Arabia. The results gathered will help in understanding the advantages of incorporating BIM with TQM, especially for the construction sector in Saudi Arabia.

Based on the problems that have been previously stated, research and observations will be able to assist in defining the factors selected that affect the project's success when applying TQM separately and when applied with BIM. Therefore, the proposed questions for this research are the following:

1. What is the effect of BIM application in the project phases on TQM?
2. What are the effects of BIM application on the construction industry?
3. How crucial is the relationship of TQM and BIM that affects the success of construction project implementation in Saudi Arabia?
4. How can this model be applied by individuals or organizations in construction projects?
5. Coupling BIM and TQM in construction sector

1.3 Research Objective

This research aims to evaluate the importance of the application of BIM in the stages of the project that would raise the TQM in the Kingdom of Saudi Arabia and the obstacles that stand in the way of using BIM in those stages. This research also reviews previous work that discussed increasing total quality management in the construction industry in Saudi Arabia and linking them to the extent of BIM's impact on them. The goals of this research can be summarized as follows:

1. To develop and understand the application of BIM on the pre-construction phase in engineering projects in Saudi Arabia and its impact on TQM through:
    a) Developing the perception of the owner and defining its requirements, which leads to verification of the validity of the design
    b) Raising the efficiency of the process of cost estimation and accurate counting of project quantities
    c) Raising the accuracy of determining the total time of the project
    d) Creating an efficient mechanism that ensures coordination between the plans in case of design changes.
2. To develop and understand the application of BIM at the construction phase and its impact on TQM by:
    a) The contractor can obtain any quantity or information about any building element that he may need during the implementation process.
    b) Increased coordination and communication between the various functions and parties of the project that avoid collision points and overlap between works in the implementation phase.
    c) Evaluating the design and construction situation through the ability to compare the developed plan and the actual implementation, where the contractor is able to compare the design, implementation and procurement.
3. To identify the important factors affecting the failure to implement BIM in construction projects in the Kingdom of Saudi Arabia.
4. To develop a guide that helps determine the degree of factors based on the theoretical model that has been developed

5. To develop a model to Integrate TQM and BIM in a Building project and to show that it contributes to improve the quality and efficiency of construction projects in KSA.

1.4 Research Significance

The importance of this research is targeted at developing the essential principles to enhance the Total Quality Management of construction project execution in Saudi Arabia through the application of the construction model on the project's phases, as shown in the following figure,

Additionally, the impact of Building Information Modelling (BIM) on the success of TQM application will also be evaluated to establish a practical model for future works. This model will help contractors and project owners/clients in Saudi Arabia to assess the factors that may obstruct the success of applying such practices in the construction industry. There is an urgent demand for such a model to help in enhancing the management of time, cost and quality for the construction projects.

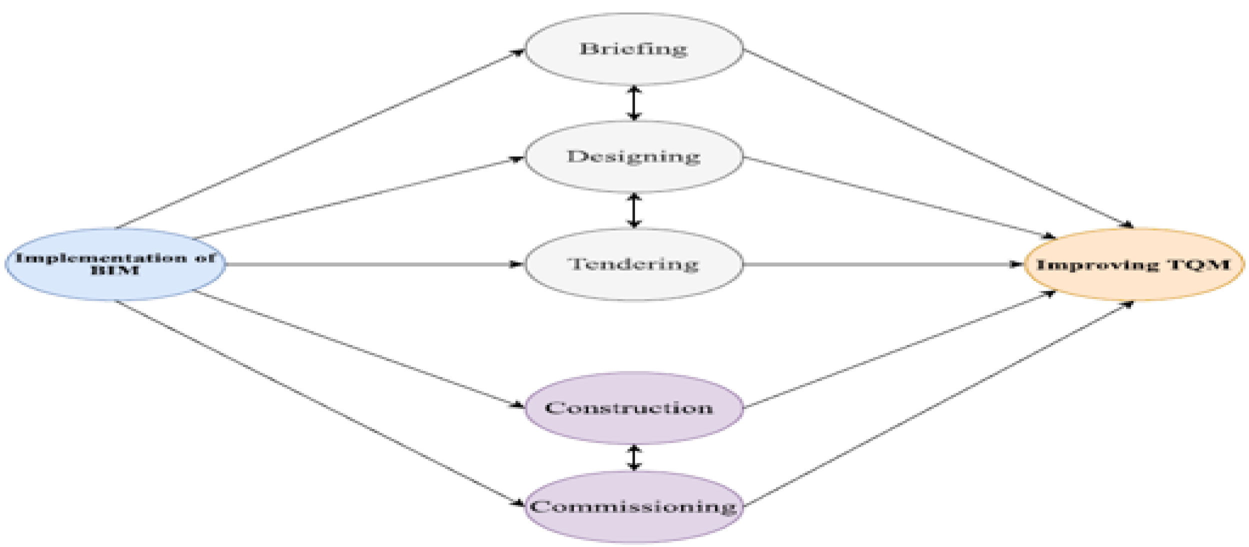


Figure 1-1 Research Significance

1.5 Research Limitation

1. This study concerted on implementation of total quality management and the integration of building information modeling in the construction management sector in Saudi Arabia developing a theoretical model to determine the important factors affecting the implementation of BIM in construction projects in the Kingdom of Saudi Arabia and the extent of their impact in raising the TQM.

1.6 Research Hypothesis

In general, the hypothesis of this research contemplated investigating the validity for each of the following:

Null hypothesis 1 (H0): There is no significant relationship when applying TQM and BIM simultaneously, which affects the success of construction project implementation in Saudi Arabia.

Alternative hypothesis 1 (H1): There is a significant relationship in the application of TQM and BIM simultaneously that affects the success of construction project implementation in Saudi Arabia

1.7 Research Methodology

The objective of this research will be accomplished based on two phases. The first phase is the theoretical phase that requires intense data collecting and research to better comprehend the research subject. The second phase is the practical phase, which is the mathematical section of the research. The two phases will be reviewed in detail below.

I. Theoretical Phase:

This phase is known as the literature review and is completed through extensive research and gathering of previous papers, journals, reports, books, theses and documents that address the TQM and BIM concepts generally, or specifically in analyzing the factors that impact the success of both applications. This phase will be able to assist in classifying the important factors that will be manipulated, as well as providing the framework for evaluating the factors.

II. Practical Phase:

This phase will be divided into two stages.

1. The First Stage consists of primary data that will be collected through several methods, which will be discussed below.
   a) A questionnaire was established and composed of five main categories. It requires evaluation of specific points accurately and objectively based on the respondent’s opinion and experience in the field of engineering work for

design and construction in light of the actual reality in the Kingdom of Saudi Arabia.

b) Construct the theoretical model that will be applied to assess the factors and define the significance of TQM and BIM application utilizing the statistical package for social science (SPSS) the relative importance index and mean values.

c) Discussing the process of acquiring the relative importance and mean values for each factor, which is the base for comparing the factors in order to achieve the factors ranking significance.

2. The Second Stage will be composed through the practical application of BIM on the Student Residence building project at King Khalid University in Saudi Arabia. as well as evaluate its impact on TQM and compare the results of those projects before and after the application of BIM. Through this stage, we can evaluate the impact of the research hypothesis on engineering projects before starting the second stage through quantifiable performance indicators within the project, such as lack of information needed for the implementation process, alteration orders, and estimating construction costs.

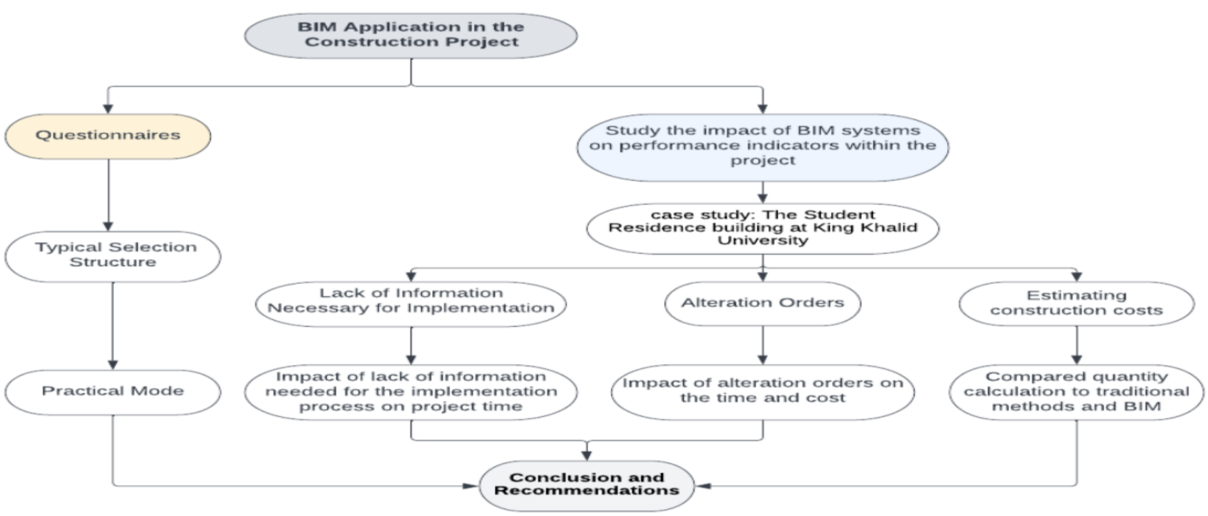


Figure 0-2 Research Methodology Structure

1.8 Achievements

The research gives a notion about the benefits of BIM based quality model, how it benefits to project team and the limitations of the model. Quality in construction depends on several factors such as completing work on time within budget, meeting requirements, conforming to design specifications etc. To satisfy all the factors responsible for the quality, an efficient quality management system should be there. The achievements of this research are summarized as follows:

1. To provide better communication among stake holders and project parties. One of the main disadvantages of conventional quality control methods is the lack of communication among project participants. The architectural, structural and MEP team will be in clash during the design phase. By using BIM, they can work together to resolve the problems. Also, the design wing can give all the necessary information to the construction wing through BIM.

2. To identify and resolve clashes for any construction project. During the design stage itself, we can detect the interference between architectural, structural and MEP elements. Clash detection helps to integrate all design information into a master model which is considered to be easier and less time-consuming than the traditional method.

3. To allow an uninterrupted flow of information. Information consistency is one of the main advantages of using BIM. The information can be shared from the design phase to the construction phase without any loss. Therefore, the quality requirements that the designer specifies can be executed by the construction team.

4. To maintain a strong database by utilizing BIM. The BIM software has a strong database so that all the information can be stored and preserved for present and future use. The model will be a digital model of a particular project, hence, this information can also be used for maintenance.

5. Integrating BIM will offer a better understanding of quality requirements. The quality model provides a better experience about the quality requirements so that every individual participating in the project with less knowledge about quality control can simply execute the work.

6. To be able to automatically detect failed components. The software allows users to simulate certain conditions in order to detect the failed components. After feeding the inspected data into the model, it will automatically detect the components which have failed to meet the conditions provided, as well as detecting uninspected products.

7. To cut back on time and project costs. The completion of a project on time within budget is one of the crucial factors which affects quality in construction. By using BIM, we can detect the errors early on and resolve it, which will save time. Also, each construction activity can be pre-planned by simulating the 4D model, thus the wastage and underutilization of resources can be avoided.

8. To integrate BIM as LPS. This allows a 4D model to be used for developing weekly working plan or short-term working plan. This will ensure the execution of the activity on time without any delay.

1.9 Novelty, Originality and Motivation of this Study

The Kingdom of Saudi Arabia suffers from a weak application of TQM in engineering projects. As Saudi Arabia has been working for years to raise the efficiency of quality through traditional methods (courses and conferences and motivating companies to work on raising quality), but these methods still do not achieve the desired goals,

That is why this research presents a new way to raise quality through the use of BIM software that enables the project to automatically link the project components (plans, quantities and characteristics) through a single model, which makes the possibility of control and human error unimaginable and helps to understand the project requirements and objectives from The first stages of the owner, designer and contractor

For this research, a case study on applying Building Information Modelling to The Student Housing Building at King Khalid University in Saudi Arabia was analyzed. Furthermore, a comparison was made between the 3D plans generated by the Revit program and the basic 2D plans designed by AutoCAD program. The outcomes revealed the contribution of the BIM application in addressing: the lack of necessary information, orders of alterations caused by errors and oversights, poor perception before reaching the implementation stage, and the automatic management of alterations during the implementation phase. This would raise the efficiency of applying the concepts of total quality management in engineering projects by avoiding an increase in time and cost of the project, as well as focusing on customer satisfaction, and increasing coordination between elements and plans. The results indicated that the construction projects in Saudi Arabia still suffer from setbacks in the application of the concepts of TQM and suffer from a lack of administrative, scientific and technical applications.

For the best authors, these models have never been used in any technical literature which is an additional novelty of this thesis.

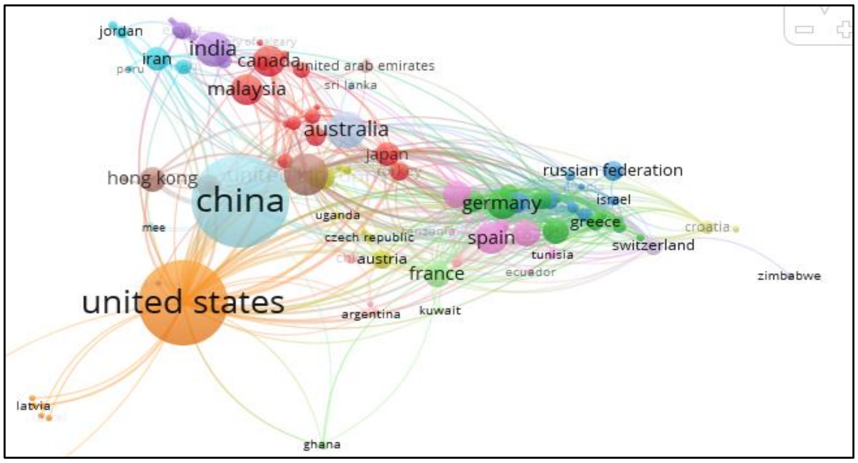


Figure 0-3 The investigated the research region on the TQM application in construction (2008-2022)

1.10 Structure of the Thesis

Chapter One: Introduction: The first chapter will familiarize the research subject, isolate the research problem and signify the importance of this research as well as the process that will be employed to fulfill this thesis. Moreover, the research hypotheses, the objective of the research study and general steps of the research methodology have been specified.

Chapter Two: Implementing Total Quality Management (TQM) in the Construction Industry: This section introduces the concept of Total Quality Management and its definition. Additionally, an overview of the application of TQM in the construction industry, along with the various models and advantages of TQM will be incorporated.

Chapter Three: Application of Building Information Modelling (BIM) in the Construction Industry: In this chapter, the innovative program, Building Information Modelling will be familiarized and defined. The importance of BIM, its advantages and effect on the industry will also be discussed.

Chapter Four: Research Methodology: This chapter will explain the research methodology for this thesis. It will describe the techniques exercised in order to identify the factors. It will rely on receiving expert opinions on their personal judgements for a factor. The calculation process will be explained in detail to understand the outcomes of this research.

Chapter Five: A New Model (case study): According to chapter Five, BIM systems that have been applied to the case study of the research will be conversed. It will present the comparison assisted in understanding and determining if the use of BIM systems would increase the efficiency of applying TQM concepts or not in the implementation phase through quantifiable performance indicators within the project, such as lack of information needed for the implementation process, alteration orders, and estimating construction costs.

Chapter Six: Data Collection and Analysis: According to chapter six, the mathematical calculations and practical methodology of the research will be conversed. It will present the theoretical model utilizing the statistical package for social science (SPSS), the relative importance index and mean values. The results obtained from the questionnaires related to the preference of the factors are utilized to obtain the relative importance for the factors and their mean values.

Chapter Seven: Results and Discussions of the case study: This chapter summarizes the research outcomes which examines the importance of using BIM systems to increase the efficiency of TQM in engineering projects in Saudi Arabia. The following chapter will briefly discuss the practical chapters of this research as well as summarize the outcomes.

Chapter Eight: Conclusion: The final section of this thesis is dedicated to identifying the essential outcomes that have been gathered from this research. Moreover, recommendations will be provided on the application of TQM with BIM and suggest future works.

CHAPTER II

2 Implementing Total Quality Management (TQM) in the Construction Industry

2.1 Introduction

All over the world, construction industries are faced with many problems because of rapid technical developments and advancements, making project maintenance more complicated and perplex. Many enhancements occurred within the construction industry to resolve the growing complications of projects, specifically the development of Total Quality Management (TQM). The TQM can be utilized with the traditional and modern planning methods to develop the implementation of construction projects significantly.

Quality is perceived as one of the essential elements of an effective construction project. Reaching an acceptable quality level is one aspect that has been an issue in the construction industry for quite some time. Human and material assets such as time, money and resources are annually wasted because of unproductivity or the lack of quality management practices. For construction firms to be competitive in the current market, they must offer more consistent quality and value to their owners and clients. This has led many industries, globally, to adapt the Total Quality Management (TQM) concepts, which assist in increasing production, reducing costs and enhance reliability.

Moreover, TQM is considered an innovative method in the domain of quality following quality assurance (QA), quality control (QC) and ISO in the construction industry. Presently, the majority of the organizations have begun employing TQM with the perception of evaluating and improving the quality levels. TQM is capable of developing the economy of an association, better client satisfaction, operative involvement and enhanced management of labors in the establishments.

The following section of this research identifies the various concepts of Total Quality Management (TQM). A detailed explanation of the significant elements of TQM, the barriers that might obstruct the success of TQM and the main advantages of TQM implementation, as well as the most prominent TQM models used are provided.

2.2 The Evolution of TQM from Quality

Many classifications of the term quality can be found throughout several literature works. Take for example (Juran, 1986), who identified quality to be “fitness for use”, or (Crosby, 1979) who classified quality being “conformance to requirements”. The two classifications are aimed at the satisfaction of the customer’s necessities. Concurring to (Feigenbaum, 1991), who claimed that quality is the complete combination of merchandise and maintenance features of publicizing, manufacturing, production and continuance wherein the merchandise as well as the maintenance shall convene to consumers requirements. As defined by the ISO 900, quality is the all-inclusive characteristics of a merchandise or maintenance that tolerate beyond its capability to appease affirmed or indicated desires (ISO 9000, 2004). On the other hand, (Garvin, 1988), expanded quality by studying eight primary dimensions which include implementation, characteristics, dependability, conformance, endurance, serviceability, aesthetics, and identified quality.

Furthermore, quality can be defined as the ability of a certain merchandise to satisfy, or rather surpass the requirements and expectations of the consumer. All of the definitions on quality are attained from various perspectives that emphasize several problems. Take for instance, Crosby's definition of quality as "conformance to requirements" which has a manufacturer perception, as well as "Deming's and Juran's" classifications provide a service provider outlook. As seen from the aforementioned definition of the term quality, it emphasized the extension to fixate on consumer demands, where the consumers in reality are seeking "resolutions" to their demands and not only quality merchandise.

2.2.1 Quality Inspection

Throughout World War II, the stages of inspection and quality control progressed as the production procedure became more complex. Moreover, with the presence of a massive workforce appointed to various supervisors, there was the risk of losing control of the work itself. Therefore, the necessity of assigning inspectors on a full-time basis was required in order to assure that quality was sustained. At this phase, quality was associated with inspection, which generally occurred throughout the manufacturing procedure (Dahlgaard et al., 2007). Correspondingly, (Harris et al., 2013) acknowledged checking and inspection as the primary component of quality at this phase in the development, which resulted in TQM. Additionally, (Costin, 1994) viewed inspection as the main feature of quality throughout this stage. During the manufacturing procedure, inspection was recognized as an assessment moment for quality assertion. If mechanisms or resources failed to coincide to specific quality descriptions, they were declined or sent back for modification. Conversely, this tactic, where the quality of the product was evaluated, did not precisely incorporate any of the operatives, providers or consumers.

2.2.2 ***Quality Control***

The second stage in the growth of Total Quality Management was identified by much further concentration to quality control by complying with requirements, calibration and measurement. Moreover, quality control was strongly dependent on statistics and the revoking of merchandises at the completion of the procedure, for those that did not conform to the requirements. This encompassed the utilization of control records and random experimenting tactics established by Stewhart and Dodge-Roming during the years 1924 and 1931. In the manufacturing procedure, Stewhart acknowledged two apparent forms of alternatives, in which the first alternative was unintentionally produced, a kind of natural disparity. The second form of alternative was a result of specific reasons in the manufacturing procedure that may be dealt with through quality control interference. Interferences such as these may enhance the probability of the production procedure (Dahlgaard et al., 2007).

The ISO (2008) identified quality control as the functioning activities and methods that are implemented to achieve the quality constraints. This classification implies that any activity, whether it be enhancing quality or assisting the control management, is acknowledged as quality control activity containing operation, procedure, merchandise design and productions. Furthermore, quality control was associated to attaining quality specifications by utilizing statistical methods. It is correlated to the inspection procedure of the completed merchandises and services, but it is further focused on avoiding and evading any limitations and studying operation procedures to ensure whether they were operating in such a manner as to attain the compulsory standards (Ismail, 2012). (Ellis et al., 2005), observed how efficient quality control techniques were resulting in fewer errors and flaws and improved procedure control. They further added that quality control is not a procedure for developing paradigms. Rather, it is a procedure to maintain and sustain the paradigms by means of selection, flaw prevention and measurement.

2.2.3 *Quality Assurance*

Throughout the third stage in the growth of TQM, it observed an alteration from classifying flaws at the end procedure towards an enduring development method that aimed to tackle the main reason behind the flaw at cause. This development phase stressed structural planning targeted at the elimination of flaws and their manifestation, which is considered the objective of quality assurance (Dale et al., 2013). In a study by Dahlgaard et al. (2007), it showed that quality assurance was built based on the previous two phases including a strong concentration on achieving the consumers' demands. There are many key phrases within the quality assurance phase that include "right first time" and "fit for purpose" that emphasized the reliability in the delivery of quality. Moreover, the quality assurance standards are internationally set by the International Quality Standard ISO 9000 and its associated sets of standards (Harris et al., 2013).

Concurring to Besterfield et al. (2012), quality assurance is a group of actions completed before the planning procedure or production of products to ensure improved quality to the consumers. Additionally, it highlights flaws and errors prevention by enhancing manufacture and relevant procedures to minimize or avoid any contingencies, which may cause errors or flaws in the beginning. Alternatively, quality control is a set of activities completed throughout manufacturing products or delivering services to customers but assessing and blocking the release of flaw production; hence, it only concentrates on flaw detection.

2.3 Definition of TQM

Initially, the term TQM was devised by the Department of Defense in the United States (Evans & Lindsay, 2001). It is recognized as the fourth phase in the enhancement of quality and was implemented in the 1980's as a method of developing quality so that the US organizations could participate efficiently with their Japanese equivalents (Talha, 2004). Because of its highly enhanced technology, lower labor costs compared to that of the US, as well as its work ethic, Japan became a major contender in the 1980's. They also gained a major position in the US market because the American companies were restricted by labor laws and government policies (Mele &Colurcio, 2006). Hence, the TQM philosophy was viewed as a response to the Japanese effectiveness and was broadly adopted because of its more refined tactics and its greater attention to all company stakeholders, which encompassed internal and external consumers.

The Construction Industry Institute (CII, 1993) also defined TQM in a detailed phrase. They stated that TQM is a "management ideology that efficiently establishes the demands of the consumer and offers the framework, environment and culture for meeting them at the lowest possible cost".

In other terms, TQM can be identified as “an effectual, widespread management approach that has proven successful worldwide, in manufacturing, service and construction organizations”.

2.4 The Concept of TQM

Ever since quality has emerged during the mid-20th century, it has maintained its position as a dominant matter in management assessment (Beckford, 2010). The concept of quality is not acknowledged as a contemporary enhancement. The majority of the literary works regarding business and the concept of quality is rather up to date, given that it was written during the latter half of the 20th century, and it was a fundamental element of societies all over the globe for some ages.

The fundamental concept of TQM was introduced by three well-known experts who are Deming, Juran and Feigenbaum in Japan during the year of 1940. The phrase ‘Total quality’ was used during the first international conference regarding quality control in Tokyo by Feigenbaum in the year 1969.

During the years of 1980-1990’s a new phase of quality control and management initiated, which has come to be known as Total Quality Management (TQM). Initially, TQM was utilized in the manufacturing industry and automobile industries. TQM was focused on client’s needs and developing a quality-oriented managing method for constant enhancement. With time, TQM proved to be an influential success in achieving good quality products. Due to its success, the TQM concepts were adapted by the construction industry.

Before the concept of TQM is debated, it is vital to comprehend and evaluate the concept of quality. In their study, researchers (Djerdour and Patel, 2000), indicated that quality is no longer elective; it is a crucial tactic for survival. (Billich and Neto, 2000), emphasized the essential significance of quality as a fundamental factor of TQM execution tactics, while also drawing the attention to the necessity of its presence even in the standard operations of the organization alternating from policy formulation and decision-making through to the appropriation of resources, staffing and product or service delivery to meet the customers anticipations. In fact, researcher (Juran, 1991) selected customer approval as the specific most significant feature of providing quality service to the consumer. However, there is a broad range of meanings for the term quality that is found throughout previous works, each with its own specific emphasis and formulation of the concept of superiority (LaKhal et al., 2006).

On the contrary, a majority of the quality visionaries and specialists have defined the term quality in which some of those recognized definitions include the following:

• Quality is fitness for utilization, stated by Juran (1989),

• Quality can be condemned by the customer, averred by Deming (1986)

• Quality is equal to consumer approval, declared by Ishikawa (1985)

• Quality is enduring customer necessities, as stated by Oakland (2003).

Today TQM is considered to be of the few utmost prevalent as well as commonly operated managerial methods within the US corporations. According to the classifications previously mentioned, it may be stated that TQM is composed from numerous elements; the particularly significant are four elements, which are the following:

1. The continuous search for attaining consumer contentment.
2. Enduring as well as determined labor for enhancement of quality and improvement.
3. Application of assignment potencies, also the contribution of each employee within the corporation.
4. Awareness of the data and structures improvement.

Corresponding to "Lau and Anderson (1998)", in order to comprehend as well as efficaciously apply Totally Quality Management, it necessitates employing TQM theories in addition to linking such theories with the precise function in contemplation. The common components utilized to classify TQM were extracted on the idealistic rank. The following table, Table 2.1 below summarized these components.

Table 2-1 Components of TQM

Total	Quality	Management
Necessitate operative contribution and cooperation	Consumer (inner and outer) compelled	Necessitate liability commencing higher administration
Each individual should acquire an implication of quality proprietorship	Highlighting ongoing development (Kaizen)	Create objectives and principles of the organization
Include each rank and occupation of the corporation	Methodological problems: preparing for proficiencies and comprehension	Management is essential
Employ structures reasoning	Benevolent problems: inspire modernization.	Makes suitable modifications within managerial society.

2.4.1 Elements of TQM

Total Quality Management can be developed into a framework that incorporates the fundamental elements of TQM. The amount and significance of the selected elements differ from one researcher to another. In Figure 4, the TQM framework is illustrated. The nine elements depicted were manipulated during the development of the questionnaires to evaluate the scope of TQM familiarity between the participating parties of the construction sector in Saudi Arabia.

The majority of the literature works regarding TQM elements are outdated, and the research presently conducted on TQM do not highlight TQM elements given that they have been extensively addressed in researchers during the initial stages of TQM appearance. There is abundant research on TQM and its aspects that have surfaced during the late 1980s and early 1990s. Contemporary studies are more fixated on the challenges and suitable practices for implementing TQM in the industries.

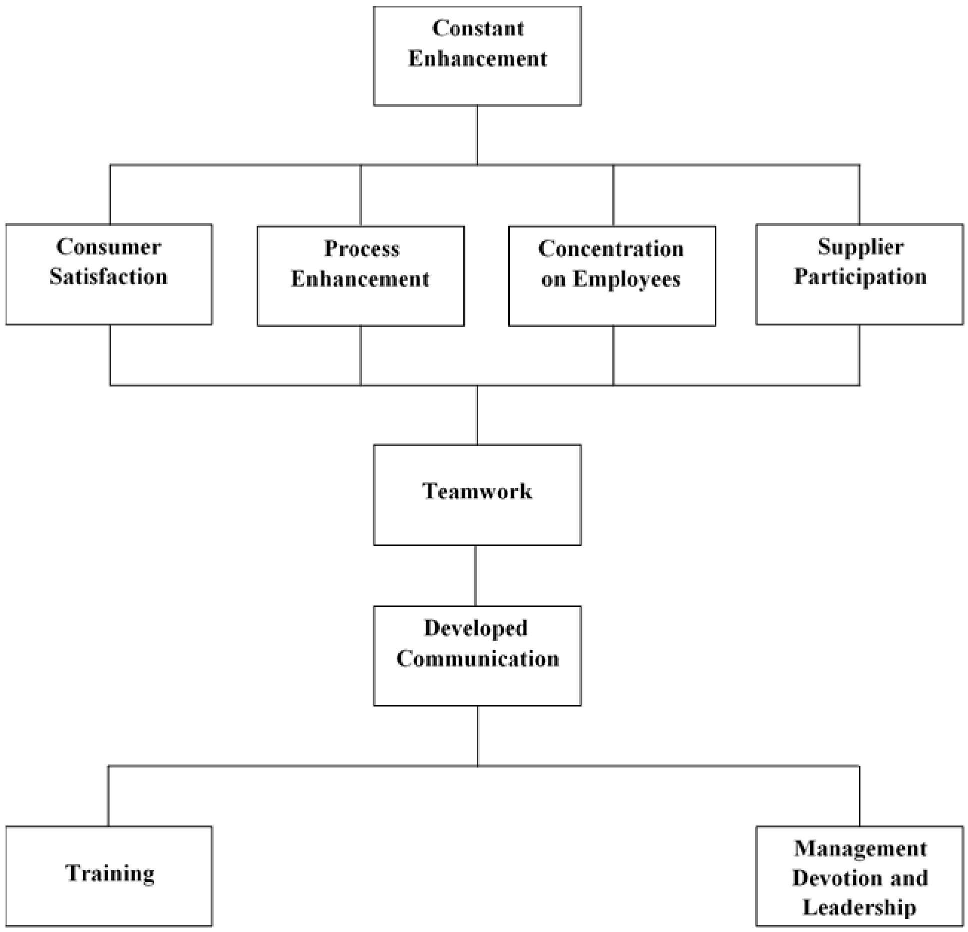


Figure 2-1 Structure of TQM (Nasim, K. (2018).

The two fundamental elements of the TQM structure are ‘Training’ and ‘Management devotion and Leadership’ and may be acknowledged as the foundation of the structure. The association among the foundation and other elements of the TQM structure are signified by ‘developed communication’ and ‘teamwork’. The element ‘developed communication’ is found under the ‘teamwork’ element to represent its importance and priority. The elements ‘consumer satisfaction’, ‘process enhancement’, ‘concentration on employees’ and ‘supplier participation’ are corresponding to designate their equivalent significance. The top of the structure is represented by the element ‘constant improvement’ to serve as an oversight that embraces the remaining elements. The elements will be briefly identified in the following section.

2.4.1.1 ***Training***

Training is considered a fundamental element for the success of quality management practice. Many experts and CEOs who have successfully utilized TQM in their establishments have acknowledged the significance of training, in which everyone in the establishment must participate in the program seeing that TQM is the responsibility of every employee in the establishment. It is essential that the entire workforce comprehends the necessity of TQM, its concept, methodology and its outcomes (Burati, 1992, Chase, 1993, and Oakland, 2000). This allows employees to obtain a fundamental realization that can be associated to more innovative subjects.

Team training is vital because TQM demands a collaborative, methodical and structured system to enhance management. The training program should encompass cause-and-effect assessment, team problem resolving, interactive communication and collaboration, primary statistical approaches, budget of quality extent, and the gathering and estimation of quantifiable data (Burati, 1992, Chase, 1993 and Oakland 2000).

2.4.1.2 Management devotion and Leadership

The availability of management devotion and leadership is necessary for successful TQM application. The management must have extensive comprehension of TQM before committing to management. Management devotion incorporated with leadership and support within TQM application will result in providing the required resources of time and capital to allow enhancement.

The higher managements are required to provide a vison and mission statement that summarizes the establishment's values and emphasize on the consumer satisfaction and quality. The presence of TQM in an organization necessitates workers to handle issues in a different manner; hence, the collaboration of management is crucial. It is vital that the organizations environment is modified in order to modify the behavior of employees and enhance quality. Not doing so will hinder the success of TQM application in the organization. Therefore, management should understand how to handle challenges rather than cope with the existing organizational systems.

2.4.1.3 Communication

To accomplish TQM, good communication is essential where it will lead to eliminating distress. When employees are distressed, they tend to be reluctant in sharing their opinions or enquire policies, processes and judgements, in other words they are prevented from participating. Employees should be able to understand the cause behind their work being rejected or the importance of the work they provide for the organization. If employees do not understand these factors and there is miscommunication, this can lead to the employee believing that he/she has no significance to the organization (Strange, 1993).

Open lines of communication are one strategy that can be manipulated to resolve the issue of miscommunication. It permits direct contact to higher management to pose a concept for enhancement or if there is a specific matter. Before enforcing open lines of communication in an organization, employees and management need to be taught for such a process, or else it will not be an effective technique. (Sanders, 1993).

2.4.1.4 Teamwork

Teamwork is essential to accomplish an establishment's objective while applying TQM. It has been proven that teamwork among working individuals to reach common goals are usually more effective than when individuals work separately. TQM identifies that team approach should not be restricted to the internal establishment's team, but it should embrace investors and external clients under its patronage.

The quality team is the consultant committee accountable for forming and improving the strategies and processes for the TQM application procedure. The members must be able to identify the organization's demands. Moreover, the team leader should not play the role of the expert but rather proceed as an implementer for these consultations. It is anticipated that team leaders should be accomplished in areas such as communication, group changing aspects, statistical procedures, and problem-solving systems, practices, and group leadership (Imai, 1986 and Burati, 1992).

The main obligation of a quality team is to recognize the extents of enhancement and the causes of the problem. Once that is completed, the team should choose the particular objective for enhancement and followed by the clarifications to resolve these complications should be applied. The efficiency of the clarification needs to be evaluated for any compulsory helpful actions. Once the clarification is proved efficient, a new standard should be established and continuously monitored (Burati, 1993 and Imai, 1986).

2.4.1.5 Consumer Satisfaction

The fundamental focus of TQM is to acquire consumer satisfaction regardless of if the consumer is internal, such as facilities of the same establishment), or external (the recipient of the final product). The first phase in obtaining consumer gratification is to classify the consumer's demands and desires and then interpret these demands and desires into principles. Consumer gratification is not restricted to attaining the consumer's expectancies, but it must attempt to surpass them through constant enhancement.

To acquire consumer anticipations, the establishment should implement a data-collecting system that measures the level of consumer satisfaction. The development of this form of system assists the establishment to classify the dissatisfaction fields so that corrective action can be administered to disregard the basis of dissatisfaction. There should be two systems developed for measurement; one that measures external consumer gratification and the other to measure the internal consumer gratification (Chase, 1993).

Consumer satisfaction can be attained by applying the following actions (Chase, 1993):

1. Make the consumer (internal and external) conscious of the organization's quality management program.
2. Identify consumer anticipations.
3. Evaluate the consumer's extent of gratification.
4. Engage in methods to enhance gratification.

2.4.1.6 Continuous Enhancement

Thomas Oswald and James Burati stated, "Total Quality Management is consistently labelled as a passage and not a destination" due to its character as a group of processes and methods focused on enhancement. They are conducted in an altered management setting. The ideology of 'continuous enhancement' embraces that this setting must exist throughout the entire lifecycle of the organization, where the techniques will become consistently utilized on a normal and repeated basis. The enhancement program is an ongoing phase with no end. The management applying TQM should understand to the technological developments and the upgrading of management methods. Great alterations within the performance levels are attainable through modernization (Burati, 1992).

The utilization of continuous enhancement requires attention on the programs in order to alter them to become more effective. The extent if success is categorized based on comparisons of the progress among the specified criteria. The procedure of measuring and comparing is better known as ‘benchmarking’, which is a methodical pursuit of the best methods that result in extraordinary functioning (Fisher, 1995 and Lema, 1995).

2.4.1.7 Process Enhancement

There is a mutual association between process enhancement and continuous enhancement. Based on several research, process enhancement is identified as statistical techniques or Statistical Process Control (SPC) since the measurement and evaluation of information is crucial to enhancing process. It is important that the information obtained is precise to assist the employees and management to formulate effective judgements on process enhancement.

Any organization is able to construct a quality enhancement team to assess the systems. In which the team should be composed of a delegate from each field that may be participating in the system. The objective of this team is to classify and distinguish the reasons for quality complications and advocate resolutions. These resolutions are then assessed, and the most appropriate resolution is selected for employment. Ensuing performance needs to be measured and assessed to decide if extra action is needed (Chase, 1993).

Some instruments can be manipulated to help examine the processes. These include histograms, cause-and-effect charts, check sheets, Pareto diagrams, graphs, control charts, and scatter diagrams.

2.4.1.8 Concentration on Employees (Empowerment)

The concept of TQM portrays staff member gratification as a fundamental aspect in enhancing the participation of each staff member. It also views the worker as an internal client with whom the establishment shares data and services. Moreover, TQM advocates the idea of employees being clients to one another. Hence, each member must attempt to satisfy their internal clients, which is accomplished by training and management insistence (Chase, 1993).

It should be considered by management to allow the working environment to be open. This permits honest opinions that are made without the fear of consequences. Essentially, employees are the individuals who best understand the accuracy and imprecision of a system since they operate it. The management must be accountable for delivering intensive training for its staff members to guarantee the appropriate implementation of a process. The management should also promote propositions along with a procedure that must be established to take action on the implications. Failing to act on the propositions within an adequate period will prevent members to spend time to prepare their implications.

2.4.1.9 Supplier Participation

TQM acknowledges that the quality for any phase during the process is reliant on the quality of the preceding phase. Hence, TQM is attentive to the suppliers and investors of the establishment. Preserving a tight and enduring association with the suppliers can lead in obtaining the finest economy and quality. When the association is a limited one, the suppliers are given bigger orders which assists in gaining their loyalty. Upholding a tight association as well as open communication between the suppliers and organizations helps the suppliers to better comprehend and grasp the consumer’s demands. The outcome is improved products that satisfy the organization’s needs (Burati, 1992 and Pyzdek, 1991).

Unlike the customary procurement techniques that rely on several suppliers, partnerships necessitate an individual or restricted group of suppliers. Even though numerous sources are capable of providing the organization with agility if complications occur or failing to meet the delivery date, still, the availability of many suppliers is costly. The high prices of maintaining a large group of suppliers may be more than the probable savings produced because of the supplier’s competitiveness (Burati, 1992 and Stuart, 1993).

2.5 Interpretation of Total Quality Management

Researchers “Reeves and Bender (1994)” propositioned several classifications for quality. The initial classification can be stated, as “quality is conformance to specifications” followed with the next classification that is “quality is satisfying or exceeding customers’ expectations” subsequently the third classification is “quality is achieving excellence standards” and last but not least the final classification is “quality is creating value of products, services and process”.

Correspondingly, “Kanji (1990)” expresses Total Quality Management to be the constant method dedicated towards endless development in order to please consumers’ requirements. Furthermore, “Besterfield, Besterfield-Michna, and Besterfield (2003)” identify TQM in a similar method that refers to the concept as philosophy and ideologies, which are targeted to establish the persistent enhancement procedure in an association. Additionally, “Wolkins (1996)” ensued the exact method while classifying TQM to be a mixture of management methods as well as methodological tools concentrated on enduring development of organizations.

Moreover, “Ahire and Ravichandran (2001)” complemented ongoing enhancement of client contentment where they identified TQM to be the conception of administration pursuing to develop procedure as well as merchandise quality that resulted in consumer contentment. The similar method was endued by “Dean and Bowen (1994)” in which they identified TQM being the management conception described by practices, values, and techniques.

Researchers “Steingrad and Fitzgibbons (1993)” identify Total Quality Management beginning at the production and manufacture methodology. The researcher’s description defines Total Quality Management as processes and methods targeted at minimizing deficiencies of a manufacturing procedure/ maintenance delivery.

Additionally, “Evans and Lindsay (2008)” classified Total Quality Management as a managerial conception that guides the accomplishment of a corporation by obtaining clients’ anticipation. Additionally, “Zheng (2010) and Zhao (2005)” defined TQM to be a structure established upon constant criticism to develop the quality of maintenances merchandises utilizing all-inclusive practices and approaches.

The following section has been able to unveil numerous classifications. The aforementioned classifications can be compiled from the debate given by Garvin (1987). Garvin claims TQM descriptions are composed of five main methods: “(I) Product-Based Approach; (II) Marketing, and Operations Management Approach; (III) Manufacturing-Based Approach; (IV) Operation Management Value-Based Approach; and (V) User-Based Approach”.

2.6 Application and Advantages of TQM

Established upon the four exceptional paradigms of TQM grants, Abdullah et al., (2009) classified TQM methods within two groups: “soft TQM” approaches and “hard TQM” aspects. It was debated that “soft” approaches engage in a far more significant part towards application and outcomes of Total Quality Management. Soft approaches include management, structural understanding, cooperation, procedure management, preparation, and interaction.

“Lewis et al., (2006)” observed Total Quality Management features within the standards of the ISO 9001:2000 accreditation. Constructed upon profounder evaluation implemented upon information composed from eight countries, the attention was drawn to twelve approaches, which were envisioned as the utmost significant methods involving TQM employment and accomplishment. These approaches include quality information and recording, consumer contentment, human resource exploitation, managing procedure control, preparation and edification, administration assurance, ongoing enhancement, guidance, tactical quality organization, implementation measurement, client emphasis, as well as interaction with providers and qualified acquaintances.

It has been shown that TQM holds positive outcomes as well as effects on establishment implementation and function “(Zakuan et al., 2008; Abdullah et al., 2009; Kaynak 2003; Samson and Tersioviski 1999)”, particularly occupational establishments “(Bon et al., 2012)”. According to literature assessment, developments of Total Quality Management employment display that establishments could be exposed to either one of two principal classifications: establishments employing TQM concept and the establishments excluded from the corporate market “(Hoang et al., 2010)”. Additionally, Hoang and his associates’ extensively debate how great organizations involving TQM employment established additional modernizations and acquired greater competing rank associated to minor establishments within the Asian area. Moreover, it has been observed that establishments implementing the TQM procedures attained improved modernizations as well as larger market commission.

Total Quality Management contains substantial optimistic influence regarding managerial execution “(Zakuan et al., 2008)”. The outcomes attained showed that associations winner of MBNQA endure establishment and accomplishment of massive financial operation.

2.7 Effects of TQM Implementation

The influences of TQM on the performance of projects were examined by researchers Nashwan Mohammed, Noman Saeed and Awad Sad Hasan (2012). They developed a TQM structure based on previous research, which illustrated the association of TQM with the construction project performance by evaluating the impacts of nine TQM models regarding three factor levels of project implementation. The advocated structure and theory were analyzed by manipulating information gathered from construction organizations in Yemen. The results showed that the advocated structure had a positive impact on teamwork contentment, quality of project execution, client gratification, and project functioning. The research was able to provide valuable information on the establishment of an appropriate TQM model for construction organizations.

In another study, Ahmed S. A (2010), discussed the method in which construction experts apply TQM and the utilities used in the various phases of the construction project. The outcomes of this study proved that TQM enhances business quality, maximizes client satisfaction; minimizes budgets; saves time and more. Due to the vagueness of construction professionals on the TQM concepts and methods, the application of TQM gained recognition much later within the construction industry. Advocating the advantages of TQM in the construction sector requires more effort by professionals, and the concept of TQM should be studied in undergraduate programs by future engineers.

In a study performed by Abu Hassan bin Abu Bakar, Khalid Bin Ali and Eziaku Onyeizu (2011), they identified the efficiency extent of implementing TQM concepts by contractors in the Sultanate of Oman throughout highly ranked construction firms. Several significant factors were acknowledged based on the internal clients of these firms. The outcomes of this study discovered that construction firms usually consider the concepts of TQM.

2.8 TQM Methods

Former research on “Quality Management (QM)” techniques studied its urgency towards corporate execution in addition to corporate ambitious compensations. Research from “Saraph et al., (1989)” and “Flynn et al., (1994)” established structures encompassing eight computable QM methodologies. Various contemporary research regarding the influence of QM towards modernization “(Kim et al., 2012)” have followed two of the eight structures.

The majority of the structures of TQM methods were analytically established “(Ahire et al., 1996; Black & Porter, 1996; Kaynak, 2013; Motwani, 2001; Samson &Terziovski, 1999)”. That research evaluated the various relationships encompassing TQM. Take for instance, the association among TQM methods and operational implementation “(Samson &Terziovski, 1999)”, and organization implementation “(Kaynak, 2013)”.

In spite of the variety peculiar to classifications regarding the theory of TQM, one overall agreement exists referring to the most significant standards to be implemented and familiarized when trying to employ TQM efficaciously, these standards include:

2.8.1 Upper Management Guidance and Patronage

Total quality can be identified as a managing-led procedure. Therefore, accomplishment through its employment relies upon the exposition of the upper management’s assurance, where the liability and participation of management must be shown and noticeable. Liability refers to a preparedness to assign sources to TQM, in order to capitalize in the program, as well as the preparedness to capitalize instantly, to obtain reimbursements in the near future. Today, liability towards total quality implies a preparedness to alter the design (and values) by which the organization functions, which could refer to modifications within the organization's managerial principles or new associations among executives and their assistants "(Islam, 2008)".

2.8.2 Tactical Quality Planning

Tactical planning engages in an essential part in guaranteeing quality productions (merchandises or maintenances) of any company. Through enduring the procedure regarding tactical planning, establishments are capable of identifying their potencies and disadvantages thus, allowing to devise suitable stratagems aligned among the altering circumstances/situation in order to achieve consumers 'necessities and requirements. Tactical quality planning comprises five procedures, which include exterior environment evaluation, inner environment evaluation, construction of the company's vision, construction of quality purposes, and classification of development activities.

2.8.3 Consumer Concentration

Quality is compliance towards consumer necessities. In order to attain the largest consumer fulfillment, each staff member, administrator, and executive needs to obtain a strong liability in attaining consumer demands, which is the key to quality and profitability (Miller, 1995). Generally, a durable liability and participation of executives, administrators, and staff members in the consumer emphasis procedure will ensure quality, expense cutback, and expand competing benefit for the related establishment.

2.8.4 Evaluation and Measurement

Measurement is considered one of the utmost crucial utilities in quality assertion. An operation measurement structure delivers significant statistics and data to administration on the present operation of a work procedure that is undergoing application.

2.8.5 Liability to Training and Acknowledgement

Efficacious employment of Total Quality Management relies on the assistance as well as contribution of a proficient and experienced labor force containing optimistic outlooks and values concerning the industry. It may necessitate constant training and acknowledgement of a structure, which stimulates the labor force in delivering excessive quality productions. For organizations that are employing TQM, in which staff contribution among decision-making, cooperation, capability, consumer concentration, association, and ongoing development upsurge from stereotypes to fundamental actualities, training is exceptionally beneficial – it is fundamentally and tremendously significant. Acknowledgement of the involvements of the employees and teamwork is an obligation to the being of the organization as a whole. The influences of employees over the years cannot be overlooked. As a result, recognition and appreciation should be presented in various forms and in place and rewarded through promotion and/or award.

2.8.6 Staff Enablement and Cooperation

In order to ensure the success of a department's quality improvement efforts, a unifying force, such as teamwork, among the employees of the department is essential. The most widespread means for staff member contribution is the formation of a team. Teamwork theorizes "teams do most things better than individuals because the members stimulate each other; they possess a broader range of skills, and anyway, working in a team can be more fun". Furthermore, cooperation among a team develops three main features regarding the procedure of quality development: enables the complimentary interchange of data and theories, encourages trust between the staff members, as well as enhancing consultation throughout the division "(Islam, 2008)".

2.8.7 "Quality Assurance"

The idea of quality assurance (QA) concentrates upon organized as well as methodical activities in order to prevent any quality complications and to assure the manufacture of flaw-free productions. Due to its overcoming of the restrictions of quality inspection and quality control methods, the majority of establishments have altered towards QA as a substitute. Consequently, QA encompasses the development and the administration of the appropriate approach within manufacturing of the products or delivering maintenances.

2.9 TQM in the Construction Industry

There has been great confusion on the application of TQM within the construction industry. Most believe that TQM is similar to Quality Control (QC) and Quality Assurance (QA), where conforming to the regulations of QA is all there is to applying TQM in projects (Jaafari, 2001). As a result, the terms are correspondently utilized in the wrong manner. The two concepts, Quality Assurance and Quality Control, can be identified as sub-elements of Total Quality Management. Yet, they are not the only elements that characterize TQM. The concept of Total Quality Management is broader and deemed extensively comprehensive. The difference between QA, QC and TQM is that QA and QC are manipulated in the course of project execution, whereas TQM is a tactical conception embraced by an establishment and applied constantly, even when the establishment is waiting to conduct a new project.

The concept of TQM incorporates the entire workforce of an establishment with hopes of enhancing performance. The application of TQM is different from one establishment to the next and from one industry to the other. In addition, variations in the design details of a project occur disproportionately during the construction procedure. Despite the differentiations of the TQM application, the objectives targeted are similar. The objectives are waste removal, cost reduction, enhancement of reputation and market share increase. Moreover, TQM objectives are vigorous in their character, which imposes ongoing modernizing and enhancement (Logothetis, 1992). TQM penetrates the all the features within the establishment to make quality a deliberate target. This is acquired by and integrated effort between the complete workforces in all levels of the establishment.

Moreover, the construction sector encounters numerous challenges that compels establishments to reassess their functioning. Throughout the construction sector, the productivity has decreased, legal actions increased, postponing project completion has become common and expensive, and the reasons for this are complex. Granting that the industry is encountering many problems now, and still will in the future, TQM is definitely one of modifying factors that will resolve these conflicts, viewing that lack of quality is one of the great causes of the conflicts occurring.

The construction industry has faced much criticism for inadequate quality performance, budget, safety and promptness due to its complex operating nature (Kanji et al, 1998). Researchers Oakland and Aldridge (1995) advised that if an industry was ever required to adapt the TQM conceptions, then the construction industry should be the industry to do so.

Two fundamental factors are hindering the development of TQM in construction projects. They are I) the poor communication skill between the project team members and the investors and II) the indulgent role of modern technologies within projects. In simpler terms, when these two elements are resolved, the challenges faced by projects decrease allowing TQM to be applied more efficiently.

Furthermore, the prevailing conflicts within the construction industry that demands the utilization of TQM processes are (Ghodoosi, Bidi, 2011):

1. Insufficient documentation on outcomes, practices and confrontations in the projects.
2. Low level of implementation quality for the projects.
3. Attention deficiency concerning the human resources and workplace requirements in the projects.
4. Shortage of workgroups and insufficient employee cooperation in the implementation of the projects.
5. Budget increase due to rework.
6. Mishaps and wastes present at the construction project site.

To prevail the aforementioned conflicts, a reflective comprehension of the primary conceptions of TQM is required. These conceptions are (Pike, Barnes, 1995):

1. A project management system that commits to applying TQM concepts in all fields.
2. Continuous concentration on the internal clients (team members of project) and external clients (consumers) and acquiring the gratification of all project investors.
3. Competent and comprehensive utilization of employees and manipulating teamwork concepts on all levels.
4. Constant enhancement of work as well as construction project procedures.
5. Handling suppliers similarly as partners.
6. Obtaining and managing quality.

2.10 The Construction Industry in Saudi Arabia

Like any other region, the construction industry in Saudi Arabia is also impacted by the country's monetary cycle. Saudi Arabia was considered a poor country and government expenditure was restricted until the oil price increased in 1973. The economy of Saudi Arabia relies on government spending. Due to the increase of oil prices and oil production for the duration of the 1970s and early 80’s, there was a significant increase in government profits. The availability of vast profits provided an opening for the government to surpass the constraints within the country’s infrastructure. The First National Development Plan (1970-75) and the Second National Development Plan (1975-80) provided the first priority of disbursements for construction that resulted in flourishment throughout the construction industry. The GDP of construction share went up by approximately 10 %, during the years 1970-82, where in 1970, it was 4.5% and in 1982, it became 14.4%.

Throughout the flourishing period, the importance was focused on constructing and finishing the projects with no concern for quality, life cycle expenses such as operation and maintenance, or even the requirements that suit the local environment. In this period, the Saudi government distributed a significant share of the annual finances to construct airports, transportation networks, educational and health institutes, and several other facilities. At this phase, money was no longer an issue granting that the finances were generous. However, the expertise in constructing such large-scale projects was restricted, which led in contractors performing at maximum capability and comprehending large profit margins (Shash, 1992).

The need of the government to enhance the construction of the country in such a short period has led to introducing the region to construction establishments from all over the world to organize business. Each company had its own business method and transferred their culture in business, technology and managing approaches to Saudi Arabia. Additionally, the availability of foreign workforce assisted in overcoming the prevailing workforce scarcity.

The workforce that came from abroad varied in skill, some were highly skilled, and others were unskilled. Nevertheless, the unskilled workforce signified the majority, where these workers were paid low income and from countries with high unemployment rates. This resulted in dominance of foreign labor within the industry leading local nationals to abandon working in the construction industry. All this time, the government sector was the major funding source for construction budgets and the private sector participation was very restricted.

The construction industry observed a recession period by the year 1983 because of the cutbacks in government profits resulting from the decrease in oil prices and the new governmental priorities that appeared due to premeditated dogmas. This economic condition taught the government a valuable lesson, where they apprehended that having the money to fund construction projects is not the only issue, but rather having constant resources to maintain and operate the projects is the real conflict. Additionally, individuals began to comprehend the importance of good planning and quality concern during the construction phase that will pay off during the project’s lifecycle. There have been several efforts to improve the construction industry and its efficiency.

The construction economy flourished again after the Gulf War in 1991, except now the private sector, who perceived construction as an investment tool, took on the leading part. The construction sector profited from the massive cash flow that was introduced to the market throughout the war and restricted investment potentials in the nation. Furthermore, the private sector studied the mistakes that occurred during the first flourishment of the industry during the

1970’s and early 80’s, in which they were attentive to quality and has been revealed in the contracting methods.

2.10.1 Challenges in the Saudi Arabian Construction Industry

During the Fourth Saudi Businessmen's Conference in 1989, the focus was on “The Progress of the Construction Industry in the Kingdom: Obstacles and Solutions”. The conference was funded by the Chamber of Commerce and Industry in Jeddah, KSA, and it exposed that the construction industry in the country is very delicate although it represents the largest division of Gross National Product beyond the non-petrol division. The following complications that the Saudi contractors faced were recapped from the conference:

1. Decline in construction demand compared to previous demands during 1983-1984.
2. The presence of foreign rivalry as well as the illegal behavior of many foreign organizations who thought it essential for survival in the Saudi market.
3. The prevailing debts and added interest fees of Saudi Arabian contractors.
4. The complex processes for relocating sponsorship of emigrant labors for several occupations among the construction companies.
5. Lacking the existence of agencies that are committed to acknowledge and resolve contractor’s issues.
6. Lack of finances committed to fund Saudi contractors, other than those provided by the commercial banks, which is the situation of the other non-petrol sectors (e.g., industrial, agricultural).
7. The inability of foreign organizations to abide by Saudi regulations during some construction phases in which 30% of their business is subcontracted by local contractors.
8. Concealing illegal laborers, particularly the smaller organizations.
9. The inefficiency of the prevailing local contractor classifying process for the current conditions that require reevaluation.
10. The vagueness of the language utilized in the contracts.

Nonetheless, after all these years these problems still prevail throughout the industry. This is due to the absence of governmental agencies that are authorized to solve all the aforementioned conflicts. However, looking closely at the problems considered they are more relevant to the business environment than they are to the participant groups of the industry.

Granting that the majority of the complications mentioned above may have been settled by direct governmental contribution shows that the construction division in the country lacks governmental attention. Al-Barrak (1993) advocated that the foremost reasons for contractor failure in KSA are the following:

1. Lack of proficiency at all levels of the management.
2. Inadequate assessment that leads to misevaluation of the contract’s bid price.
3. Insufficient limitations for those participating in the construction industry that leads to incompetent contractor’s participating within the industry.
4. The collapse of the national economy compels the revenue limitations to be smaller and more complex to maintain.
5. Overdue disbursements due to slow economic factors that leads to cash flow issues for the contractors.
6. Inadequate workforce efficiency.
7. The repressive feature of the management.

Al-Barrak's analysis acknowledged internal complications and external complications as reasons for the failure of Saudi contractors. Even though clarifications for these complications were not proposed, this analysis can be ruminated among the very limited research directed at the construction industry in Saudi Arabia as well as the challenges they encounter. The clarifications for those complications cannot be allocated to the contractor alone; most of the complications require government attention or a private facility supported by the government.

2.10.2 Construction Management within Saudi Arabia

In research performed by Al-Sedairy (1994), the present status of project management between clients, consultants and contractors throughout the public construction sector in KSA was acknowledged. The research proved that the application of project management within the industry differs from one sector to another and from owners to advisors to contractors. The owners took the lead when it came to determining the principles for the industry due to their influence, accomplished proficiency, and their use of sophisticated tools for project management. Moreover, owners were found to put a high value on the management of design quality. The study also revealed that consultants applied project management because of the pressure placed on them by the owners to establish a method for project management. Contractors are capable of establishing distinct practices for management, planning and other elements. In addition, the research observed that contractors have advanced appropriately to embrace the innovative managing practices like Total Quality Management.

In reality, very little owners manipulate complex tools for project management throughout Saudi Arabia. One example is Saudi Aramco, in which their business technique as project owners is exceptional due to their financial status and managerial quality. Furthermore, it sets a model for other establishments that are striving for superiority. It has been acknowledged that contractors, offices and suppliers that collaborate with Saudi Aramco acquire a greater rank of professionalism and enhanced quality due to its strict obligations.

Still, most owners struggle with the typical complications within the industry and the majority have troubles when handling other owners. Global influential factors constantly allow Saudi Aramco to attempt employing innovative solutions in handling management or technology improvements. Moreover, Saudi Aramco has been viewed as the opportunity for transfer of technology.

CHAPTER III

3 Application of Building Information Modelling (BIM) in the Construction Industry

3.1 Introduction

The traditional managerial systems for quality measures have failed to uphold the quality levels demanded in a project. Modification in the Information Technology (IT) and computer systems has significantly affected the world. The construction industry nowadays collaborates with the IT sector to ease and enhance construction processes. There are specific technologies that can be applied in quality management to manage project quality efficiently. Building Information Modelling (BIM) is viewed as one of the innovative systems that can be applied in quality management. This system is utilized to model, evaluate, plan and envision a project.

Building Information Modelling (BIM) is a procedure that has been increasingly gaining popularity worldwide. It is also gaining importance in the engineering industry due to its capability of providing a computer-generated design and a structural representation of a project. In addition to enabling larger levels of association and work input among the design environment and work-teams. Any quantity of data may be added into the project and stored for future works. The data presented is extracted from BIM in an organization’s product framework for efficient implementation. The application of BIM in projects is able to provide pre-construction development and evaluation in order to enhance the design depending on the customers’ demands. When the system is implemented adequately, the advantages can greatly influence the design procedure.

This section introduces the concept of BIM from previous studies. The basic concepts of applying BIM in the construction industry are addressed along with visual representation of the concept and its evolution at various phases. Moreover, the application of BIM in the Saudi construction industry will be evaluated. The advantages of applying BIM, the obstacles that hinder its application within the construction industry as well as the barriers encountered when implementing this system in Saudi Arabia will be reviewed.

3.2 History of BIM

The idea of Building Information Modelling (BIM) has been evident for a very long time, in which the concept first appeared in the 1970s. It was introduced through various papers under the term of “building model” during the mid-eighties. In the early 1990’s the phrase “Building Information Model” was initially pioneered. In spite of such evidence, the concept of BIM was not widely known until after ten years, where various researchers assisted in spreading and regulating the concept (Langar and Pearce, 2014).

The history of developing BIM for the construction sector is complex and is the product of

As of 2002, Autodesk proposed an authoritative report (white paper) labelled ‘Building Information Modelling’. Several market participants shadowed Autodesk’s approach, such as Bentley Systems and GRAPHISOFT, so that they can contribute to parallel projects (Autodesk, 2002). Contrariwise, Martens and Peters (2004) claimed that ArchiCAD, a system introduced in

1987, should be acknowledged as the initial application of the current BIM software since it presented the earliest CAD software, which was possible to install and manipulate on a personal computer to create 2D and 3D visual illustration of a design. Furthermore, ArchiCAD was the first software to establish BIM system resolutions and make them installable on personal computers (Martens and Peter, 2004).

Since the development of BIM, it has been proposed and applied by various industry experts like construction, civil, structural, and architectural engineers. These systems not only generate 3D simulated models, but also makes the cooperation among investors easier. The main objective of BIM is to manage the investors input during the project's whole lifecycle (Motawa and Almarshad, 2015). From Figure 3-1, the statistics show that the utilization of BIM in construction organizations has increased from 28% in 2007 to 49% in 2009 and 71% in 2012.

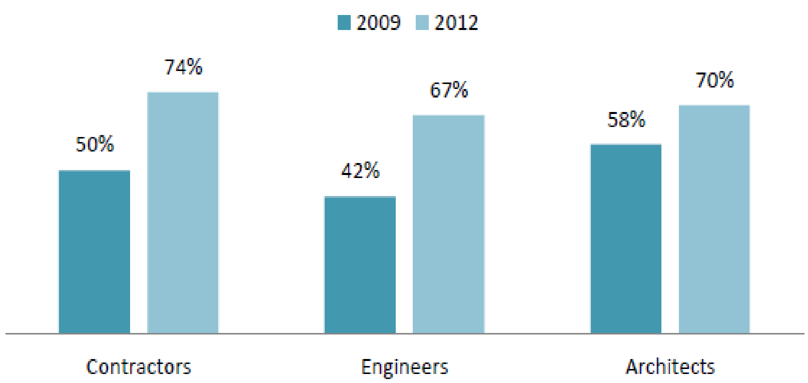


Figure 3-1 Adoption and Utilization of BIM by Various Stakeholders in the Industry the world (McGraw Hill Construction, 2012)

The majority of the companies in the construction industry have discarded visual-based CAD software and advanced in implementing BIM in the larger division of the construction project at hand (Dastbaz *et al.*, 2015). The vast alteration within the industry is transferring from a modern based approach to a 3-dimensional comprehensible model that permits the operator to verify the implementation of the strategy and the development and working data (Eastman, 2011).

The presence of BIM within the construction business is an inventive modification that allows construction processes to advance. The alteration from 2D drawings to 3D visual models has opened up the potential to arrange the models similarly as the building would be constructed along with the establishment of a 3D BIM model from the initial development cycle (Butkovic and Heesom, 2017). BIM can develop an accurate computer-generated model for a building that consists of the precise geometry and appropriate data required to comprehend the project design throughout the construction planning stage (Eastman *et al.*, 2008).

3.3 Definition of BIM

Building Information Modelling can be classified as the process of combined innovation and utilization of data on the construction to establish a consistent foundation for all decisions throughout the lifetime of the product. In other words, from the initial conceptions to the comprehensive engineering, construction, management, upgrading and annihilation.

However, the abbreviation BIM has been utilized to indicate various elements, which are:

1. A Product: that is a Building Information Model, and it is a constructed dataset depicting a building for simulation, computerization and demonstration
2. A Building process or Activity; that refers to the performance of generating a building information model (thinking, creating, planning and arranging)
3. A System: that indicates the business formations of work and communication that enhance quality and effectiveness like allocating, preservation, examining the model, classifying and sustaining. (NBIMS-US, 2007; Ahmad et al., 2012; State of Ohio, 2010).

It should be acknowledged that there is no precise definition for BIM; relatively there are various manners for clarifying what BIM represents. Many researchers have agreed that BIM is defined differently by several professionals and associations because of their opinions, background and proficiencies. Moreover, they classified BIM depending on the particular way they implement BIM (Abbasnejad and Moud, 2013).

The figure below, Figure 3-2, illustrates the life cycle of a Building Information Model.

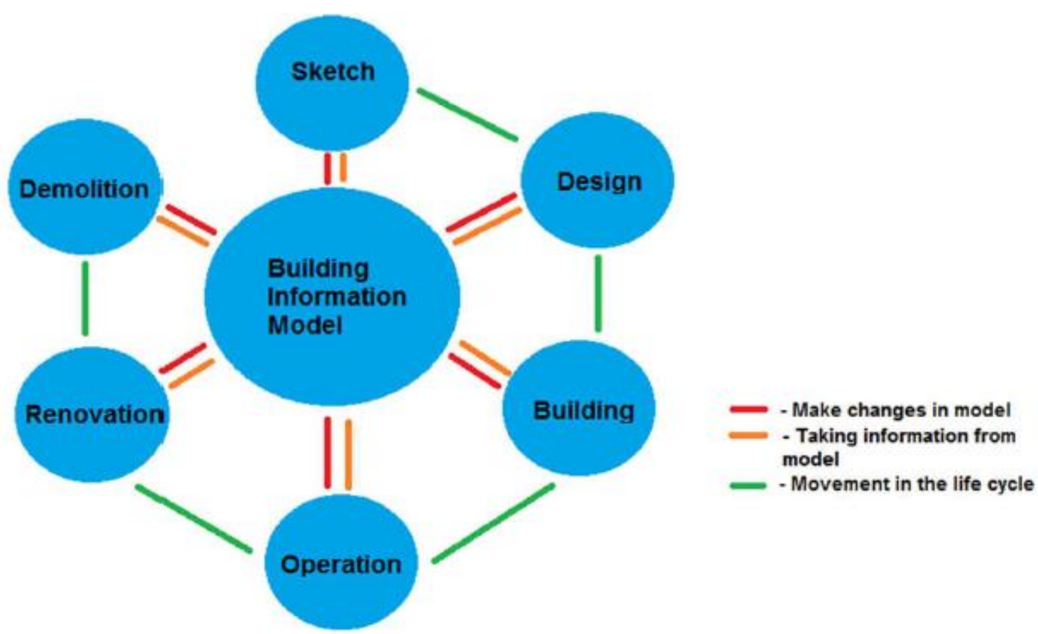


Figure 3-2 Life cycle of BIM (Reizgevi cius et al. 2018).

However, Dzambazova et al. (2009) identified BIM in a different manner. That is BIM is the management of data during the complete lifetime of the design procedure, from the initiating concept design through the construction management and even into facilities. For some individuals, BIM is simply a system of computable 3D modelling (Ellis, 2006).

A more inclusive definition for BIM is the process of manipulating information technology for allocating, modeling, assessing, collaborating and managing of a simulated building model within a structure's lifespan (Ahmad et al., 2012). Other researchers, Hardin (2009) Smith and Tardiff (2009), agreed that BIM is an innovative CAD technology and building system that has altered the building design, analyzation, and construction and management methods. The BIM model joins all the elements of a building as objects embedded with data that tracks its production, budget, delivery, installation approaches, employment expenses, and maintenance (Smith and Tardiff, 2009).

For the objective of this research, BIM can be classified by a grouping of multi-classifications, where it portrays a managing procedure for manipulating IT for the gathering, utilization and sharing of project data. At the center of BIM is a virtual model that incorporates all the documented, graphical and tabular information about the design, construction and evaluation of the project. BIM is utilized for modelling, simulating and evaluating the construction process. It also supports the association, operation and management of a building model throughout the lifespan of the building (AGC, 2005; Smith, 2007; GSA, 2007; State of Ohio, 2010; NBIMS-US, 2012; Ahmad et al., 2012).

3.4 Concept of BIM

Building Information Modelling assists in identifying any probable risks linked to the design from the initial stages. This permits the designer to imitate and assess any significant influence that may take place throughout the stage of project implementation. BIM allows the designer to construct a digital building preceding the construction of the actual structure (Smith and Tardif, 2009).

The BIM program simply is a database that is manipulated for allocating data and transferring the data for the different forms of activities to be executed within the construction projects in addition to the several program applications that are needed during the lifetime of the project to obtain a BIM-based shared workflow (Kiviniemi, 2015). The data that is stored within the database may be utilized whenever necessary during the construction procedure. All the entered and allocated bit of data from any third contributor (3D modelers, contractor's staff or subcontractor staff) is crucial to establish an integrated model that is then simulated into the BIM program. The entire staff of both contractors and subcontractors are compelled to work utilizing the BIM program instead of the traditional paper-based records. Accordingly, by using BIM a 3D illustration can be acquired rather than 2D drawings. Members within the construction team can picture their needed data from the model established by the BIM software. Such a cooperative workflow establishes the demands for new practices and approaches that may be embraced by all project investors as a modern working method. Such innovative approaches evidently clarify the significance of IT to support such workflow (Alazmeh et al., 2017).

Granting that BIM establishes a simulated design for the project being constructed, it may be tested and modified based on the physical structures design constraints before the construction procedure (Kymmel, 2008). If any flaws or complications are discovered in the simulated design, no serious damage will be initiated to the project given that they may be modified and fixed as needed. All the features of the construction project are acknowledged and assimilated within the BIM program for the virtual building to prevent any inconsistencies throughout the actual construction project. BIM is able to offer both 2D and 3D drawings and graphical representation of the complete procedure of the construction project such as the range of information, qualifications, expenses information and the project schedule (Elvin, 2007 and Hardin, 2008).

To benefit completely from the BIM software, all forms of information regarding the construction project must be presented. Some of the vital data required for the BIM are listed below:

1. Data regarding the element: the very simple data that offers graphical drawings and visual demonstration of the construction project.
2. Parametric Data: the kind of data that involves several parameters of a product. Some of this form of info entails the area, volume and density to obtain the tangible geometry of the product depending on its weight.
3. Associated Data: the kind of data that is non-existent on the model but in a form is linked to the model.
4. External Data: information generated from outside resources. BIM is not affected by such data, take for instance the specs gathered from manufacturers regarding a product is known as external data.

Through the application of BIM, qualitative and quantitative data regarding the product may be gathered, like the representation of a window or door or wall. When viewing a 2D representation of the project, only the graphical illustration of the lines is seen. Contrariwise, when utilizing BIM, the graphical illustration of the project will show all forms of data concerning the project such as the size of the project, the expenses and scheduled duration linked in completing the project as well as the manufacturer of the products within the project.

3.4.1 General Concepts in the BIM Technique

There are many concepts for the BIM technique. The following concepts below are just a few of them.

3.4.1.1 Utilizing the database instead of drawings

In BIM technology, the design develops as a digital database, rather than a separate graphic set, but BIM works to develop the model. It uses smart objects to represent the factors of the project, whereas a smart object here represents a particular element, not only the geometric figure of the element but also carries all the data relevant to that element (Pătrăucean et al., 2015).

3.4.1.2 Distributed model concept

Currently, there are two tools utilized in BIM, drawing tools and analysis tools. BIM follows a distributional approach in order to incorporate the value of drawing tools to the value of drawing tools with the value of analysis tools within the BIM distributive environment. The design of separate models, construction and scheduling (fourth dimension/4D), cost (fifth dimension/5D), operation and the other factors are all compiles and then the appropriate analysis is conducted (McArthur and Bortoluzzi, 2018).

Since all of these models are BIM database, they can be displayed together to detect the conflicts between architectural, structural, mechanical and electrical factors. Hence, they may be resolved by default, which minimizes the cost of the project and helps to avoid site problems.

3.4.1.3 Adding value to BIM

The value of BIM is not limited to the modeling tools or the developed model, but it goes beyond to facilitate collaborative decision-making. This leads to a new trend known as Integrated Project Deliver (IPD), which translates into integrated project connectivity. It brings together the project owner with experts and specialists to help in understanding what the owner wants and in explaining the technical matters to the owner in a simplified way (Brooks and Lucas, 2014).

3.5 Technical Features of BIM

The most commonly asked question is why utilize BIM software as an alternative to computer-aided drawing software. For starters, it makes sure that there is an accurate inventory of materials before construction begins and during the process where design alterations are made, so the inventory is automatically updated. It also works on solving the communication issue among the design groups such as architect, civil, electromechanical and any participant in the design procedure and implementation. These programs are facilitated to understand the project details by everyone and share the various alterations with them in order to avoid any conflict that may cause problems or errors in implementation (Bryde et al., 2013).

The harmony between the project plans and sections is another factor, where it was a continuous issue to make modifications on one of the drawings, which eventually led to modifying the remaining drawings. Now, the entire project is available in one integrated file, in which the modification automatically appears in all drawings when working and modifying any specific drawing sheet (Love et al., 2014).

Furthermore, innovative structures suffered from the problem of lack of references or the presence of existing structures that can be used for measurement reference. Thus, unpredicted problems may occur due to the weight or factors that are not calculated, but now, BIM provides all forms of simulations to resolve the issue before it takes place. Often, the work operation is usually ceased due to waiting on receiving the materials or the importation of the materials before the required time, which necessitates additional costs for storage. Time and cost management software helped solve these problems. Additionally, the BIM system reduced the cost of adjustment to one fifth of the cost of the project since the adjustments are now completed on computers (Volk et al., 2014).

The problem of not completing the project on the scheduled time is the result of detecting problems within the site has led to extending the duration time of the project more than once. When the appropriate building modeling system is applied, the problems are detected and resolved early while working on the design. Moreover, the differentiation that occurs from what was built, and the original design is due to the implementation process on site, which forces engineers to make new drawings after the completion of the work to resemble the as-built structure. Now, what is designed is what will be implemented. Additionally, the presence of information identical to reality can be utilized in the management of building facilities and maintenance work (Eadie et al., 2013).

3.5.1 Technical Specifications of BIM

The technical specifications of BIM will be briefly listed below (Laing et al., 2015).

1. Building Information Modeling requires a lot of effort to develop the initial framework.
2. The BIM software is much more complex than other design software's using the assistance of computer-aided designs (CAD)
3. Designers who already use the CAD software's face challenges when transitioning to the BIM software.
4. BIM technologies demand a great deal of input, and this may be overwhelming and difficult for inexperienced designers.
5. The BIM technique incorporates thinking in three dimensions and visualizing the final product before the design is initiated.

3.5.2 Software tools in BIM

There are wide variety of software tools used for both modeling and analysis available in the market. A few of these tools include LOD Planner, BIM Object, AVAIL, UNIFI, Magi CAD, BIM&CO., Sketchup, Autodesk Revit, ArchiCAD, Vector Works, AECOSIM, TEKLA, CATIA, Rhino BIM, Dynamo, and so many more. Nonetheless, when selecting a software tool for a specific BIM project, most of the attention should be given to the functional features and interoperability (Ma and Zhao, 2008).

The type of information required for BIM determines the type of model needed, which in turn leads to a precise modeling tool that serves this purpose. Models are simulations of the project summary and since there is always a difference between the model and reality, the decision-making level must consider the level summary and reliability.

There are two types of modeling tools used, surface modeling and solid modeling. Surface modeling represents the size of their surfaces, which means they cannot distinguish between the mass of a solid component and the distance between it and other components. If a drawing is needed, some of the alterations must be transferred into comprehensible documents, accompanied by the required geographic information from examples of surface models (Google-Sketchup).

3.5.3 Interoperability for BIM Models

The interoperability of the BIM model is defined as the ability to manage and communicate with electronic products and project data among cooperating organizations and between members of the design, construction, maintenance and business companies.

The BIM consists of a number of models designed by several people with varying degrees of detail using different types of software tools. Thus, interoperability among operating systems, BIM programs, analytical engineering programs, cost estimation programs, scheduling programs, power management programs, and so on, all occupy a significant position in BIM techniques. Additionally, any form that needs to be integrated into a specific program must be of the same format or any compatible format.

There are a variety of software's which can be utilized as a framework for models. They are widely manipulated in BIM technology. Such software's include Autodesk Navies Works, Bentley project, wise Navigator, etc... The purpose of using this software is to provide a three-dimensional model that has interoperability. Furthermore, these programs have the ability to detect conflicts among the systems, read various file types, capable of handling large files from different sources, import files from other software's, collect several files and facilitate geographical communication throughout the project (Kiviniemi and Codinhoto, 2014).

3.5.4 Comparison of Building Information Modeling (BIM) and Computer-Aided Design (CAD)

With the development of technology, it was inevitable that this development would reflect on the architectural and construction fields, where computer-aided drawing or computer-aided design programs emerged known as Computer Aided Drafting or Design (CAD). One of the most popular of these programs is AutoCAD, which is issued by Autodesk. This type of program depends on simple two-dimensional lines and shapes to allow the designer to create the form he desires in the same manner he would manually. These programs saved engineers the costs of treating their back pains and provided them with more time and possibilities to unleash their imagination. As time passed these programs have become indispensable and have been taught throughout colleges and universities. Within the same period, the design of the different stages has become computer-driven; to draw structural elements there are construction programs such as Sap and Etabs (Azhar et al., 2008).

Although, there are many programs that make three-dimensional simulation, these programs deal with abstract models such as cubes and spheres, in which only the user is able to form such models to give it the final form he desires. From the initial moment, the designer feels as if he is actually building the structure but in reality, it is on a computer screen and inside a BIM program (Migilinskas et al., 2013).

3.6 A simplified model for the utilization cycle of BIM

The process begins with a modeling program, such as Revit, ArchiCAD, Tekla and so on, where the axes and coordinates of the project are laid out. An architectural model is then constructed, followed by a structural model. The structural model is then exported to a structural analysis program to be evaluated, designed, making sure the segments of the components are correct. The architectural model, if required, is then modified accordingly. The models are also exported to energy analysis program, in circumstances where the project is large in order to attempt to reduce energy consumption. It is also possible to create a model for the electrical, mechanical, and plumbing networks. The three models, architectural, structural, and networks, are integrated to identify the areas of conflict among them, in order to avoid any future problems during implementation (Janssen et al., 2016).

When entering the time information for the final model, we can call the model a four-dimensional model (4-D). Using these techniques can take a long time to design, but it greatly compresses the time and cost of implementation. Engineers have a complete imagination of each part of the structure, and a full expectation of all the challenges they may encounter, hence allowing them to prepare resolutions for them in advance (Migilinskas et al., 2013).

The role of BIM does not stop once the design is completed, but any modification to the structure during implementation or in the future must be added, so that you may have a model that is identical to the executed structure, which is called a six-dimensional model (6-D), which facilitates any future development of the structure.

3.7 Implementation of BIM

Building Information Modelling and its employment if data has a fundamental part to partake in order to acquire the objectives of the construction project. Certainly, there are modifications from two-dimensional drawings to modelling. BIM may be applied during the various stages of the construction project lifetime for enhanced planning and collaboration with reliable, exchangeable and enriched information that may be employed by all members of the project staff for evaluation and visual aims. The utilization of BIM in various stages of the construction projects are further explained.

3.7.1 BIM Application in the Planning Phase of a Construction Project

The planning stage in the construction project is viewed as the crucial phase. This phase involves all the project features such as the aim, targets, accessible materials, shared expenses, project delivery and planned completion time of the project. Successfully executing the planning phase means that the project may well be completed on time by manipulating the shares expenses for the project. Researchers determined the following actions to be linked with the planning phase of the construction project:

1. Planning for execution: In general, construction projects are split into various sectors that must be completed in a rational order depending on the significance and interdependence of various activities.

2. Scheduling for execution: It involves the timetable of the constriction project in which the anticipated duration for project completion of every activity must be incorporated.

3. Scheduling for resources: This includes materials, workforce and equipment. Scheduling and assessment of all the resources that are demanded for the activities of the project.

4. Project expenses and expenditure expectancy: With the assistance of project expenses, it is possible to estimate and share the total costs of the project.

3.7.2 BIM Application in the Design Phase of a Construction Project

The initial stages of any construction/architectural design follow a repetitive system to allocate the information base of the design phase to develop resolutions for the construction or architectural project (Al-husban, 2012). This system abides by a set of principles and conditions of the design complication, project constraints, and the anticipated restrictions of the architectural projects. Some researchers have advocated that design ideas of an architecture project rely on the comprehension of the design phase and intellectual capability of the engineers. Others viewed that the design ideas were reliant on the previous knowledge and experiences of previous projects of the engineer.

Certainly, the utilization of the traditional design methods, (pencil and paper), for sketching and drawing throughout the initial phases of the designing process is crucial to determine and study the probable design options for the project. The traditional methods are an important part in assessing the alternate concepts and sharing ideas throughout this stage. Contrariwise, using CAD programs is more efficient when compared to the traditional method regarding expenses, efficiency and smooth utilization during the designing process. Yet, the CAD programs are not able to carry out early design works such as producing ideas and sharing concepts.

Carious researchers proposed that the design programs must include and be assimilated with fundamental alternatives that allows the designers to discover other abilities when it comes to designing and revising. By using the BIM program, designers can benefit from the visual assessment representation, graphic documentation of reports, and design, planning, preparation and budget evaluation for the project (Foqué, 2011). Additionally, BIM assists the designers in this stage to assess and consider the design alternatives, keeping in mind the similar circumstances and presenting the necessary data on a specific project. It may be concluded that BIM provides important data during the initial design phases of the construction project that is vital for the complete design of the project as well as the outcome.

3.7.3 BIM Application in the Construction Phase of a Construction Project

Given that the project has different phases, so does the utilization of the BIM program. For instance, in the planning, design, execution and maintenance phases of the project there is a different sector in which BIM may be applied. It may be utilized in the planning stage by improving the management over the entire project, where BIM is capable of affecting the expenditures of a project. Implementing BIM assists the project staff to create modern ideas and resolutions in the expectancy of any complications that may enhance the project expenses. This is only possible through close cooperation and participation among the groups of the project. Participation between various investors and members connected to the project is a fundamental advantage of BIM application during the planning stage.

The implementation of BIM is also capable of analyzing and evaluating the energy and resources used in a project (Azhar et al., 2011). The generation of 3D models assists the project owners to visualize whether the design adheres to the required standards or not (Azhar et al., 2011). Conferring to Messner et al., (2009), BIM has countless uses in a construction project development where cost assessment, on-site graphic demonstration, and production are the main benefits of BIM during the planning phase of a construction project.

BIM may be efficiently applied during every phase of the constriction project regardless of the project deliverables (AIA, 2007; AGC, 2006; Eastman et al., 2008). Yet, regarding the advantages of a project, the efficiency of BIM may be developed throughout the project and utilized for assimilated approaches in projects (Eastman et al., 2008; AIA, 2007; Elvin, 2007).

3.7.4 BIM Application in the Post-Construction Phase of a Construction Project

BIM may be applied in the post-construction stage to plan and implement safe operating and maintenance techniques for the completed construction project. Generally, the operation stage involves 60% of the total expenses originating during construction. The functions that take place during these processes are greatly linked to the idea of maintenance and reparation (Sullivan et al., 2010). Nonetheless, researchers have proved that BIM is usually utilized during the initial phases with gradually less utilization in the following phases of the project’s development. As a result, BIM is not being utilized to its maximum capacity in the managing phase of the projects.

However, the BIM model is composed of vital data regarding the manufacturing specs and maintenance guidelines associated to the building components with the objective of offering a sufficient archive for the consumers and users (Sabol, 2008). In which every object within the BIM model incorporates links to the operation, maintenance and guarantees data. Hence, it can be concluded that the BIM may significantly influence the post-construction stage and specifically facility management (Eastman et al., 2008).

3.8 The Familiarity of BIM in Saudi Arabia

Saudi Arabian researchers like Al-rashed et al. (2014), Sidawi and Al-Sudairi (2014), predict that Building Information Modelling will evolve the traditional management approaches for construction projects throughout the Saudi construction industry. Such approaches and practices will push the embracing of BIM within construction associations. There are numerous aspects encouraging this perception, of which includes the potential of revenue increase, growth of pressure in competition, and the ability to participate universally and confront the market complications by reevaluating the matter (Sidawi and Al-Sudairi, 2014). Additionally, researcher, Ahuja et al., (2010) express the construction industry adopting a computer-based ICT will permit successful communication between project team members and investors, whom in general are isolated. Moreover, researchers note that the tactical embracing of ICT necessitates all associations within the construction procedure as well as the participating supply chain to follow the appropriate regulations of communication to allow them to seize the advantages of IT efficiently.

The Building Information Modelling software is an innovative instrument that can advance the Saudi Arabian construction industry in numerous manners, giving that the country must

Being that BIM is a technology driven idea, it assists the Saudi construction industry to develop an envisioned simulated design of the process of construction for a structure before the actual constriction occurs (Azhar et al., 2011). By utilizing BIM in Saudi Arabian construction works, the uncertainty concerning the construction phase may be minimized to a lower level as well as guaranteeing safety. Hence, BIM may produce abundant efficacy as it strengthens the collaboration of all investors participating in the project and the association's approaches into a combined process that sanctions the minimization of resources and develops proficiency throughout the entire phases of the constriction projects in KSA (Ikediashi et al., 2014). Moreover, BIM may also be applied to maintain and administer the working office after the project is completed.

To determine the awareness of BIM within the Middle East region, a study was conducted by Building Smart (2011). It showed that when it came to adapting BIM, the nations that were part of the GCC (Gulf Cooperation Council), which is now known as Cooperation Council for the Arab States of the Gulf, still fall back on the global fads. Yet, when it comes to the awareness of the advantages of BIM throughout the construction sector, the study showed that there is a great rate of BIM benefits awareness among the GCC nations. The results obtain revealed that the United Arab Emirates had the highest rate at approximately 77% followed by Saudi Arabia with a rate of almost 41% and finally Qatar with a rate of 35%. The participants of the study were from different positions, where 36% of the overall participants were contractors, and 8-10% were government officials, consumers, staff and developers. From the responses gathered almost 25% of the construction projects apply BIM. This is considered a medium level of utilization when compared to those abroad with North America at 49% and Western Europe at 36%. However, it should be acknowledged that BIM has been used for specific objectives rather than an assimilated tool for construction projects (Building SMART ME, 2011).

As for Saudi Arabia, the civil and construction engineers are the foremost experts of the construction industry who are manipulating the construction business within the region. Therefore, there is a prejudice allotment of BIM between various construction industry experts, whereas support is compulsory from all experts to achieve a successful and cost-efficient project finishing (Sodangi et al., 2017).

3.8.1 Outcomes of the Study on BIM Adoption in the Middle East Region

From the previous section, Building Smart (2011) conducted a study. The results and assumptions are stated below:

1. The main operators of the BIM software were contractors, while the construction consultants applied BIM for the design of construction projects.
2. In the Middle East, throughout the construction sector, the adoption of BIM was large among the developers.
3. In general, BIM embracing within the Middle East comparatively little in comparison with North America and West Europe.
4. The construction experts that did not utilize BIM were about 54%.

5. Of the participants in the Building Smart study, 21% were unfamiliar with BIM and were incapable of finishing the survey concerning the embracement of BIM in the Middle East.
6. The participants who reported that they applied BIM for their personal objective were about 25%.
7. The application of BIM throughout the Middle East was shown to be at a beginning stage, and they implemented BIM for visual representation of the project.
8. Familiarity concerning the BIM was extreme in the Middle East area, in which almost 79% of the participants had high regards for BIM advantages.
9. The adoption of BIM must be directed and supported by government officials in the Middle East regions.
10. Overall competencies and training courses concerning BIM handling ought to be endorsed and demanded by the construction industry specialists.
11. BIM teaching and employment comprehension on BIM must be introduced within the academic course in the Middle East.

Therefore, the key discovery from the study conducted by Building Smart was that the embracing of BIM in the Middle East region is very small when compared to the percentages of BIM adoption in North America and Western Europe.

3.8.2 Outcomes of Study on the Obstacles to BIM Adoption in the Middle East Region

Based on the study carried out by Building Smart (2011) in the Middle East, the primary obstacles hindering BIM adoption are listed:

1. The insufficient availability of compatible and experienced staff who are familiar and trained to implement BIM software.
2. Expenditure of using BIM software.
3. Scarcity of education and proper practice methods for employing BIM program.
4. Approximately half of the participants in the study stated that they had very low comprehension level and recognition on BIM application. Moreover, the education and understanding were self-taught.

For the construction industry in Saudi Arabia, the technology of BIM is still considered at an undeveloped phase with respect to the increasing level of awareness. Some researchers have advocated that because of the insufficient number of trained experts and the inadequate expertise training, the majority of the construction firms and contractors are not implementing this innovative software within their works. Furthermore, a major obstacle for embracing BIM is disregard and unwillingness to adopt new technology, a conduct acquired between the experts and consumers.

It should be acknowledged that the public sector in the Middle East region does not take any procedure for authorizing the utilization of BIM, not even for public projects. Additionally, the need for BIM principle, restrictions and guides is critical. There is also a need for government branch, cadre or national BIM cooperation to establish a national BIM educating program for both governmental and industry organizations among the Middle East regions that were studied.

3.8.3 Analysis of BIM Study Results in Regard to Saudi Arabia

Even though the advantages of BIM may be devised concerning cost-efficiency and time-efficiency in completion of the construction project, it has been proven to be somewhat of a challenge to notify individuals on the advantages of BIM implementation in Saudi Arabia. However, the leaders of the construction industry and the government of Saudi Arabia have not taken any structured initiation to utilize BIM for construction projects.

Transferring from the traditional two-dimensional CAD softwares and paper-based methods onto BIM and the practice of collaborating three-dimensional graphic models is significantly beneficial. Still, some obstacles or complications effect the utilization of BIM in the Saudi Arabian construction sector.

3.9 Obstacles to Implementing BIM throughout the Kingdom of Saudi Arabia

It may be acknowledged that the successful application and recognition of BIM throughout the Saudi construction industry is targeted at abandoning the traditional approaches identified by the physical motion of paper-based designs and written documents from government authorities (Azhar, 2011). The availability of the BIM program will result in disregarding and replacing the old methods by association through software cooperation tools. Hesitation in embracing the innovative technology alternatives for cooperation can impede the success of BIM implementation in KSA, apart from the investment expense and complex level of the functions (Sodangi et al., 2017).

Likewise, the manipulation of BIM in KSA’s construction works can be reduced depending on the technical abilities of the experts that are needed to contribute powerfully among the BIM program (Ikediashi et al., 2014). Experts have anticipated that government authorities, selected contractors and designers will require limitless quantities of data regarding the functions accessible by BIM. Failing to involve technically capable operators in BIM may be disadvantageous to any project in which it will not produce the expected effectiveness.

3.10 Towards Applying BIM Successfully in the Kingdom of Saudi Arabia

In order for BIM application to be a success it necessitates both a top-down and bottom-up application technique that regulates the working systems of the construction sector as a whole and simplifies the smooth course of the input and output data of the BIM archive (Vass and Gustavsson, 2017). This demands suitable designing, tolerance and the complete devotion of all investors. The starting stage of implementation in BIM regards the developments of an operating schedule by means of an action proposal. This proposal guarantees that the application will stay on course during the project’s lifetime. The planning stage focuses on gathering applicable data concerning the current methods, the systems and technical abilities of the consumer. Determining the existing circumstances may assist the pertinent association or government facility to comprehend the practical, qualified and financial abilities needed (Krygiel et al., 2010). As soon as these parameters are developed, the phase that follows is known as implementation.

Due to the new ideas emerging from BIM, this requires training on the application and utilization of BIM among the investors and workforce is a vital feature to acknowledge while planning for BIM application. The training is comprised of preparing the operators with the information and ability to enable the efficient course of data to and from the BIM archive.

Therefore, for BIM to function efficaciously in KSA, based on the intensive research done for this study, the following major features must be considered to operate:

1. BIM Familiarity
2. IT necessities
3. Preparation of construction workforce and investors
4. Functioning culture modification within the construction sector

3.11 Future Perspective for BIM software

BIM technology has great potential to control the construction industry as a whole. Yet, it is still under development and requires more time and work to avoid the flaws mentioned previously, and to develop its numerous tools. Nonetheless, with the continuous development in the computer industry and associated technologies, BIM might just succeed in starting a new era for the construction industry (Wortmann et al., 2017).

CHAPTER IV

4 Research Methodology

4.1 Introduction

The following section will explain the research methodology followed for this research. The methodology applied was selected to fulfill the research requirements and objectives. In this chapter, information regarding the study plan/approach, population, sample study size, method of data collection, questionnaire framework and its validity. Moreover, it will include the pre-test of the questionnaire, pilot study, the final content of the questionnaire and the analytical techniques applied to the information collected.

Additionally, The BIM systems approach was applied on the case study (The Student Residence building at King Khalid University in Saudi Arabia) through utilization of one of the BIM software. In addition, a comparison was made between the plans generated by the Revit program and the basic plans designed by the AutoCAD program. The objective of this comparison determined whether the use of BIM systems would increase the efficiency of applying TQM concepts in the implementation phase through quantifiable performance indicators (such as lack of information needed for the implementation process, change orders, or estimating construction costs) in the project or not.

4.2 Research Plan

Typically, the approach for any research relies on the method and type of data that is collected as well as the manner in which the results can be examined. The research plan selected will affect the form and value of the gathered information (Ghauri and Grønhaug, 2010). the strategy selected for this research is to develop a model to contribute to the construction sector and evaluate objectives. A quantitative survey method was adapted to study the research questions and hypothesis regarding the significance of applying BIM concepts in the phases of the project that will increase TQM within the Kingdom of Saudi Arabia.

Additionally, the case study relied on for this research was The Student Residence building at King Khalid University in Saudi Arabia. The BIM systems approach was applied on the case study through utilization of one of the BIM software, which in this research was the Autodesk Revit program. In addition, a comparison was made between the plans generated by the Revit program and the basic plans designed by the AutoCAD program. The objective of this comparison determined whether the use of BIM systems would increase the efficiency of applying TQM concepts in the implementation phase through quantifiable performance indicators (such as lack of information needed for the implementation process, change orders, or estimating construction costs) in the project or not.

4.3 Research Location

The research will focus on the construction industry in the Kingdom of Saudi Arabia. Therefore, the study will be conducted within the Kingdom of Saudi Arabia.

4.4 Target population, sampling of the questionnaire and data collection

The questionnaire survey was conducted in 2020 (January). Research population includes professionals engineering organizations and construction companies (Architects, Civil Engineers, Mechanical Engineers, Electrical Engineers, and any other professional with related specialization) in the construction industry in KSA as a target group.

The sample size was determined by using a sample size calculator found online. The mathematical equation to determine the sample size is as follows:

$$n = N * \frac{\frac{Z^2 * \mathrm{p} * (1-\mathrm{p})}{\mathrm{e}^2}}{[N-1+\frac{Z^2 * p * (1-p)}{e^2}]} \quad \ldots\ldots (1)$$

4.5 Questionnaire Design and Development

The information required for the research was gathered by questionnaires that were personally distributed to the respondents. The questionnaire was established based on three essential phases, and they are as follows:

1. Classifying the questions that are a common concern.
2. Establishing the final structure of the questionnaire.
3. The phrasing of the questions.

Finding the items or components for the research and preparing the questionnaire was an essential process to ensure the success of this research. There have been tremendous amounts of important studies on the component of BIM technology that affect TQM in engineering facilities within the Kingdom of Saudi Arabia. Moreover, these studies have developed theoretical models to classify the numerous factors hindering the application of this approach in the projects.

Based on the previous literature works regarding the impact of BIM concepts on TQM within the construction sector, an innovative questionnaire was established for the research. The questionnaire was composed of multiple-choice questions (clode-ended).

- Section One: Composed of the Respondents Personal Information
- Section Two: Degree of knowledge on the Building Information Modelling (BIM) in general.
- Section Three: Degree of Total Quality Management (TQM) application in engineering projects throughout the Kingdom of Saudi Arabia.
- Section Four: Awareness and Recognitions of Building Information Modelling (BIM) within the construction industry in the Kingdom of Saudi Arabia.
- Section Five: Obstacles and Restrictions towards Conforming Building Information Modelling (BIM) throughout the Kingdom of Saudi Arabia.
- Section Six: Major Strategies for Building Information Modelling (BIM) within the Kingdom of Saudi Arabia.

Moreover, the questionnaire was presented with a cover letter to explain the research objectives, the confidentiality of the data provided in order to encourage higher response rates and the method of responding. The multiplicity of the questions is targeted to meet the goals of the research, cover the primary research questions, gather all the information needed to support the outcomes and discussions, in addition to the recommendations in the research.

Once the respondents answer the first section of the questionnaire regarding the Personal Information of Respondents, they are required to rate every component in all of the second, third, fourth and fifth fields based on a five-point Likert rating scale. The Likert rating scale requires a ranking from 1-5, in which ‘1’ represents the lowest rank on the scale and ‘5’ represents the highest ranking for the component.

The rating scale was selected to structure the questions of the questionnaire in typical relevant sets of response categories called quantifiers, which represent the intensity of a specific judgement contained (Naoum, 2007). These quantifiers were exploited to simplify understanding, which is shown in Table (4.1).

Table 4-1 Likert scale

Part Two	**Very Great Extent**	**Great Extent**	**Average Extent**	**To a small Extent**	**Never**
Parts (three, four, five and six)	**Completely Agree**	**Mostly Agree**	**Slightly Agree**	**Mostly Disagree**	**Completely Disagree**
Scale	5	4	3	2	1

The first outline of the questionnaire was modified through three primary phases that are the face validity, pre-testing the questionnaire and the pilot study. In each phase, the questionnaire was further modified and enhanced. The following sections will discuss the details regarding each phase.

4.6 Face Validity

Face validity is a crucial element to determine whether the questionnaire seems to be valid or not. It is a practicality evaluation by the professionals in the fields of the AEC industry and statistics (Salkind, 2010). The questionnaire was delivered either personally by hand or via email, at various times to five experts so that they can evaluate the validity of the questionnaire. There were several constructive and significant alterations made to the questionnaire. These alterations are clarified in Table (4.2).

Table 4-4-2 Results of the face validity

Name	Country	Specialization	Alteration(s) Made
Expert A	KSA	MSc. Of Statistics	* Adjusted the verbalization of the questions concerning Statistics in the first section of the questionnaire.
Expert B	KSA	Distinguished Prof. of Construction Eng. And Management	* Reviewed the English Language of the first draft for the questionnaire and altered some phrases. *Recommended the word phrasing for the rating scale (Likert scale) for all the fields.
Expert C	KSA	Prof. of Statistics	* Revised the English Language in the first draft of the questionnaire as well as the Arabic translation of the questionnaire.
Expert D	KSA	PhD in Architectural Design and Construction Technology	* Assisted in designing the questions for the second section of the questionnaire regarding “The Awareness level of BIM by Professionals”.
Expert E	KSA	MSc of Statistics	* Suggested a statistical alteration for the questions relevant to the first objective, which regarded evaluation of the level of recognition of BIM among professionals. * Adjusted the statistical formulation of the hypothesis.

4.7 Pre-testing the Questionnaire

The questionnaire was pre-tested to guarantee the delivery of the appropriate information and to ensure the quality of the information gathered. In a simpler form, pre-testing the questionnaire was a significant and vital phase to discover if the questionnaire had any logical concerns, if the questions were to complex, whether the phrasing of the questions is unclear, or if there were any bias responses, and so on (Lavrakas, 2008). The pre-testing was performed in two stages with twelve specialists in the construction industry in KSA, where each stage was tested with six specialists.

Pilot Study

Following the success of the pre-testing phase for the questionnaire, a trial run was performed before delivering the questionnaire to the study sample to receive valued replies and to identify the parts of probable flaws (Thomas, 2004). Bell (1996) explained the pilot study to be an approach that rids the instrument, in this case the questionnaire, of any defects. As well as to ensure that the subjects of the main study will not encounter any complications to finish, and the researcher can execute a first-round evaluation to determine if the formulation and layout of the questions will present any complications when the main data is evaluated (cited in Naoum, 2007).

Based on such information, 40 copies of the survey were appropriately delivered to the target group. All copies were gathered, coded and evaluated by the Statistical Package for the Social Sciences IBM (SPSS) version 22. The tests performed were as follows:

1. The statistical validity of the questionnaire and the validity of the relevant criterion.
2. The reliability of the questionnaire using the Half Split approach as well as the Cronbach's Alpha approach.

4.7.1 Statistical Validity of the Questionnaire

In regard to quantitative research, validity is considered the degree to which a study utilizes a specific tool to quantify what it sets out to measure. Therefore, two statistical tests must be performed to guarantee the validity of the questionnaire. The first test is the criterion-related or internal validity test (Pearson test) that measures the correlation coefficient between every component within a specific field and the whole field.

4.7.1.1 Internal Validity Test

The internal reliability of the questionnaire was determined by the survey sample, which is the sample pilot study that consisted of 40 questionnaires. The reliability was calculated by measuring the correlation coefficients (Pearson test) between each component within one field and the entire field (Weiers, 2011; Garson, 2013)..

4.7.1.2 Structure Validity Test

The second statistical test that is applied to determine the validity of the questionnaire's structure is the structure validity test. The test works by testing the validity of every field as well as the entire questionnaire. It computes the correlation coefficient between the single field and all the other fields of the questionnaire with the equivalent level of the ranking scale (Likert scale) (Weiers, 2011; Garson, 2013). The following table, Table 4.3, the significance values (P-values) are less than 0.05, which determines that the correlation coefficients of all the fields are significant at $\alpha = 0.05$. Hence, it can be deduced that the fields are valid to determine what they are set to measure in order to acquire the main objective of the research.

Table 4-3 Structure validity of the questionnaire

Fields	**Pearson correlation coefficient**	**P-value**
Degree of knowledge of Building Information Modeling (BIM) technology and its application in the work field	0.421	0.01
Degree of Total Quality Management (TQM) application in engineering projects	0.477	0.00

Awareness and Benefits of Building Information Modeling (BIM) in the Building Industry	0.42	0.01
Obstacles and Restrictions to Adapting Building Information Modeling (BIM) in the Building Industry	0.43	0.01
Major Strategies for Building Information Modeling (BIM)	0.38	0.02

4.7.2 Reliability Test

Reliability determines the consistency or dependability extent of a tool, in this case the questionnaire, to measure what it has been established to measure. The reliability test is performed by re-distributing the questionnaire to the same sample group that is targeted, but at different periods. The scores from the first questionnaire are then compared to the scores gathered from the second questionnaire by determining the reliability coefficient. In most situations, the reliability coefficient is considered satisfactory if the value is found to be higher than 0.7. Moreover, the duration of time in which the questionnaire should be redistributed for the second time is recommended to be at least two weeks or up to a month (Field, 2009; Weiers, 2011; Garson, 2013). However, because of the complicated conditions, it was very difficult to redistribute the questionnaire to the same sample group in such a short time frame. To resolve such complications and to determine the reliability, the Half Split method and Cronbach's Alpha coefficient test were applied using the SPSS software.

4.7.2.1 Half Split Method

From the table provided, Table 4.4, all the values of the corrected correlation coefficients are shown to range from 0.82 and 0.88, where the general reliability for all components is computed to be 0.86. Additionally, the significance values are lower than 0.5, which implies that the corrected correlation coefficients are significant at α= 0.05. In accordance with the Half Split approach, it can be deduced that the studied fields are all reliable.

Table 4-4 Split-Half Coefficient method

No	Fields	Pearson-Correlation	Spearman-Brown Coefficient	Sig. (2-tailed)
1	Degree of Knowledge of Building Information Modelling (BIM) technology and its application in the work field	0.75	0.86	0.00*
2	Degree of Total Quality Management (TQM)	0.7	0.84	0.00*

	application in engineering projects			
3	Awareness and Benefits of Building Information Modelling (BIM) in the Building Industry	0.69	0.82	0.00*
4	Obstacles and Restrictions to Adapting Building Information Modelling (BIM) in the Building Industry	0.79	0.88	0.00*
5	Major Strategies for Building Information Modelling (BIM)	0.77	0.87	0.00*
	All Items	0.74	0.854	0.00*

4.7.2.2 Cronbach's Coefficient Alpha (Cα)

The Cronbach Alpha approach is used to determine the reliability of the questionnaire between any single field and the Mean value of all fields within the questionnaire. The normal scope for Cronbach's coefficient alpha (*Cα*) value ranges from 0.0 and +1.0, in which the higher value indicates a higher extent of internal consistency (Field, 2009; Weiers, 2011; Garson, 2013).

Table 4-5 Cronbach's Coefficient Alpha for reliability

No	Fields	Cronbach's Alpha (*Cα*)
1	Degree of Knowledge of Building Information Modelling (BIM) technology and its application in the work field	0.89
2	Degree of Total Quality Management (TQM) application in engineering projects	0.84
3	Awareness and Benefits of Building Information Modelling (BIM) in the Building Industry	0.92
4	Obstacles and Restrictions to Adapting Building Information Modelling (BIM) in the Building Industry	0.89
5	Major Strategies for Building Information Modelling (BIM)	0.87
	All Items	0.88

4.8 Quantitative Data Analysis

In this research, a quantitative approach was adapted. Quantitative approaches for data analysis can be valuable to the researcher when drawing significant results from a large quantity of qualitative data. The primary advantageous feature of this approach is that it provides the Means in order to distinguish the large numbers of perplexing factors that frequently hinder the main qualitative findings (Field, 2009; Salkind, 2010, Abeyasekera, 2013). Statistical approaches play a dominant role in the majority of research that depends on quantitative assessment of data, which is completed by converting the original data to numeric data through a ranking scale. As previously mentioned, for this study the five-point Likert ranking scale was applied. This method assists the researcher to determine better results, associate and compare the results gathered with previous studies to depict the contrast and degree of progress. Moreover, quantitative analysis aids the researcher to find the degree of accuracy of the data for the study and allows the summary results to be reported in numerical terms with a definite degree of assurance (Field, 2009; Treiman, 2009; Salkind, 2010).

4.9 Measurements

The data for this research was analyzed by using the IBM SPSS Statistics (Statistical Package for the Social Sciences) Version 22(IBM). The quantitative measures that were followed for data analysis are as follows:

4.9.1 Cross-Tabulation Assessment

In statistical terms, cross-tabulation or crosstab is a form of table in a matrix format that portrays the multivariate (involving two or more variable quantities) frequency distribution of the variables. Such assessment techniques are widely used in survey studies, business intelligence, Engineering and scientific studies. They offer a fundamental image of the interrelation between two variables and can assist in finding relations between them. In simpler terms, the cross-tabulation is an instrument that permits the researcher to compare the relationship between two variables.

4.9.2 Calculating the Relative Importance Index (RII) of Factors

The relative importance index (RII) approach was applied to determine the ranking of the items or variables as perceived by the respondents in each section of the questionnaire (section 2-5). The relative importance index was calculated by using the following formula (Sambasivan and Soon, 2007; Field, 2009):

$RII = \Sigma W / (A * N)$

Were.

Given that such analysis does not provide any significant results in regard to comprehending the clustering impacts of the similar items and predictive capacity, which requires further assessment by using advanced statistical approaches. A factor assessment was applied to minimize the items and analyze the clustering impacts.

4.9.2.1 The Distribution of Data

The theory of normalization is the fundamental requirement to simplify the outcomes of the factor assessment test past the sample collected (Field, 2009; Zaiontz, 2014).

4.9.2.2 Validity of the Sample Size

The consistency of factor assessment largely depends on the sample size. For samples that have less than 100 respondents but more than 50 respondents, the PCA can be applied. The standard principle is to imply that the sample size is composed of at least 10-15 respondents for every item or variable. In much simpler terms, the sample size must be a minimum of ten times the quantity of the items or variables, and a few individuals who recommend twenty times the items or variables (Field, 2009; Zaiontz, 2014).

4.9.2.3 Validity of Correlation Matrix (Correlations among variables)

The correlation matrix is simply a rectangular array of numbers that provides the correlation coefficients between a single variable or item and all the other items or variables in the research. The value of the correlation coefficient between a variable and itself is always equal to 1, therefore the standard diagonal of the correlation matrix includes 1's.

4.9.3 Normal Distribution

Normal distribution estimates natural occurrences very well. The method of normal distribution has been established into a principle of reference for numerous possibility complications (Field, 2009). The majority of the parametric statistical assessments usually assume the data has a normal distribution, given that when the data is not normal, it yields unqualified outcomes. By using the Central Limit Theorem, the normality is evaluated. This theorem claims that when the samples used are large quantities (higher than about 30), the sampling distribution will take the form of a normal distribution not considering the population form in which the sample was taken from (Field, 2009; Levine *et al.*, 2009). Accordingly,

Table 4-6 Skewness and Kurtosis results

No.	Fields	Skewness	Std. Error of Skewness	Kurtosis	Std. Error of Kurtosis
1	Degree of knowledge of Building Information Modeling (BIM) technology and its application in the work field	0.77	0.15	0.16	0.3
2	Degree of Total Quality Management (TQM) application in engineering projects	-0.53	0.15	-0.19	0.3
3	Awareness and Benefits of Building Information Modeling (BIM) in the Building Industry	-0.52	0.15	-0.19	0.3
4	Obstacles and Restrictions to Adapting Building Information Modeling (BIM) in the Building Industry	-0.62	0.15	0.04	0.3
5	Major Strategies for Building Information	-0.71	0.15	1.08	0.3

	Modeling (BIM)				
	All Items	-0.51	0.15	-0.04	0.3

4.9.4 Parametric Tests

A parametric assessment is a test that demands data from one of the large lists of distributions, where statisticians have claimed that in order for the data to be parametric, certain expectations must be accurate. The expectations for the parametric tests are normally distributed data, consistency of variance, interval statistics and independence (Field, 2009; Weiers, 2011).

4.9.4.1 Pearson's Correlation Coefficient

Correlation represents any comprehensive class of statistical relations concerning dependency. The most recognized dependency measurement between two quantities (two groups of data or two variables) is the Pearson product-moment correlation coefficient or Pearson's correlation coefficient, which is commonly referred to as the correlation coefficient. This coefficient represents the linear relationship between two arrays of data. Two symbols are used to symbolize the Pearson correlation: Greek letter rho (ρ) for the population and the symbol (r) for the sample (Filed, 2009; Treiman, 2009).

4.9.4.2 Proposed Model Developments and Validation

The major motivation of this work is the employment of nonlinear soft-computing models for the improvement of TQM in the construction companies of Saudi Arabia. To the best authors knowledge these models have never being employ in any technical literature which as additional novelty of this thesis. In this section, the linear and non-linear models would be provided to improve the Total Quality Management (TQM) based on different criteria. As stated above the proposed research methodology contained two different scenarios, the first includes appraising the impacts of employing the concepts of TQM to the construction projects in Saudi Arabia. Despite several works done in the field to enhance the TQM, the research outcomes proved that companies applying BIM concepts are capable of adhering to project schedule, cost and customer satisfaction unlike those companies that do not apply BIM in their projects and that higher managements are incapable of committing to the application of TQM concepts when BIM is not used in the construction projects.

In this work, knowledge of data science and analysis is essential for any data-driven method, the data were collected from experimental studies performed by(Abba, Kawu, et al., 2022; J. Abdullahi et al., 2022) (Khajeh & Barkhordar, 2013) in which solid-phase extractions were performed with domestic tea waste as an improvised sorbent for the extraction and preconcentration of Mn from food samples. The understanding of data science and analysis is necessary for every data-driven modeling technique. Meanwhile, this study proposed the potential application of two nonlinear data-driven intelligent algorithms, namely multivariate linear regression (MVR), artificial neural network (ANN), and ANFIS (a hybrid learning algorithm) for the improving the TQM based on different criteria (Cost reduction (CR), Time reduction (TR), Improve Employee Performance (IEP), Coordination improvement (CI), Negative risk reduction (NRR), Scope clarification (SC), Increase customer satisfaction (ICS), and Greater process control (GIC)). However, some of the inputs criteria of Building Information Modelling (BIM) includes Coordination between elements and plans (CEP), 3D Modeling (Visual Verification) (3DM), creating a common database (CCD), Availability of Information (AI), Accuracy and Possibility of Modification (APM), and Compilation or Classification (CC), Following data collection, the data were preprocessed and normalized using Equation 1 as shown in the flowchart.

$$y_{norm} = 0.05 + \left(0.95 \times \left(\frac{y - y_{min}}{y_{max} - y_{min}}\right)\right) \tag{1}$$

Where y_{norm} represents the normalized data, y is the observed data, and $y_{min}$and y_{max} represent the minimum and maximum values of the observed data, respectively.

4.10 Conceptual Modeling Approach

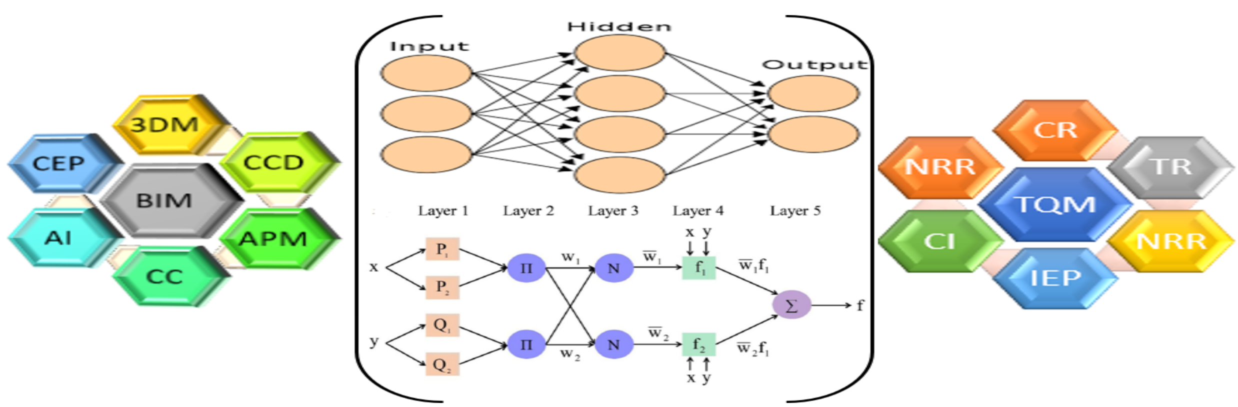


Figure 4-4-1 The proposed modeling schema

4.11 Multi-Variate Regression (MVR)

4.12 Adaptive Neuro-Fuzzy Inference System (ANFIS)

The Adaptive Neuro-Fuzzy Inference System (ANFIS) is an amalgamation of the Artificial Neural Network (ANN) and the fuzzy inference system (Fig. 4.2). Therefore, it combines the learning capability of ANN with the ability of a fuzzy system to handle data uncertainties (Yaseen, Ghareb, et al., 2018), (Huang, 2012), (Ebtehaj & Bonakdari, 2014). Although many types of ANFIS have been established such as Mamdani, Sugeno, and Tsumoto (Kaur, 2012), the Sugeno system has been widely used (Sanikhani & Kisi, 2012). The structure of the ANFIS model consists of nodes acting as membership functions (MFs), fuzzy values in the interval of 0 and 1, and a set of rules that map the relationship between the input and output. In practice, several membership functions are used, including trapezoidal, triangular, sigmoid, and Gaussian. Although the Gaussian function is the most frequently used MF (Karimi et al., 2013), the triangular function showed promising results in the present study.

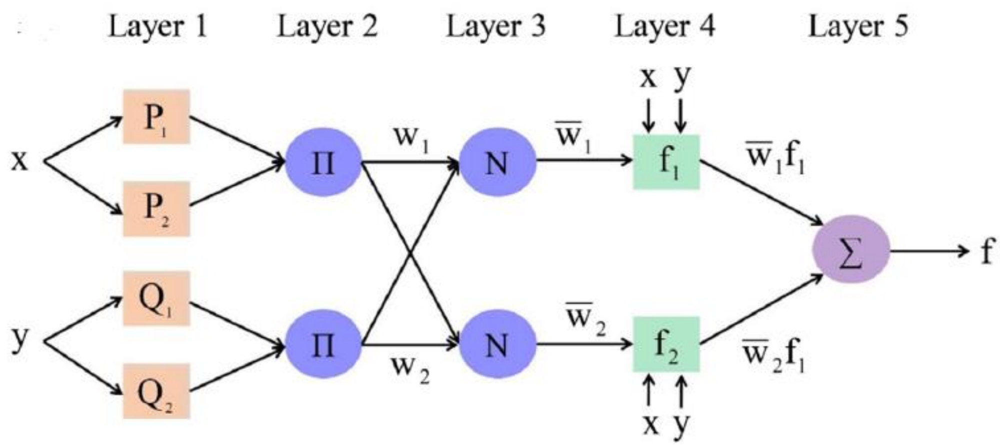


Figure 4-4-2 ANFIS model architecture with two inputs and five layers (Yaseen, Ramal, et al., 2018)

4.13 Performance Evaluation Criteria

From the results it can be observed that the predictive modeling approaches have achieved different adequacy in accordance with evaluation criteria. Besides, the overall results demonstrated that ANFIS model served as the best simulation in term of performance criteria. Although it is difficult to rank the models in accordance with the achieved accuracies, nevertheless the ANFIS model approach relatively showed the best predictions accuracy

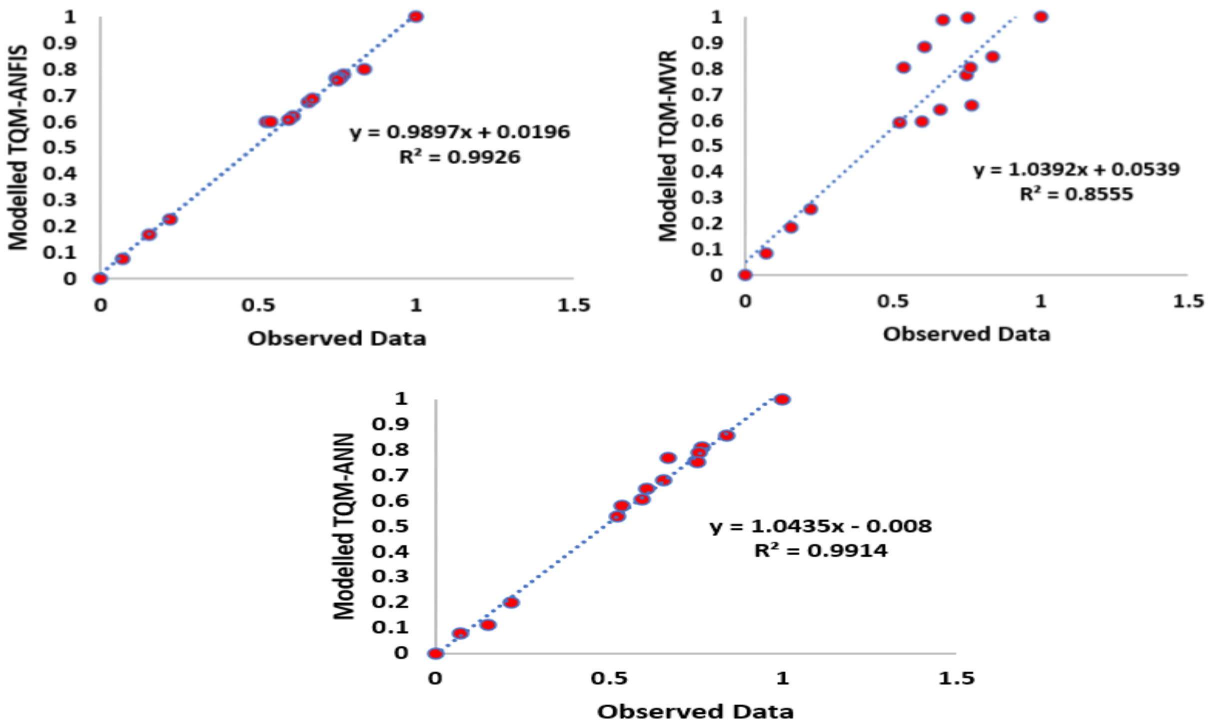


Figure 4-3 Scatter plot for the ANFIS, ANN, and MVR model

CHAPTER V

5 A New Model (Case Study)

5.1 Introduction

For this research, BIM systems have been applied to the case study: The Student Residence building at King Khalid University in Saudi Arabia. The student residence was chosen because it is a massive project, encompasses various elements, and was subjected to many amendments. Moreover, the project information and data was available to the researcher by using one of the BIM softwares, in this case the Autodesk Revit program, which made it simpler to conduct comparisons between the plans executed from the Revit program and the basic layouts designed by AutoCAD. The comparison assisted in understanding and determining if the use of BIM systems would increase the efficiency of applying TQM concepts or not in the implementation phase through quantifiable performance indicators within the project, such as lack of information needed for the implementation process, alteration orders, and estimating construction costs.

5.2 Use of BIM to Reduce the Lack of Information Necessary for Implementation

After analyzing the information required from the contractor and consultant, it became obvious that most of the factors affecting implementation in projects are a result of errors, oversights and lack of coordination between the plans.

Through extensive research on solutions using BIM systems, studies revealed that problems resulting from a lack of information needed for implementation might be resolved using Bi-directional links between the building elements (Parametric Object). This contributes to the automatic coordination of each component designed with all the plans and quantities associated with that element within the project database.

5.2.1 Bi-Directional Linkage (Parametric Objects)

When using the term ‘Bi-directional linking’ it indicates that through the use of a single model design using the BIM software, it is able to create all the charts from plans, elevations, sections, details, perspectives and non-graphical data such as tables of quantities and properties of the project elements. This means that the change in one plan will be automatically reflected on the rest of the plans, which saves a lot of time and contributes to eliminating human error or oversight that result from manual modification of the plans and quantities. By referring to the concerns of the executing authority, this research observes the differentiation’s that result from the mismatch of the windows in the plans with the tables.

For example, inconsistency between the plans and tables of the windows (project element) is found to be a result of the lack of correlation between the plans and overseeing the modification. By modeling the structure using the BIM program, it contributed to the automatic correlation between the plans and the tables of quantities and properties of windows through a single model, which made the possibility of oversight and human error unthinkable. This achieves better coordination between project plans and contributes to the optimal management of changes. As shown in figure (5.1), each element (the windows for this case study) has properties according to its type and the numbering of the elements is given by default values, which are changeable for example in windows for this case study numbering of the elements is given by natural numbers; {1,2, 3,…}.

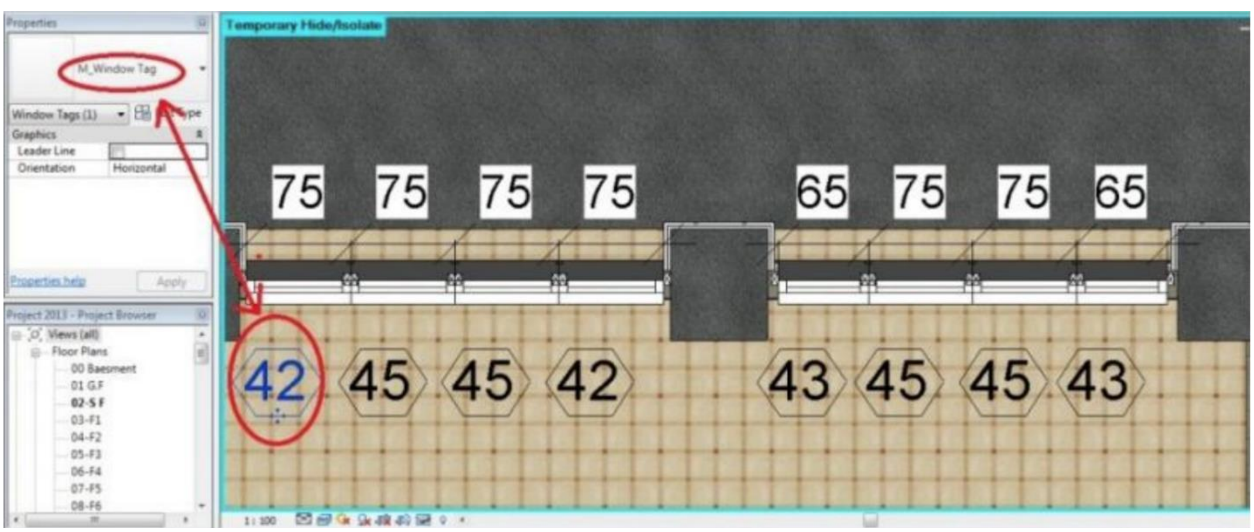
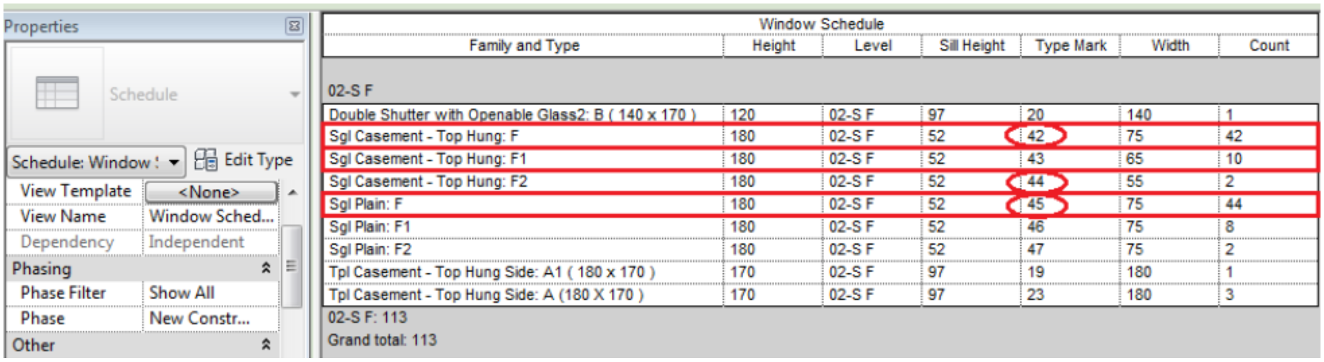


Figure 5-1 Window Properties from Revit Program

Figure (5.2) shows the table of quantities for windows that contain all the properties of the defined windows, which appear as adjustable and addable properties within the graphical charts.



Window Schedule						
Family and Type	Height	Level	Sill Height	Type Mark	Width	Count
02-S F						
Double Shutter with Openable Glass2: B (140 x 170)	120	02-S F	97	20	140	1
Sgl Casement - Top Hung: F	180	02-S F	52	42	75	42
Sgl Casement - Top Hung: F1	180	02-S F	52	43	65	10
Sgl Casement - Top Hung: F2	180	02-S F	52	44	55	2
Sgl Plain: F	180	02-S F	52	45	75	44
Sgl Plain: F1	180	02-S F	52	46	75	8
Sgl Plain: F2	180	02-S F	52	47	75	2
Tpl Casement - Top Hung Side: A1 (180 x 170)	170	02-S F	97	19	180	1
Tpl Casement - Top Hung Side: A (180 X 170)	170	02-S F	97	23	180	3
02-S F: 113						
Grand total: 113						

Figure 5-2 Windows Quantity Tables from Revit Program

Thus, once the modeling process is completed, the tables of quantities will automatically be generated. An automatic link will be created for the window with all the plans and tables contained on that window, as shown in figure (5.3), so that in the event of any modification, this will be reflected on the quantities and the windows tables of properties, interfaces, projections and sections.

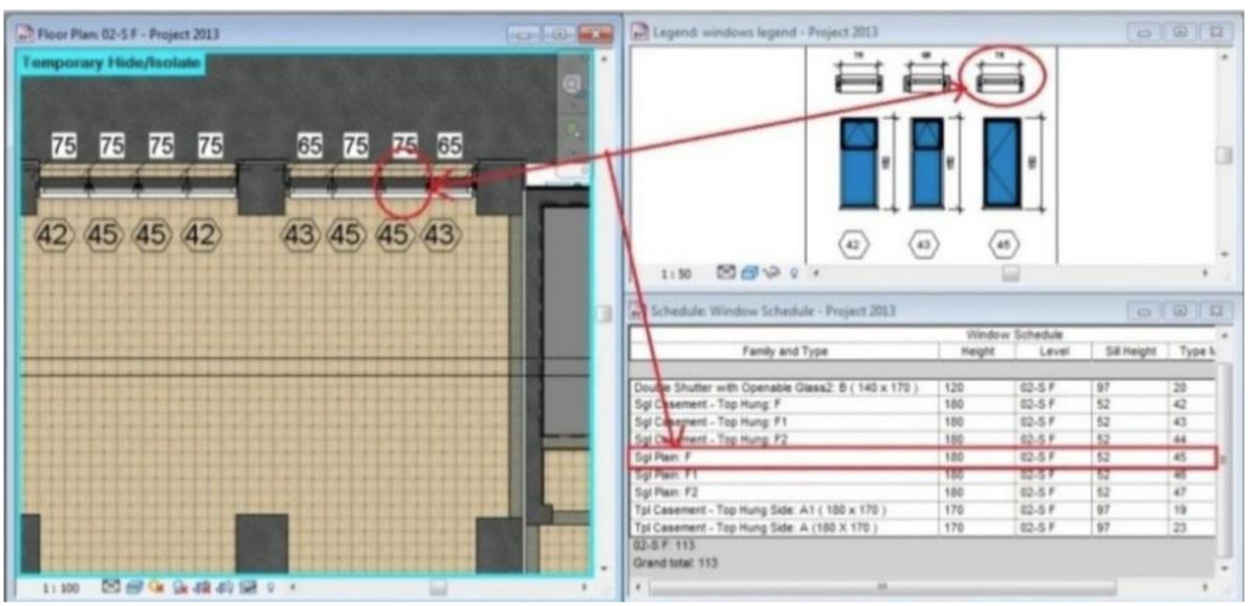


Figure 5-3 Automatic Linking of Items from the Revit Program

5.3 Use of BIM to Reduce Alteration Orders

After analyzing the change orders, it became clear that most of them are due to errors and oversights, lack of coordination between specialties (such as conflicts between architectural windows and concrete beams) and poor perception of the owner. By researching BIM systems solutions, it is found that the problems resulting from the change orders are addressed by creating a common database that leads to technical communication and effective coordination between the work team that improves the perception of the owner, avoids high costs, and increases time.

It is possible to avoid inconsistencies between the different disciplines by activating work with a common database that allows the overlapping of all building elements (architectural, construction, mechanical, electrical, and sanitary) with one integrated model.

For this research, a joint database has been established for the case study relied on, that is the student housing building at King Khalid University, using the Revit program. The table below, Table 5-1, shows some of the results of establishing a common database in the Bi-directional linking between the plans, the visualization of building information and the detection of inconsistencies that would address the increase of change orders during implementation and the detection of errors and deficiencies.

Table 5-1 Results of Establishing a Joint Database

No.	Description	Specialization	Solutions using BIM	Impact on time (day)	Impact on cost (SAR)
1	The inconsistency of the windows description between the plans and the description table, and the differences in symbols among them.	Architectural	Bi-directional linking between the plans	-	-
2	All internal windows without descriptions.	Architectural	Visual communication of building information	-	-
3	The displacement of some axes of columns and walls between the structural and architectural projections in the eighth block.	Structural	Bi-directional linking between the plans	10	-
4	Some of the foundations have no details such as reinforcing sections.	Structural	Bi-directional linking between the plans	3	-
5	Some of the beams on the C axis are inconsistent with the architectural facades at the ground floor.	Structural	Detecting Inconsistency	7	140,000
6	It turns out that when casting the slab to the last floor with beams, the frame leads to the protrusion of the beam on the façade.	Architectural & Structural	Detecting Inconsistency	75	850,000
7	Adjust the height of the ground level to become	Architectural &	Bi-directional linking diagrams & visual	18	-

	4.5 meters instead of 6 meters.	Structural	communication of building information		
8	Due to some changes, it is necessary to change the location of the air conditioning lines	Mechanical	Bi-directional linking diagrams & detecting Inconsistencies	9	195,000

***Visual Communication of Building Information*:** This means that BIM systems allow the user to navigate the three-dimensional structure, discovering the building as a whole in terms of the areas, elements and materials used. Moreover, it generates the perspectives necessary to understand the project, which contributes to reducing the need for enquiries regarding the elements in terms of specifications and materials that constitute them, and without the need to generate further detailed plans for clarification.

***Bi-Directional Linking between Plans*:** This means that through a single model designed using the BIM software, it is able to create diagrams from plans, elevations, sections, details, perspectives and non-graphical data such as tables of quantities and properties of elements. In other words, the alterations in one plan will be automatically reflected on the remaining plans, which saves a lot of time and contributes to cancelling the human error or oversight resulting from the manual modification of all the plans and quantities.

***Detecting Inconsistencies*:** The inconsistency detection tool automatically verifies that the building elements do not overlap with each other. For example, this tool avoids problems regarding the clashing of ventilation ducts and concrete beams, which contributes to saving time and cost resulting from change and re-work orders, thus, improving quality and productivity.

5.3.1 The Effect of Alteration Orders on Project Time

By reviewing the timeline of the case study project with the executing agency as shown in Figure (5.4), the tasks included with the alteration orders resulting from errors, oversights and poor perception were studied along with the inquiries of the executing agency. The case study was carefully studied and analyzed by setting the actual start and end dates for the tasks and comparing them with the planned start and end dates in the timetable. The tasks are then located on the critical path, in which its delay leads to an increase in the project’s time. In addition, the tasks that are not located on the critical path that consumed the total reserve of the task or process (total float) were identified, and consequently, the subsequent tasks made it almost critical.

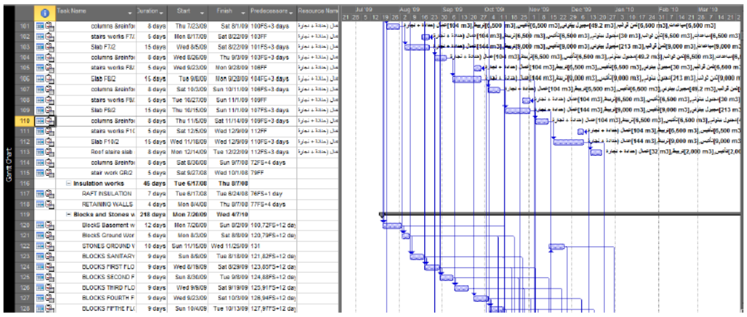


Figure 5-4 Project Timeline

In conclusion, the increase in the times of tasks associated with the alteration orders and the executing agencies inquires, which amounted to 449 additional days for the planned periods of tasks that was calculated. Of these, 359 days were located on critical paths, with a completion rate of 63% for the current time, as the project is still under construction. Therefore, the saving rate in time has become 47% of the project time to the current stage. Hence, if the building information Modeling systems were applied to the student housing building project at King Khalid University, it would have produced an estimated timesaving of 47%.

5.3.2 The Effect of Alteration Orders on the Cost of the Project

Through referring to the project files and the correspondence sent from the executing agency and by conducting systematic meetings with the implementing authority, the costs of alteration orders due to errors, oversights and poor perception were obtained. This was done through analyzing the cost of alteration orders that lead to the replacement or reworking, including materials, employees, mechanisms, and the inactive waiting times and its impact on both rental and employment mechanisms.

The previous table, Table (5-1), shows the cost of each alteration order, including all the elements incorporated into the analysis of the replacement and re-work expenses. From the analysis, it was discovered that there was an increase in the cost of the project amounting to 7,525,000 SAR. When compared to the project cost at the current stage, in which most of the mechanical work has not yet been completed and is considered the largest cause of inconsistencies, it is found that the cost abundance percentile amounted to 2% of the cost resulting from the works to the current stage (completion rate 63%). This corresponds to local and global statistics on the percentage of increase in cost due to alteration orders from errors, oversights and poor perception, which amounts to approximately 3% to 10%.

5.4 Estimated Construction Costs

Cost is an important factor in the early stages of the project, and it is important to obtain a rapid initial cost that contributes to the decision-making process for evaluating different alternatives. Given the nature of rapid project implementation, material expenses are necessary when any change occurs during the implementation phase. Therefore, the process of estimating costs is the backbone of project implementation success and accuracy, an essential factor in estimating expenses.

The process of calculating quantities was evaluated using BIM systems in comparison to the traditional methods of the architectural divisions. An example in this research is the case study, where it is considered good for evaluating quantities due to the large size of the project, the complexities associated with the project and the diversity of its components.

The Revit program was selected as one of the BIM software systems since it is commonly used for modeling, designing and supporting many objectives including three-dimensional plans, building visualization and obtaining unofficial data such as the tables of materials and quantities. Among the traditional software systems, the commonly used program is Excel, which was used to calculate the quantities of the student housing building at King Khalid University.

Returning to the methods of quantity calculations and their importance for the process of estimating construction costs, there have been criterions adopted. These criteria contribute to evaluating the mechanisms and methods of quantity calculations and comparing traditional methods with the methods associated to BIM systems. These criteria are the factors required to analyze data and provide the required results. The criteria were categorized as follows:

1. **Availability of Information:** Researching whether the program can provide quantities for various needs.
2. **Accuracy and Possibility of Modification:** Researching the accuracy of calculated quantities and the effect of the modifications applied to the drawings on the quantities of materials.
3. **Compilation or Classification:** Researching the extent of the program’s ability to compile quantities of elements based on certain criteria. For example, the user needs to know the amount of a certain material type at a particular level or a specific section of the building.
4. **Visual Verification:** Researching the programs strength, observing the components of the building whose quantities are calculated. For example, checking the program’s ability to see specific quantities in origin by isolating them or highlighting them in the diagrams.
5. **Final Outputs and Reports:** Researching the program’s ability to produce well-coordinated and clear reports.

5.4.1 Quantity Calculation Using BIM Systems Compared to Traditional Methods of Architectural Divisions

Going back to the two-dimensional plans, it shows that there are about 15 types of architectural sections. Including various forms, the project did not contain a plan to characterize the types of walls with respect to the different thicknesses and the layers that compose the wall.

The mechanism of calculating the quantities of architectural sections is not an easy matter, since it consists of various materials and must calculate the quantities of each material separately.

The vast amounts of information in the plans that contain different types of sections make it difficult to limit their quantities and increases the chances of forgetting some walls and omitting some quantities.

In the figure below, Figure (5.5), a building plan of the first floor and its architectural sections are shown.

Figure 5-5 The Architectural Sections for the Student Housing Building

5.4.1.1 Availability of Information

The characteristics of the architectural sections in both programs are listed in the table below, Table (5-2). Since the sections are composed of various elements, the feature of the Revit program presents the quantities of each material separately through the Material Takeoff tool. In situations where Excel is used, the user will calculate each material in a special file by giving color or symbolic indications for various plans according to the material whose quantities are required (block-blue-paint-ceramic…etc), which is an exhausting process that leads to large time consumption for the user.

Table 5-2 Characteristics of Architectural Sections from Revit and Excel programs

<table>
<tr><th></th><th>Revit</th><th>Excel</th></tr>
<tr><td>Area</td><td>The program provides the required information directly</td><td>Indirectly extracted from the program</td></tr>
<tr><td>Length</td><td>The program provides the required information directly</td><td rowspan="4">The program does not provide the required information and it cannot be indirectly extracted.</td></tr>
<tr><td>Thickness</td><td>The program provides the required information directly</td></tr>
<tr><td>Height</td><td>The program provides the required information directly</td></tr>
<tr><td>Specifications of the sections composed materials</td><td>The program provides the required information directly</td></tr>
</table>

From the table above, it shows that the Revit program can find most of the quantities required for cost estimation and building life cycle analysis. As for the Excel program, it requires manual entry of the data and uses indirect methods for all quantities required depending on the types of sections that are manually entered.

5.4.1.2 Accuracy and Adaptability

In Table (5-3) below, the calculated quantities for the architectural sections using both Revit and Excel programs are identified. The table also shows the error percentiles of precise quantity calculations.

Table 5-3 Error Percentage of Quantity Calculations for Both Programs

Elements		Area (m2)		Error Percentile	Height (m)		Error Percentile
		Revit	Excel		Revit	Excel	
Block	10 cm Block	799.59	652.77	18.3%	291.62	308	5.3%
	15 cm Block	397.22	369.62	6.9%	153.56	155.15	1.2%
	20 cm Block	836.61	727.80	13%	269.35	268.85	0.18%
Ceramic		1386.65	1210.50	12.7%	153.56	155.15	1.2%
Paint		2419.27	2023	16.3%	269.35	268.85	0.18%

In Table 3 above, the varied quantities calculated by using both Revit and Excel programs, are shown. The largest quantities were the quantities extracted from the Revit program for the following reasons:

1. Since the length and height calculations of the sections are close to both programs, the problem is in the deductions that were calculated using the traditional methods. By observing the excel quantities tables and comparing them with the plans, a difference is found in the dimensions of the openings between the plans and the quantity tables, as shown in figure 5.6.

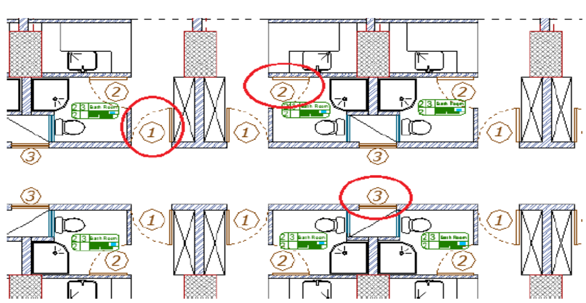


Figure 5-6 The Openings in the Plan

X	W	V	U	T	S	R	Q	P	O
FIRST--- Mass-5--Enter Brick Wall									
TOTAL Volume m3	TOTAL Area cm2	NUMBER	Volume m3	Area cm2	Thickness	Wall High	Wall Length	Wall No.	NOTICE
15.34	767040	6	2.5568	127840	20	272	470	1	
15.18	758880	6	2.5296	126480	20	272	465	2	
5.55	277440	6	0.9248	46240	20	272	170	3	
3.26	163200	6	0.544	27200	20	272	100	4	
22.91	1527200	2	11.454	763600	15	332	2300	5,6	
-4.05	-270000	12	-0.3375	-22500	15	250	-90	1	room door sub..
-1.66	-110400	6	-0.276	-18400	15	230	-80	3	gain door sub..
-0.32	-21600	12	-0.027	-1800	15	60	-30		beam sub..
-0.30	-20000	1	-0.3	-20000	15	250	-80	2	door sub..
-0.17	-11400	38	-0.0045	-300	15	20	-15		بروز النجفات
4.61	461175	11	0.41925	41925	10	215	195	7	
2.13	213180	11	0.1938	19380	10	228	85	8	

Figure 5-7 Height and Length Calculations from Excel

2. Failure in properly defining the levels of several sections due to the lack of clarifying the levels in the 2-dimensional plans, unlike the 3D plans, which allow the user to identify the levels precisely, as shown in Figure 5.8.

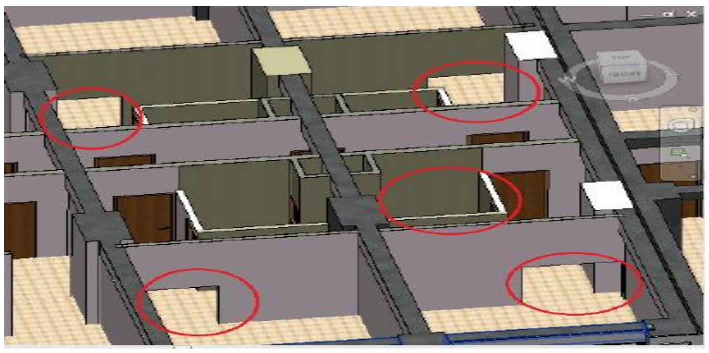


Figure 5-8 Variation of Levels in the Section

3. Ignoring the deduction quantities during the quantity calculations of the perpendicular beams in the section, using the traditional methods due to the difficulty of visualizing the section with 2D diagrams, as opposed to the 3D diagrams that provide the user with a realistic visualization of the structure. This assists the user in computing the quantities more accurately as shown in Figure 5.9.

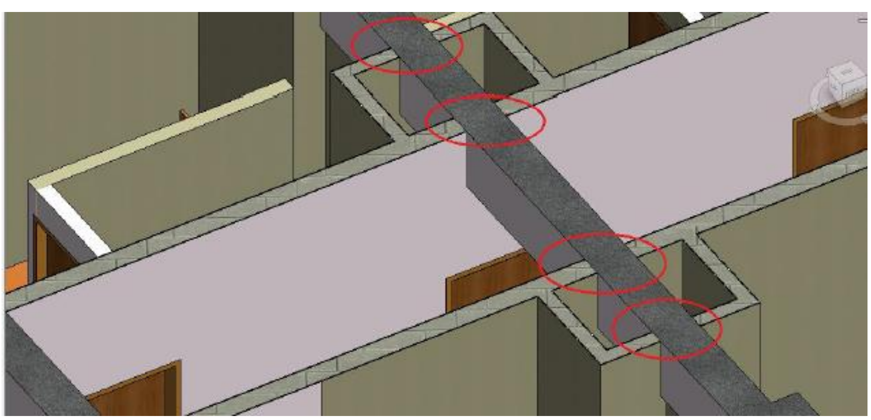


Figure 5-9 Details of the Beams with the Architectural Sections

4. Forgetting to resolve the problems in certain doors and windows through traditional methods due to the similarity and frequency of the sections and openings, which can be avoided using BIM programs.

4.3.1.3 Compilation or Classification

For this criterion, compilation or classification, the Revit program is found to be superior to others in terms of its ability to classify elements according to any of its characteristics (level - type - material - length - width - thickness - spaces - sizes - sectors or sections of the building ... etc.).

As for the Excel program, the user only manually classifies the elements. The user can create more than one file to establish more classification criterions for the elements, for example (a file according to the level - a file by type - a file according to the building's sections ... etc.) and then assigning each pretext according to the classification method. In comparison to the Revit program, this method is time consuming, especially if the user wants to modify the classification criteria.

4.3.1.4 Visual Verification

When using the Excel program, associations between the quantities and the plans are completely absent. Therefore, the possibility of visual-verification is non-existent and the likelihood of overseeing or forgetting some elements is probable in relation to the large size and complexity of projects. Hence, the user resorts to place the indications of the elements on the plans manually to ensure that no element is forgotten, given that the responsibility of project verification lies on the user.

The Revit program is characterized by the automatic association feature between the quantities and the plans. This allows the user to relax and leave the task of checking every element. Moreover, through the Revit program the user can visualize the building through a section or plan of the building as shown in Figure 5.10, which contributes to visual verification and ensures accurate quantity calculations.

Figure 5-10 Building Section from Revit Program

5.4.1.3 Final Outputs and Reports

By using Excel, the user is must prepare a form for printing and works to associate the final quantities computed with the model by hand (manually). For example, the user is able to enter any equation to calculate any quantity required by using the data, which is manually entered and very time consuming.

On the other hand, using Revit is an excellent tool to extract quantities, which are automatically calculated once the modeling of the elements is completed. It also features an automatic linking mechanism between the 3D building model and the quantities, which leads to automatic modification of quantities once any plan is modified. It is characterized by a classification tool that allows the classification of elements according to any feature of the elements properties.

CHAPTER VI

6 Data Collection and Analysis

6.1 Introduction

The objective of this research was to evaluate the importance of the application of BIM in the stages of the project that would raise the TQM in the Kingdom of Saudi Arabia and the obstacles that stand in the way of using BIM in those stages. The following chapter covers the analysis and discusses the results gathered from field surveys. The mathematical calculations and practical methodology of the research will be conversed. It will present the theoretical model utilizing the statistical package for social science (SPSS), the relative importance index and mean values. The results obtained from the questionnaires related to the preference of the factors are utilized to obtain the relative importance for the factors and their mean values.

The field surveys were utilized to ensure collecting the data needed to complete this research. There were 200 questionnaires in total completed and returned with a valid response rate of 97.8%. The data was analyzed quantitatively using IBM (SPSS) version 22, including Descriptive and Inferential statistical tools. The respondent's profiles and the method of work implementation, quantitative analysis of the questionnaire, and the summary framework of the results were also included in this section.

6.1.1 Qualification of participants in the questionnaire

Table 6-1 Frequency and Percentage of qualification of participants

Qualification	Frequency	Percent
Bachelor	122	61%
Master	43	22%
PhD	35	18%
Total	200	100%

Figure 6-1 further illustrates the results obtained in a pie chart. From the graph shown, it can be deduced that the participants who are Bachelor have a higher percentage, followed by the Master

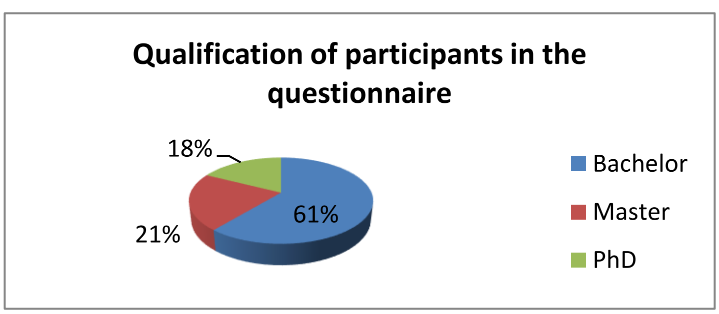


Figure 6-1 Percentage of qualification of participants

and PhD.

6.1.2 Occupation of the participants in the questionnaire

Table 6-2 Frequency and Percentage of Participants Occupation

Job	Frequency	Percent
Company manager	73	37%
Site Manager	58	29%
Site Engineer	69	35%
Total	200	100%

Figure 6-2 further illustrates the results obtained in a pie chart. From the graph shown, it can be deduced that the participants who are company managers have the higher percentage, followed by the site engineers and site managers.

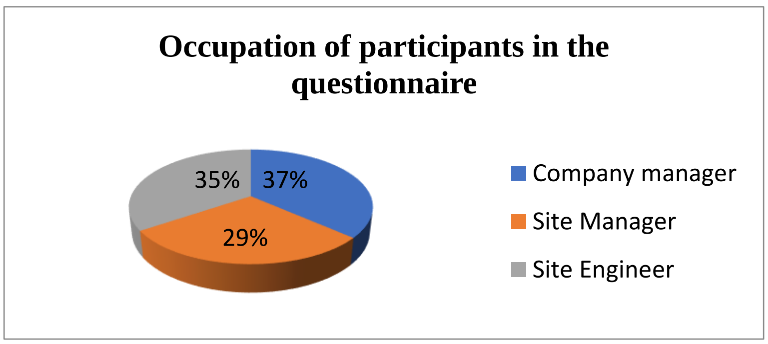


Figure 6-2 Occupation of Participants in the questionnaire

6.1.3 Experience of Participants in the Questionnaire

Table 6-3 Frequency and Percentage of experience of participants

Experience	Frequency	Percent
1-5 years	52	26%
5-10 years	67	34%
More than 10 years	81	41%
Total	200	100%

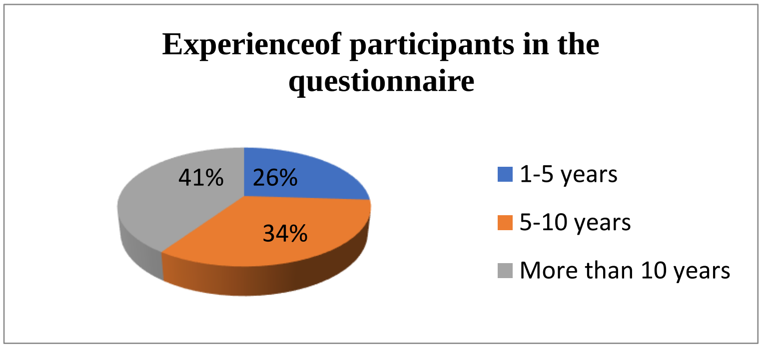


Figure 6-3 Frequency and Percentage of experience of participants

6.1.4 Organization of Participants in the questionnaire

Table 6-4 Frequency and Percentage of organization of participants

Organization	**Frequency**	**Percent**
Government	43	22%
Consultant	66	33%
Contractor	91	46%
Total	200	100%

From the graph shown, the participants who are part of contractor organization had the highest rate at 46%, where 33% were part of consultant organizations and only 21% were part of government organizations.

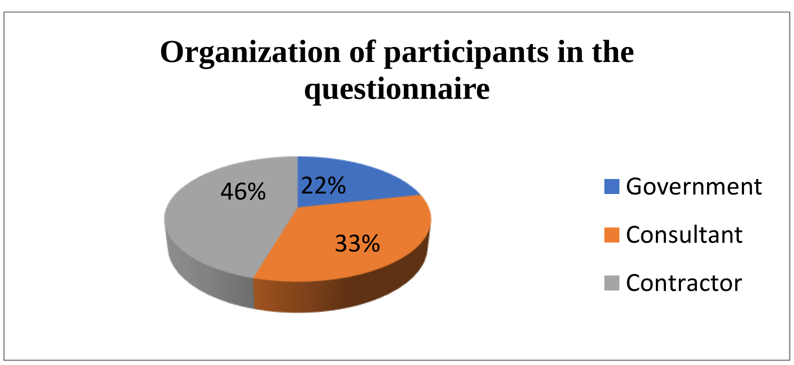


Figure 6-4 Percentage of organization of participants

6.2 Analysis of the Questionnaire Surveys

The questionnaires utilized in this study assisted in understanding the extent of BIM and TQM application in construction projects within the Kingdom of Saudi Arabia. The following sections will analyze the results acquired from each field and the items within each field as well as the conclusions attained from each field.

6.2.1 The Degree of Knowledge on BIM Technology and its Application in the Work Field in Saudi Arabia

In this section, companies and engineering sectors were questioned on the extent of BIM application in the building construction phases. The mean and frequency were analyzed as the first stage in order to categorize the companies and engineering sectors that do or do not use BIM in the construction stages. Where the companies with a mean value less than 3 will be classified as not using BIM, and companies with a mean value higher than 3 will be classified as using BIM. This classification will allow for the comparison of the extent of application of the TQM concept in these companies and sectors.

The following table, Table 6-5, shows the Frequency and mean results provided by the respondents from the questionnaires. According to these results, the number of companies and sectors that apply BIM in the construction stage are 98 and the companies that do not apply BIM are 102.

Table 6-5 Frequency and Mean Results

No.	Item	Mean less than 3	Mean more than 3
1	I have previously read some research and studies on Building Information Modeling (BIM) technology	90	110
2	During my time at university, I took some courses on Building Information Modeling (BIM) technology	98	102
3	I have a good idea about the concept of Building Information Modeling (BIM) technology	100	100
4	I have an idea on how to apply and implement Building Information Modeling (BIM) technology	104	96
5	I have previous knowledge regarding the Revit and Archi Cad program, so what is Building Information Modeling (BIM) technology	93	107
6	I think Building Information Modeling (BIM) technology is important for the design and construction industry in engineering projects	92	108

7	Building Information Modelling (BIM) technology is applied in the pre-construction phase of buildings	99	101
8	Building Information Modeling (BIM) technology is used in the construction phase of buildings	102	98
9	Use Building Information Modelling (BIM) to work overall	98	102
TOTAL		97.33333	102.6667

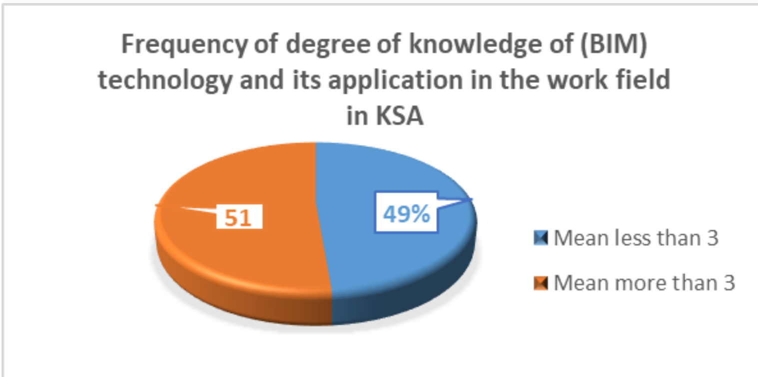


Figure 6-5 Frequency and Mean Results

The questionnaire will be analyzed in two phases. The first phase will analyze the questionnaire regarding the engineering companies and the sectors that do not apply BIM in the construction stages of the buildings. The second phase will analyze the questionnaire related to engineering companies and sectors that do apply BIM in the construction stages.

6.3 Analysis and Discussion of the Questionnaire Regarding the Engineering Companies and Sectors that Do Not Apply BIM in the Construction Stages of Buildings

6.3.1 Analysis of the Questionnaire Concerning the Degree of Knowledge on BIM Technology and its Application in the Work Field in Saudi Arabia

The first questionnaire surveyed the extent of BIM technology knowledge and its application in the work field in Saudi Arabia. The question field contained nine items, where the 9 items were taken from the literature review and adapted by modifying or integration according to the face validity results and pretesting of the questionnaire (as discussed in Chapter 5).

Table 6-6 The Means and Test Quantity Values Concerning the Degree of Knowledge on BIM Technology and its Application in the Work Field in Saudi Arabia

Q.	Item	Mean	Prop. Mean	Std. Dev.	Rel. Imp. (RII)	Test value	P value (Sig.)	Rank

1	I think that BIM technology has a positive impact on the sustainable environment.	2.300	46%	1.055	0.460	-3.633	0.000	2
2	I took some courses on BIM technology during my time at the university	2.033	41%	0.718	0.407	-7.370	0.000	8
3	I have a good idea on the concept of BIM technology	2.267	45%	0.944	0.453	-4.428	0.000	3
4	I have an idea on how to use and implement BIM technology	2.067	41%	0.868	-5.887	-4.253	0.000	7
5	I have previous knowledge of Revit and ARCHICAD BIM programs	2.100	42%	0.759	0.420	-6.496	0.000	6
6	I think BIM technology is important for design and construction of engineering projects	2.333	47%	0.959	0.467	-7.370	0.000	1
7	Use of BIM technology at current workplace	2.000	40%	0.788	0.400	-6.952	0.000	9
8	Use of BIM technology at current workplace	2.167	43%	0.791	0.433	-5.767	0.000	5
9	Use of BIM technology at current workplace	2.266	45%	0.907	0.453	-4.428	0.000	4
All items		**2.170**	**43%**	**0.866**	**-0.266**	**-5.633**	**0.000**	

The results indicated that the item “I think BIM technology is important for design and construction of engineering projects” (Q6) with (RII =47 %; Mean=2.33and P-value =0.000) obtained the highest rank according to the overall respondents. This result is consistent with the result of the researchers who found that BIM has recently acquired widespread recognition in the construction of engineering projects (Azhar et al., 2008a).

The item “I took some courses on BIM technology during my time at the university” (Q2) was ranked as the eighth position with (RII = 41%, Mean=2.03 and P-value = 0.000). Judgements have shown that the study location influences the extent of BIM knowledge. According to the outcomes, a huge percentage of the overall respondents who studied in KSA, at 80%, had never taken courses on BIM in their universities. The lowest percentage was for the respondents who have studied outside of Saudi Arabia, in which 75% of the overall respondents had never taken courses on BIM in their universities. According to these outcomes, the absence of interest on BIM education through courses in universities is evident. Therefore, the lack of BIM awareness is a logical and anticipated result.

6.3.2 Conclusions for The Field 'Degree of Knowledge of BIM Technology and Its Application in The Work Field in Saudi Arabia'

The general outcomes for the field "Degree of Knowledge of Building Information Modeling (BIM) technology and its application in the work field in Saudi Arabia" show that the Mean value for all items is found to be 2.17. The total RII value is calculated at 43.4%, and to analyze the result, it was crucial to compute the neutral value of RII and compare the total RII value with the neutral value of RII. Accordingly, the average value of the five-point Likert scale used to rate the items was found to be (3). Hence, the neutral value of RII is (3/5) *100=60%, where the number 5 refers to the rating scale that was applied and the number 3 represents the average value of that rating scale, as mentioned previously. The results proved that the p-values were less than 0.05, which signifies that the corresponding coefficients of the subjects for this field were found to be significant at $\alpha = 0.05$.

According to the results acquired, the awareness level of BIM by professionals in the construction industry in KSA is very low. These results also concur with the outcomes obtained by Keegan (2010) through information gathered from the interviews and meetings that were conducted in the United Kingdom (UK). Keegan confirmed that the general knowledge of BIM and its advantages were little and that only 42% of the respondents were familiar with it. Thurairajah and Goucher (2013) also stated that there is a general lack of knowledge and understanding of what BIM is in the UK, regardless, some locations have adopted BIM in their works.

Newton and Chileshe (2012) conducted a field study in the South Australian construction industry about the recognition and application of BIM. The outcomes revealed that most of the respondents have slight or no comprehension of the concept of BIM and the application was very low. Similar results were shown in a study by Mitchell and Lambert (2013). They deduced that individuals in Australia suffer from insufficient knowledge of BIM and its distinct capacities within the construction industry field. Along with the existence of various research and reports that support this result, where Gu et al. (2008) and NBS (2012) claimed that BIM is completely misunderstood across the management team. Furthermore, only 54% of Architectural practices are aware of BIM (NBS, 2013). Many studies (such as Arayici et al. (2009); Kassem et al. (2012); Khosrowshahi and Arayici (2012); Löf and Kojadinovic (2012); Elmualim and Gilder (2013); and Aibinu and Venkatesh (2014)), have generally deduced that there is a lack of BIM awareness and its advantages in the field of construction industry as well as the business value of BIM from a financial perception.

However, there was an exception in research performed in Ireland by Crowley (2013), in which the study was directly related to the recognition and application of BIM by the Quantity Surveyors (QS) profession. The results gathered from the questionnaire survey revealed that 73% of the sample (105 responses) were only aware of BIM without applying the concept; 24% were aware of BIM and applying the concept to perform their jobs; and finally, only 3% who were not aware of BIM.

6.3.3 The Degree of Total Quality Management (TQM) Application in Engineering Projects in Saudi Arabia

The statistical results gathered from the questionnaire responses suggested that there is a Degree of Total Quality Management (TQM) Application in Engineering Projects in the Kingdom of Saudi Arabia. For further analysis of the gathered information, the RII and Mean are utilized to rank the statements applied (Q1- Q23), in order to evaluate the awareness level of TQM application in engineering projects in the Kingdom of Saudi Arabia by the experts based on the scores provided by the respondents. The following table, Table 6-7, depicts the statements and statistical figures for the questionnaire concerning TQM application in Saudi Arabia.

Table 6-7 The Values of the Means and Test Quantity Related to 'The Degree of Total Quality Management (TQM) Application in Engineering Projects in Saudi Arabia'

No.	Item	**Mean**	**Prop. Mean**	**Std. Dev.**	**Rel. Imp. (RII)**	**Test value**	**P value (Sig.)**	**Rank**
1	The department undertakes statistical observation to control TQM	2.333	47%	0.959	0.467	-3.808	0.001	7
2	The concept of TQM in the company includes focusing on customer satisfaction	2.533	51%	1.106	0.507	-2.311	0.028	3
3	The company's quality concept involves specifically dividing quality responsibilities	2.267	45%	0.944	0.453	-4.253	0.000	10
4	The concept of TQM in the company utilizes quality methods in everything	2.133	43%	1.008	0.427	-4.709	0.000	19
5	The administration informs its employees on the relationship between product quality and costs.	2.100	42%	0.759	0.420	-6.496	0.000	21
6	The administration is constantly improving the activities of the comprehensive quality management system	2.300	46%	1.055	0.460	-3.633	0.001	9
7	The administration takes the necessary measures to remove causes that hinder TQM application	2.167	43%	0.791	0.433	-5.767	0.000	14
8	Corrective measures include procedure to prevent recurrence of TQM implementation	2.267	45%	0.907	0.453	-4.428	0.000	11

9	The administration applies practical approaches to achieve effective control and efficiency of operations	2.667	53%	1.124	0.533	-1.624	0.115	1
10	The company applies practical methods to enhance TQM performance	2.633	53%	0.928	0.527	-2.164	0.039	2
11	The company has access to the necessary competencies (administrative, scientific and technical) to implement the concepts of TQM	2.333	47%	0.922	0.467	-3.959	0.000	8
12	Presence of a committee keen to observe the application of TQM concepts	2.433	49%	1.223	0.487	-2.538	0.017	5
13	Courses for scientific and technical cadres on TQM application are available	2.133	43%	0.860	0.427	-5.517	0.000	20
14	TQM concepts are explained to workers and engineers	2.167	43%	1.020	0.433	-4.475	0.000	15
15	TQM effects time when applied	2.167	43%	1.020	0.433	-4.475	0.000	17
16	TQM impacts cost when applied	2.467	49%	1.137	0.493	-2.570	0.016	4
17	There is an impact on the scope of the project when TQM is applied	2.200	44%	1.064	0.440	-4.120	0.000	12
18	Satisfaction of the project owners/customer is related to the implementation or design of the project under the principles and standards of TQM	2.167	43%	1.020	0.433	-4.475	0.000	16
19	The company defines customer requirements including delivery requirements and post-delivery services	2.367	47%	1.299	0.473	-2.670	0.012	6
20	The company specific requirements for obligations related to implementation, design, regulatory and legal requirements	2.200	44%	0.925	0.440	-4.738	0.000	13
21	The company reviews each order request to ensure availability of its implementation requirements	2.067	41%	0.868	0.413	-5.887	0.000	22
22	The new requirements are presented by the customer to the relevant departments and divisions for their opinions before	2.167	43%	0.913	0.433	-5.000	0.000	18

	implementation							
23	The results of the reviewed applications, procedures and the following procedures are recorded in a register approved for the specified purpose.	2.000	40%	0.830	0.400	-6.595	0.000	23
	All items	**2.270**	**45%**	**0.987**	**0.454**	**-4.200**	**0.010**	

The results showed that the item "The administration applies practical approaches to achieve effective control and efficiency of operations" (Q9) obtained the following values (RII = 53%; average = 2.667 and P-value = 0.115) and ranked as the highest item according to the overall judgements. The result is consistent with the results of researchers who found that engineering departments began applying scientific methods to achieve oversight and effectiveness in building engineering projects (Azhar et al., 2008a).

The item "The Company applies practical methods to enhance TQM performance" (Q10) acquired the following figures (RII = 53%; average = 2.633 and P-value = 0.039) and achieved the second highest ranking. This result supports the first outcome. Seeing that the respondents have a sense of importance in applying practical approaches to enhance TQM performance in the construction industry (Kolpakov, 2012).

The item "The Company reviews each order request to ensure availability of its implementation requirements" (Q21) was ranked in the 22nd position with the following values (RII=41%, Mean=2.067 and P-value= 0.000). The results reveal that companies are weak in processing orders to ascertain requirements that must be met before the implementation starts.

Last but not least, the item "The results of the reviewed applications, procedures and the following procedures are recorded in a register approved for the specified purpose" (Q23) ranked in the 23rd position as the lowest statement within the field of Total Quality Management (TQM) Application in Engineering Projects in Saudi Arabia. The item obtained the following values (RII= 40%, Mean= 2.00, P-value= 0.000). According to the respondent's judgements, there is a lack of recording for the results and requests that can help companies avoid earlier mistakes.

6.3.4 Conclusions for the Field Regarding the Degree of TQM Application in Engineering Projects in Saudi Arabia

The overall results for the field of "Degree of Total Quality Management (TQM) application in engineering projects in the Kingdom of Saudi Arabia" revealed that the Mean values for the overall statements was calculated at 2.27 and the total RII value equals 45%. In order to analyze this outcome, it was vital to compute the neutral value of RII and compare the total RII value with the neutral value of RII.

The results gathered from the questionnaire analysis revealed that the majority of the respondents lack sufficient knowledge on achieving the essential administrative, scientific and technical capabilities to apply the concepts of TQM within construction projects. Moreover, the research advises that there is no sufficient committee to manipulate TQM within companies. The overall results obtained prove that there is a lack of capabilities within the administrative, scientific, technical, and professional teams.

6.3.5 Awareness and Benefits of Building Information Modeling (BIM) in the Building Industry in the Kingdom of Saudi Arabia

The following field was composed of eleven items regarding the benefits of BIM. The list of eleven items were taken from literature reviews and adapted through modification or merging based on the results of the face validity and pre-testing the questionnaire (as shown in Chapter 5). The items were subjected and analyzed according to the views of respondents. The descriptive statistics, which are the Mean, Standard Deviations (SD), t-value (two-tailed), probabilities (P-value), Relative Importance Indices (RII), and Ranks, were established and provided in the following table, Table 6-8.

Table 6-8 Descriptive Statistics for the Field 'Awareness and Benefits of Building Information Modeling (BIM) in the Building Industry in the Kingdom of Saudi Arabia'

No.	**Item**	**Mean**	**Prop. Mean**	**Std. Dev.**	**Rel. Imp. (RII)**	**Test value**	**P value (Sig.)**	**Rank**
1	Awareness and benefits of BIM in the construction industry in Saudi Arabia	3.100	62%	0.885	0.620	0.619	0.541	3
2	There is an increasing demand for the use of BIM in Saudi Arabia	3.067	61%	0.907	0.613	0.403	0.690	7
3	BIM helps shorten the project schedule	2.967	59%	0.890	0.593	-0.205	0.839	11
4	Using BIM reduces the total cost of a project	3.033	61%	0.809	0.607	0.226	0.823	10
5	Using BIM reduces project conflicts	3.110	62%	0.759	0.622	0.722	0.476	5
6	BIM makes information accessible to all project members	3.066	61%	0.740	0.613	0.494	0.625	8
7	Using BIM helps improve project designs	3.133	63%	0.819	0.627	0.891	0.380	2
8	Using BIM makes communication between team members easier	3.167	63%	0.747	0.633	1.223	0.231	1
9	Using BIM facilitates the sequencing and scheduling of project activities	3.070	61%	0.740	0.614	0.494	0.625	6
10	Project life-cycle evaluations can be performed using modeling	3.040	61%	0.669	0.608	0.273	0.787	9
11	By using BIM visualization of real project duration is possible	3.067	61%	0.740	0.613	0.494	0.625	4
All items		**3.074**	**61%**	**0.791**	**0.615**	**0.512**	**0.604**	

The findings revealed that the item, "Using BIM makes communication between team members easier" (Q8), is the most valuable BIM advantage, in which it may convince professionals to adopt BIM within the construction sector in KSA. Based on the overall respondents' judgements, the item ranked in first position with the following statistical values; (RII = 63%, Mean=3.167 and P-value =0.231). The outcome is consistent with the discussions made by Eastman et al. (2008, 2011), in which they claimed that BIM is an enabling platform that presents opportunities to facilitate collaboration and information sharing throughout the design and construction of a project. An example of such is the changes that occur to the architectural model will generate modifications to the structural model and vice versa.

The items that were ranked as the lowest valuable BIM advantage are "BIM helps shorten the project schedule & Using BIM reduces the total cost of a project" (Q3 & Q4). According to the judgements of the respondents, the two items acquired the following statistical values (RII=61%; Mean = 3.033; and P-value =0.823). In contrast to the results gathered from the analysis, McGraw-Hill Construction (2009); Eastman et al. (2011); Barlish and Sullivan (2012); and Barlish and Sullivan (2012

6.3.6 Conclusions for the Field Regarding the Awareness and Benefits of Building Information Modeling (BIM) in the Building Industry in the Kingdom of Saudi Arabia

From the respondent's judgements, the top three advantages of BIM were found to be logical and acceptable as the most valuable advantages of BIM. These results will assist in encouraging professionals and specialists to adapt the concept of BIM within the construction industry in Saudi Arabia. The results for all the item regarding the field of BIM benefits revealed that the Mean for all the items is 3.081, the total RII is 62%, which is greater than 60% (the neutral value of RII (3/5) *100 = 60%), and the total P-value is 0.604, which is more than the significance level of 0.05. Based on the results attained, BIM benefits are considered significantly valuable for the professionals in the construction industry in Saudi Arabia.

6.3.7 Obstacles and Restrictions to Adapting Building Information Modeling (BIM) in the Building Industry in the Kingdom of Saudi Arabia

The following field consisted of 12 items regarding the barriers of BIM. the list of twelve item were taken from previous studies where they were adapted and modified or merged according to the face validity results and pre-testing of the questionnaire, as shown in Chapter 5. The items were analyzed and ranked according to the respondents' opinions. The following table, Table 6-9, presents the computed Descriptive Statistics, i.e., Means, Standard Deviations (SD), t-value (two-tailed), probabilities (P-value), Relative Importance Indices (RII).

Table 6-9 Descriptive Statistics for the Field 'Obstacles and Restrictions to Adapting Building Information Modeling (BIM) in the Building Industry in the Kingdom of Saudi Arabia'

No.	Item	Mean	Prop.	Std.	Rel.	Test	P	Rank

			Mean	Dev.	Imp. (RII)	value	value (Sig.)	
1	The customer does not require the use of BIM to develop architectural/structural designs and analysis processes	3.467	69%	1.106	0.693	-0.413	0.683	9
2	Lack of the awareness of BIM by stakeholders	3.610	72%	1.072	0.722	0.264	0.821	1
3	Lack of knowledge of how to apply BIM software	3.600	72%	1.070	0.720	0.256	0.800	2
4	The unwillingness of Architects/ Engineers to learn new applications because of their educational culture and their bias toward the programs they are dealing with	3.400	68%	1.037	0.680	-0.792	0.435	12
5	There is no legal basis for who owns the form and how the form will be exchanged between team members	3.560	71%	0.855	0.712	0.320	0.751	6
6	Team members such as architects and engineers do not require the use of BIM to develop a project design	3.533	71%	0.973	0.707	-0.094	0.926	7
7	The price of the software is very high that only the major companies can obtain it	3.420	68%	1.037	0.684	-0.800	0.535	11
8	It takes time to learn all the tools in BIM programs and it is difficult to understand the function of the various menus on the programs	3.433	69%	0.935	0.687	-0.683	0.500	10
9	A library or code that enhances and facilitates development in the form using local standard building codes is not available in the Kingdom of Saudi Arabia	3.567	71%	0.774	0.713	0.118	0.907	5
10	It takes more time to develop a BIM that the traditional method	3.500	70%	1.075	0.700	-0.255	0.801	8
11	There is lack of qualified personnel to run BIM software	3.572	71%	1.070	0.714	0.256	0.921	3
12	BIM does not add much value to the organization that I am part of	3.567	71%	1.040	0.713	0.088	0.931	4
All items		**3.519**	**70%**	**1.004**	**0.704**	**-0.145**	**0.751**	

The results discovered the item “Lack of the awareness of BIM by stakeholders” (Q2) as the strongest barrier preventing the adaption of BIM technology within the construction industry in Saudi Arabia. From the respondents’ judgements, it ranked in first position with the following values (RII = 71%, Mean=3.610 and P-value = 0.821), which implies that a large majority of the respondents have little or no knowledge of the concept of BIM. The results are consistent with the discoveries found by Kassem et al. (2012), in which they claim that the lack of Bim recognition was acknowledged by professionals in the construction industry as the primary barrier to BIM and 4D adaption within the UK. Additionally, the results are consistent with the research conducted by Thurairajah and Goucher (2013), whom in their research revealed that while cost consultants in the UK are aware of BIM, there is an overall lack of knowledge and understanding on what BIM actually is. According to the research conducted by Löf and Kojadinovic (2012) in Sweden, the reason behind the lack of BIM knowledge is the scarcity of guidelines on the application and alignment of BIM in the production phases of construction projects. The insufficiency of knowledge and comprehension regarding BIM has resulted in a slow uptake of the technology and ineffective adoption management (Mitchell and Lambert, 2013; NBS, 2013).

Ultimately, the item “The unwillingness of Architects/ Engineers to learn new applications because of their educational culture and their bias toward the programs they are dealing with” (Q 4) was ranked as the lowest barrier. It ranked in the 12th position with the following values (RII = 69 %; Mean=3.4 and P-value = 0.435) as per insights of all the respondents. This opinion can be interpreted in more than one way, such as they do not know the actual amount of the cost needed to adopt BIM. Most respondents who work in consulting offices also claimed that the initial costs that must be spent in beginning would not financially affect the organization, as long as there are substantial benefits to be gained from adopting BIM in the end. Therefore, expenses are not seen as a barrier for BIM adoption. In contrast to this result, when the respondents of QS in Australia were requested to list the barriers regarding the application of BIM features, the results revealed that the implementation cost was the most frequently cited barrier by the respondents (Aibinu and Venkatesh, 2013). There are numerous examples of the high expenses required for BIM implementation, in which some of them are:

1. Software licensing
2. The expenses needed to enhance the server capacity to support the high IT requirements
3. The continuous maintenance fees
4. The cost of proper creation of a building model
5. The costs of training team members (Keegan, 2010; Aibinu and Venkatesh, 2013; and (Lee et al., 2007; Lee et al., 2009; Choi, 2010; Smart Market Report, 2012) (cited in Lee et al., 2014).

6.3.8 Major Strategies for Building Information Modeling (BIM) in the Kingdom of Saudi Arabia

The following field was composed of eight items focusing on the major strategies for BIM. The items were derived from previous studies and were adopted, modified and merged according to the results of the face validity and the pretesting of the questionnaire as shown in Chapter 5. These items were subjected and analyzed according to the opinions of the respondents. The Descriptive Statistics (Means, Standard Deviations (SD), t-value (two-tailed), probabilities (P-value), Relative Importance Indices (RII), and ranks) were established and presented in Table (6-10).

Table 6-10 Descriptive Statistics for the Field ‘Major Strategies for Building Information Modeling (BIM) in the Kingdom of Saudi Arabia’

No.	Item	Mean	Prop. Mean	Std. Dev.	Rel. Imp. (RII)	Test value	P value (Sig.)	Rank
1	BIM service providers should begin to clarify and demonstrate the importance of BIM	3.467	69%	1.042	0.693	-0.438	0.665	8
2	Develop the necessary legislation to implement BIM	3.630	73%	0.894	0.726	0.306	0.762	1
3	Urgent need to train cadres in BIM	3.500	70%	0.974	0.700	-0.281	0.781	7
4	BIM should be part of the courses studied in Saudi universities	3.566	71%	1.104	0.713	0.083	0.935	6
5	More effort is required to make BIM workable	3.533	71%	1.137	0.707	-0.080	0.937	4
6	The adoption of BIM will give Saudi construction organizations more value	3.610	72%	0.855	0.722	0.320	0.751	3
7	Does the Saudi government provide moral support to encourage BIM adoption by government/non-government institutions	3.567	71%	1.006	0.713	0.091	0.928	5
8	Does a law need to be enforced to compel government/non-government institutions to use BIM?	3.620	72%	1.102	0.724	0.249	0.805	2
All items		**3.562**	**71%**	**1.014**	**0.712**	**0.031**	**0.821**	

The finding showed that the item “Develop the necessary legislation to implement BIM” (Q2) is the strongest strategy required to adopt BIM in the construction industry in the Kingdom of Saudi Arabia. It was ranked first with (RII = 73%, average = 3.630 and P-value = 0.306) according to the respondents’ overall judgements. This result indicates that a large percentage of the respondents believe that developing the necessary legislation will significantly contribute to urging companies and engineers to implement BIM in the construction stages.

The item “BIM service providers should begin to clarify and demonstrate the importance of BIM” (Q1) was ranked as the lowest strategy for BIM validation. Based on the respondent’s judgements the following values were obtained (RII = 69%; mean = 3.467 and P-value = 0.655). Some of the respondents who work in consulting firms claimed that the BIM service providers do not properly clarify the benefits and influence of BIM implementation within engineering projects.

6.3.9 Conclusions for the Field Regarding the Major Strategies for Building Information Modeling (BIM) in the Kingdom of Saudi Arabia

The major strategies that prevent the validation of BIM, which were analyzed by the respondents, are logical and acceptable. The results reveal the items selected as the strongest strategies that assist BIM validation in the construction industry in Saudi Arabia. The overall outcomes for the field 'The Major Strategies for Building Information Modeling (BIM) in the Kingdom of Saudi Arabia' were calculated as follows; the mean at 3.562, the total RII at 71%, which is greater than 60% (neutral value of RII (3/5) * 100 = 60%, and the P-value at 0.821, which is larger than the significance value of 0.05. According to the previous results, the proposed strategies would greatly assist in the adoption of BIM within the construction industry on the Kingdom of Saudi Arabia.

6.4 Analysis and Discussion of the Questionnaire Regarding the Engineering Companies and Sectors that Do Apply BIM in the Construction Stages of Buildings

6.4.1 Degree of Knowledge of Building Information Modeling (BIM) Technology and Its Application in the Work Field in Saudi Arabia

The following field is comprised of nine items focusing on the degree of BIM knowledge and its application in the work field in Saudi Arabia. The items were taken from literature reviews and adapted, modified or merged based on the results obtained from the face validity and pre-testing of the questionnaires (see Chapter 5). The items were judged and analyzed by the respondent's personal insights. The following table, Table 6-11, depicts the descriptive statistical figures (Means, Standard Deviations (SD), t-value (two-tailed), probabilities (P-value), Relative Importance Indices (RII), and ranks) for the field.

Table 6-11 Descriptive Statistics for the Field 'Degree of Knowledge of Building Information Modeling (BIM) Technology and Its Application in the Work Field in Saudi Arabia'

No.	Item	Mean	Prop. Mean	Std. Dev.	Rel. Imp. (RII)	Test value	P value (Sig.)	Rank
1	I have read studies and research on BIM technology	3.633	73%	1.066	0.727	0.685	0.499	6
2	I took some courses on BIM technology during my time at the university	3.633	73%	1.033	0.727	0.707	0.485	6
3	I have a good idea on the concept of BIM technology	3.467	69%	0.973	0.693	-0.188	0.852	9
4	I have an idea on how to use and implement BIM technology	3.600	72%	0.968	0.720	0.566	0.576	8
5	I have previous knowledge of Revit and ARCHICAD BIM programs	3.667	73%	0.994	0.733	0.918	0.366	5
6	I think BIM technology is important for design and construction of engineering	3.600	72%	0.814	0.720	0.673	0.506	4

	projects							
7	Use of BIM technology at current workplace	3.767	75%	1.073	0.753	1.362	0.184	2
8	Use of BIM technology at current workplace	3.800	76%	0.887	0.760	1.853	0.074	1
9	Use of BIM technology at current workplace	3.767	75%	0.971	0.753	1.504	0.144	2
All items		**3.659**	**73%**	**0.976**	**0.732**	**0.898**	**0.410**	

The statistical values attained from the questionnaire responses provided an implication of the awareness level of BIM by the professionals in the construction industry in Saudi Arabia. For further analysis of the data collected, the RII and Mean approaches are utilized to rank the items (Q1 to Q9) in order to evaluate the awareness level of BIM by the professionals based on the scores provided by the respondents. Table 6-11 provides the RIIs, mean and ranks of the items, respectively.

The results show that the item “Use of BIM technology at current workplace” (Q8), obtained the highest rank with the following values (RII =75 %; Mean=3.800 and P-value =0.074). The computed vales correspond with the results of researchers who found that BIM has recently gained wide recognition throughout the construction of engineering projects (Azhar et al., 2008a).

The item “I have a good idea on the concept of BIM technology” (Q3) was ranked ninth, as the lowest statement in the field. The statistical values were found to be (RII = 69%, average = 3.467 value P = 0.852). According to the respondents, companies that apply BIM in their business have a serious understanding on the concept and advantages of implementing BIM technology.

6.4.2 Conclusions for the Field Regarding the Degree of Knowledge of Building Information Modeling Technology (BIM) and its Application in the Work Field in Saudi Arabia

The overall results gathered for the following field revealed that the Mean for all the data in the field was computed at 3.659. The total RII value was found to be 73%, which is higher than 60%, where the neutral value of RII is (3/5) * 100 = 60%. Finally, the P-value for all the elements was found at 0.410, which is greater than the 0.05 significance level. According to all the previous outcomes, it can be stated that the respondents of this field in the questionnaire do indeed apply BIM technology in the construction stages within their companies.

6.4.3 Degree of Total Quality Management (TQM) Application in Engineering Projects in the Kingdom of Saudi Arabia

The numerical figures obtained from the questionnaire responses revealed a trace of Total Quality Management (TQM) application in engineering projects in the Kingdom of Saudi Arabia. To further assess the collected data, the RII and Mean approaches are used to rank the statements (Q1 to Q23) employed, which will assist in evaluating the awareness level of Total Quality Management (TQM) application in engineering projects in the Kingdom of Saudi Arabia by the professionals based on the judgements provided by the respondents.

Table 6-12 Descriptive Statistics for the Field 'Degree of Total Quality Management (TQM) Application in Engineering Projects in the Kingdom of Saudi Arabia'

No.	Item	Mean	Prop. Mean	Std. Dev.	Rel. Imp. (RII)	Test value	P value (Sig.)	Rank
1	The department undertakes statistical observation to control TQM	3.634	73%	1.066	0.727	0.428	0.672	16
2	The concept of TQM in the company includes focusing on customer satisfaction	3.867	77%	0.860	0.773	2.016	0.053	1
3	The company's quality concept involves specifically dividing quality responsibilities	3.467	69%	0.973	0.693	-0.469	0.643	23
4	The concept of TQM in the company utilizes quality methods in everything	3.800	76%	1.064	0.760	1.288	0.208	6
5	The administration informs its employees on the relationship between product quality and costs.	3.850	77%	1.064	0.770	1.288	0.208	2
6	The administration is constantly improving the activities of the comprehensive quality management system	3.830	77%	0.925	0.766	1.481	0.149	3
7	The administration takes the necessary measures to remove causes that hinder TQM application	3.766	75%	1.073	0.753	1.106	0.278	10
8	Corrective measures include procedure to prevent recurrence of TQM implementation	3.700	74%	0.988	0.740	0.832	0.412	12
9	The administration applies practical approaches to achieve effective control and efficiency of operations	3.777	76%	0.971	0.755	1.222	0.232	7
10	The company applies practical methods to enhance TQM performance	3.610	72%	0.855	0.722	0.320	0.751	19
11	The company has access to the necessary competencies (administrative, scientific and technical) to implement the concepts of TQM	3.630	73%	0.894	0.726	0.306	0.762	18
12	Presence of a committee keen to observe the application of TQM concepts	3.810	76%	0.805	0.762	1.701	0.100	5
13	Courses for scientific and technical cadres on TQM application are available	3.767	75%	0.858	0.753	1.383	0.177	9

14	TQM concepts are explained to workers and engineers	3.666	73%	0.498	0.733	0.550	0.587	14
15	TQM effects time when applied	3.820	76%	0.925	0.764	1.481	0.149	4
16	TQM impacts cost when applied	3.600	72%	0.932	0.720	0.294	0.771	21
17	There is an impact on the scope of the project when TQM is applied	3.733	75%	0.691	0.747	1.452	0.157	11
18	Satisfaction of the project owners/customer is related to the implementation or design of the project under the principles and standards of TQM	3.636	73%	1.033	0.727	0.442	0.662	15
19	The company defines customer requirements including delivery requirements and post-delivery services	3.769	75%	0.728	0.754	1.630	0.114	8
20	The company specific requirements for obligations related to implementation, design, regulatory and legal requirements	3.533	71%	0.860	0.707	-0.106	0.916	22
21	The company reviews each order request to ensure availability of its implementation requirements	3.633	73%	0.890	0.727	0.513	0.612	17
22	The new requirements are presented by the customer to the relevant departments and divisions for their opinions before implementation	3.667	73%	0.994	0.733	0.643	0.525	13
23	The results of the reviewed applications, procedures and the following procedures are recorded in a register approved for the specified purpose.	3.600	72%	0.894	0.720	0.306	0.762	20
All items		**3.706**	**74%**	**0.899**	**0.741**	**0.895**	**0.419**	

The findings indicated that the item “The concept of TQM in the company includes focusing on customer satisfaction” (Q2), with the following values with (RII = 77%; average = 3.867 and P-value = 0.053), obtained the highest rank based on the respondents’ judgements. This result proves that BIM application assists in focusing on customer satisfaction, which is the most important objective of TQM application.

The item that obtained the lowest rank in the entire field is “The Company’s quality concept involves specifically dividing quality responsibilities” (Q3), with the following values (RII = 69%, average = 3.467 value of P = 0.643). According to the respondent’s judgements, it shows that the companies specifically divide quality responsibilities among their employees, who assist in implementing TQM in the best way possible.

6.4.4 Conclusions for the Field Regarding the Degree of Total Quality Management (TQM) Application in Engineering Projects in the Kingdom of Saudi Arabia

The overall results for the field regarding the extent of TQM application in the work field revealed that the Mean value was found at 3.706. The total RII values was calculated at 74%, which is larger than 60%, where the (neutral value of RII (3/5) * 100 = 60%). Furthermore, the P-value for all the items in the field was found to be 0.419, which is greater than the 0.05 significance level. Based on the results obtained, it is safe to say that the companies affiliated with the respondents in this section of the questionnaire properly apply the concept of TQM. In which the good implementation of the concepts of TQM in construction projects reflects the follow-up of the companies' commitment to developing programs and increasing the scientific and technical competencies that significantly contribute to increasing Total Quality Management.

6.4.5 Awareness and Benefits of Building Information Modeling (BIM) in the Building Industry in the Kingdom of Saudi Arabia

The field contained eleven items regarding the benefits of BIM, where the list of items was established from previous studies and adapted by modifying and merging based on the results of the face validity and pretesting of the questionnaire. The items were presented to the respondents to analyze and rate them based on their insights.

Table 6-13 Descriptive Statistics for the Field 'Awareness and Benefits of Building Information Modeling (BIM) in the Building Industry in the Kingdom of Saudi Arabia'

No.	**Item**	**Mean**	**Prop. Mean**	**Std. Dev.**	**Rel. Imp. (RII)**	**Test value**	**P value (Sig.)**	**Rank**
1	Awareness and benefits of BIM in the construction industry in Saudi Arabia	3.600	72%	1.037	0.720	0.264	0.794	10
2	There is an increasing demand for the use of BIM in Saudi Arabia	3.733	75%	0.868	0.747	1.156	0.257	5
3	BIM helps shorten the project schedule	3.733	75%	1.015	0.747	0.989	0.331	5
4	Using BIM reduces the total cost of a project	3.867	77%	1.106	0.773	1.568	0.128	1
5	Using BIM reduces project conflicts	3.633	73%	1.033	0.727	0.442	0.662	9
6	BIM makes information accessible to all project members	3.580	72%	0.855	0.716	0.320	0.751	11
7	Using BIM helps improve project designs	3.867	77%	1.008	0.773	1.721	0.096	1
8	Using BIM makes communication between team members easier	3.767	75%	1.073	0.753	1.106	0.278	4

9	Using BIM facilitates the sequencing and scheduling of project activities	3.667	73%	0.994	0.733	0.643	0.525	8
10	Project life-cycle evaluations can be performed using modeling	3.733	75%	0.944	0.747	1.063	0.296	5
11	By using BIM visualization of real project duration is possible	3.800	76%	0.925	0.760	1.481	0.149	3
All items		**3.725**	**75%**	**0.987**	**0.745**	**0.978**	**0.388**	**5.636**

The findings showed that the items “Using BIM reduces the total cost of a project” (Q4) and “Using BIM helps improve project designs” (Q7) are the most valuable benefits of BIM that assist in persuading professionals to adopt BIM in the construction industry in KSA. They ranked first with the following values (RII = 77%, Mean = 3.867 and P-value less than 0.05). Implementing BIM in the construction phases assist companies in reducing costs and raise design efficiency, which supports those statements made by McGraw-Hill Construction (2009)); Eastman et al. (2011); Barlish and Sullivan (2012)..

The item that ranked the lowest in the field was “BIM makes information accessible to all project members” (Q6) with the following values (RII=72%; Mean = 3.580; and P-value = 0.751). According to the respondent’s judgements, BIM allows the information related to building design and project details accessible to all engineers, designers and implementers in the project, which helps to enhance productivity.

6.4.6 Obstacles and Restriction to Adapting Building Information Modeling (BIM) in the Building Industry in the Kingdom of Saudi Arabia

The following field is comprised of 12 items regarding the BIM barriers restricting BIM implementation in the construction industry. The items were taken from the literature review and adapted by modifying and merging according to the results of the face validity and the pretesting of the questionnaire as shown in Chapter 3. The items were subjected to the insights of the respondents and evaluated. The descriptive statistics (Means, Standard Deviations (SD), t-value (two-tailed), probabilities (P-value), Relative Importance Indices (RII), and ranks) are shown in Table 6-14.

Table 6-14 Descriptive Statistics for the Field ‘Obstacles and Restriction to Adapting Building Information Modeling (BIM) in the Building Industry in the Kingdom of Saudi Arabia’

No.	Item	Mean	Prop. Mean	Std. Dev.	Rel. Imp. (RII)	Test value	P value (Sig.)	Rank
1	The customer does not require the use of BIM to develop architectural/structural designs and analysis processes	3.000	60%	0.830	0.600	0.000	1.000	11

2	Lack of the awareness of BIM by stakeholders	3.067	61%	0.828	0.613	0.441	0.662	8
3	Lack of knowledge of how to apply BIM software	3.167	63%	0.699	0.633	1.306	0.202	3
4	The unwillingness of Architects/ Engineers to learn new applications because of their educational culture and their bias toward the programs they are dealing with	2.933	59%	0.740	0.587	-0.494	0.625	12
5	There is no legal basis for who owns the form and how the form will be exchanged between team members	3.167	63%	0.834	0.633	1.095	0.283	3
6	Team members such as architects and engineers do not require the use of BIM to develop a project design	3.067	61%	0.828	0.613	0.441	0.662	8
7	The price of the software is very high that only the major companies can obtain it	3.400	68%	1.037	0.680	-0.792	0.435	1
8	It takes time to learn all the tools in BIM programs and it is difficult to understand the function of the various menus on the programs	3.067	61%	0.740	0.613	0.494	0.625	8
9	A library or code that enhances and facilitates development in the form using local standard building codes is not available in the Kingdom of Saudi Arabia	3.167	63%	0.699	0.633	1.306	0.202	3
10	It takes more time to develop a BIM that the traditional method	3.200	64%	0.664	0.640	1.649	0.110	2
11	There is lack of qualified personnel to run BIM software	3.100	62%	0.759	0.620	0.722	0.476	6
12	BIM does not add much value to the organization that I am part of	3.100	62%	0.759	0.620	0.722	0.476	6
All items		**3.119**	**62%**	**0.785**	**0.624**	**0.574**	**0.480**	

The results revealed that the item "It takes more time to develop a BIM that the traditional method" (Q10) is the strongest obstacle preventing BIM adoption in the construction industry in KSA. It was ranked first with the following values (RII = 64%, Mean = 3.200 and (P-value = 0.110) based on the overall judgements of the respondents. This outcome implies that the majority of the respondents are taking a long time to develop or implement BIM. The results correspond with the nature of many details that must be incorporated during the project implementation with BIM technology.

The item that ranked the lowest was "The unwillingness of Architects/ Engineers to learn new applications because of their educational culture and their bias toward the programs they are dealing with" (Q4). The item ranked in 12th position with the statistical values (RII = 63 %; Mean=2.933 and P-value = 1.095) as per insights of all the respondents. This judgement may be interpreted in more than one manner, for example, they do not know the actual amount of expenses needed to adopt BIM. Some of the respondents who work in consulting offices claimed that the initial costs that must be spent in the beginning would not financially affect the organization as long as there are significant benefits that will be gained from BIM adoption in the end; therefore, costs are not a barrier to adopting BIM.

Conclusions for the Field Regarding Obstacles and Restriction to Adapting Building Information Modeling (BIM) in the Building Industry in the Kingdom of Saudi Arabia

The top three obstacles hindering BIM adoption, which were rated by the respondents, are logical and acceptable to be the strongest barriers to BIM adoption in the construction industry in Saudi Arabia. Regarding the results for all items of the field, they reveal that the Mean values for all the items equals 3.119 and the total RII is found at 62 %, which is greater than 60% (the neutral value of RII (3/5) *100 = 60%). Additionally, the total P-value of all the items is computed at 0.480 and is more than the significance level of 0.05. Based on all the previous results, BIM barriers are significantly affecting the adoption of BIM in the construction industry in KSA.

6.4.7 Major Strategies for Building Information Modeling (BIM) in the Kingdom of Saudi Arabia

The following field in the questionnaire is made up of eight items, which focus on the major strategies for BIM in KSA. The items were derived from the literature review, and adopted, modified and merged based on the face validity and pretesting results of the questionnaire (see Chapter 3). The items were judged and analyzed based on the respondent's perceptions. The following table, Table 6-15, provides the descriptive statistics of the questionnaire (Means, Standard Deviations (SD), t-value (two-tailed), probabilities (P-value), Relative Importance Indices (RII), and ranks).

Table 6-15 Descriptive Statistics for the Field 'Major Strategies for Building Information Modeling (BIM) in the Kingdom of Saudi Arabia'

No.	Item	Mean	Prop. Mean	Std. Dev.	Rel. Imp. (RII)	Test value	P value (Sig.)	Rank
1	BIM service providers should begin to clarify and demonstrate the importance of BIM	3.667	73%	1.061	0.733	0.602	0.552	4
2	Develop the necessary legislation to implement BIM	3.600	72%	0.855	0.720	0.320	0.751	5
3	Urgent need to train cadres in BIM	3.467	69%	0.973	0.693	-0.469	0.643	8
4	BIM should be part of the courses studied in Saudi universities	3.700	74%	1.088	0.740	0.755	0.456	3
5	More effort is required to make BIM	3.533	71%	1.042	0.707	-0.088	0.931	7

	workable							
6	The adoption of BIM will give Saudi construction organizations more value	3.567	71%	0.898	0.713	0.102	0.920	6
7	Does the Saudi government provide moral support to encourage BIM adoption by government/non-government institutions	3.767	75%	1.104	0.753	1.075	0.291	2
8	Does a law need to be enforced to compel government/non-government institutions to use BIM?	3.800	76%	1.031	0.760	1.329	0.194	1
All items		**3.638**	**73%**	**1.006**	**0.728**	**0.453**	**0.592**	

The findings reveal that the item “Does a law need to be enforced to compel government/non-government institutions to use BIM?” (Q8) is the strongest strategy required to adopt BIM in the construction industry in Saudi Arabia. According to the respondents’ overall judgements, it ranked first with the following values (RII=76%, Mean= 3.800, and the P-value=0.194). The result implies that a large percentage of the respondents believe that the development of the necessary legislation by the government will significantly contribute to urge the companies and engineers to employ BIM in the construction stages.

The item that obtained the lowest ranking for hindering the adoption of BIM was “More effort is required to make BIM workable” (Q5). The item received the following values (RII = 71%; Mean = 3.533 and P-value = 0.931). Based on the respondent’s perceptions, some companies require greater effort to ensure its staff members are capable of implementing BIM in the project phases.

6.4.8 Conclusions for the Field Regarding Major Strategies for Building Information Modeling (BIM) in the Kingdom of Saudi Arabia

The strategies that prevent BIM adoption in the construction industry in KSA, which were evaluated by respondents, are logical and acceptable to be considered the strongest strategies that can help BIM adoption. Regarding the results of all the items in the field, they revealed that the Mean value for all of these elements is 3.638 and the total RII is found to be 77%, which is greater than 60% (neutral value of RII (3/5) * 100 = 60%). Additionally, the total value of P for all items is 0.592, which is above the significance level of 0.05. Based on all the previous results, the proposed strategies would greatly assist in the adoption of BIM in the construction industry in the Kingdom of Saudi Arabia.

CHAPTER VII

7 Results and Discussions of the Case Study

7.1 Introduction

This chapter summarizes the research outcomes which examines the importance of using BIM systems to increase the efficiency of TQM in engineering projects in Saudi Arabia. The following chapter will briefly discuss the practical chapters of this research as well as summarize the outcomes and provide some suggestions from the researcher for future directions in the field of research using BIM systems in the construction industry. The remarkable developments in BIM systems hold a lot of promise for addressing the challenges of the construction industry by allowing the project team to test the electronic model of the building prior to its implementation. As the projects that have been successfully implemented using BIM systems have brought many benefits, including the quality of design, improving the productivity of the construction site, forecasting, optimizing cost control, reducing conflicts, raising the efficiency of managerial changes, and reducing rework caused by changes. Overall, these changes lead to a reduction in cost, project time and quality improvement.

The greatest interest in research relevant to BIM systems has focused on the pre-implementation stage. Therefore, the aim of this research is to study the effect of using BIM systems on the implementation stage through the possibilities available for BIM applications in reducing change orders resulting from errors and omissions and avoiding the lack of information necessary for the implementation process and raising the efficiency of the cost estimation process. This was done by utilizing a case study to achieve the objective of the research. In addition to researching the extent of the prevalence of the use of BIM systems during the design and implementation phases among the various parties of the project and extrapolating this through the participation of the opinion of users of BIM systems on actual implemented projects.

This study suggests the use of BIM systems to improve he implementation process. It allows the design team to invest the available time for innovation and creativity by reducing the time for coordinating plans in one specialty and between different specialties, which is inefficient with the current systems in place. Moreover, it provides a virtual environment for the owner to roam in the building and preview is elements and color schemes. It makes the possibility of providing different alternatives available and directly related to its impact on the cost.

7.2 Integration of TQM and BIM in Construction Sector

Quality management such as TQM is an important and challenging task in every industry, especially in the construction industry. Due to the uniqueness of each project, the quality management plan will be different for different projects. Traditional quality management systems fail to maintain the desired quality levels in projects. This chapter aims to explain the application of BIM coupled with TQM in the construction phase.

7.2.1 interviews

Adapting interviews as a method of data collection helped gain insight into the problem of using and implementing BIM in the construction industry in Saudi Arabia. For such research, there was a need to understand why the level of BIM adoption and implementation is minimal in Saudi Arabia and how this could be improved.

7.2.1.1 The Interview Design

Referring to the standard guidelines for the best practice, which was recommended by Bryman (2012), the starting point for designing interview questions was based on findings from a critical review of the literature regarding the research objective and targets. Hence, the interview questions are designed as follows:

- The first question targeted the organizations of the interviewees.
- The questions that followed were based on the effect of using BIM on raising TQM through the proposed standards, where they were asked about the importance of those standards in contributing to raising quality as shown in Table No. 2.
- The second group of questions that followed were based on the interviewees' understanding of BIM, its benefits, its impact on providing missing information, change orders, and quantification in the construction industry in Saudi Arabia as a whole.

The interviews were conducted in Arabic because it was preferred by the participants, so that they could express themselves easily and clearly and share their opinions about all the above information obtained from them

7.2.1.2 The Sampling Process

The participants selected for semi-structures interviews had work experience in traditional BIM-enabled construction projects. Since the number of construction organizations that have implemented BIM across Saudi Arabia is largely unknown, the researcher attended the BIM workshop held in Riyadh, Saudi Arabia in October 2022, and spoke to some of the other attendees as well as the speakers at this workshop. In order to measure their knowledge and opinions about BIM and its impact on raising the overall quality, the researcher asked them if their institutions had implemented BIM or if they had sufficient knowledge of BIM to participate in the interviews for this research. The researcher also asked the attendees about the types of projects they worked on and which were implemented on BIM models about the types of construction projects. After that, the researcher tried to invite these construction professionals to participate in an interview. However, while a number of them responded, some participants did not respond at all.

7.2.2 Data Collection and Analysis

7.2.2.1 Organization Operating Sector

Questions under this section were applied to understand the sector that the interviewees worked in. The construction operations sector differentiates and can be classified as public, private or both. As shown in the table below, Table 7.1, seven of the interviewees (R1, R3, R4, R5, R6, R9 and R10) responses were based on their private sector projects while two of the interviewees (R7 and R11) responded according to their public sector (government) projects. The remaining two interviewees, (R2 and R8) have been involved in both private and public sector projects.

Table 7-1 Organization Operating Sector

NO.	Organization	Frequency	Experience In Organizations
1	private sector projects	7	R1, R3. R4, R5, R6, R9, R10
3	public sector (government) projects	2	R7, R11
4	both private and public sector projects	2	R2, R8

7.2.2.2 Results and Discussions

In order to evaluate the model, some interviews were conducted with domain experts and asked about their opinions on the impact of BIM on TQM by evaluating the effect of BIM criteria on improving the TQM. Table 7.1 shows the results and discussions and the impact of BIM criteria on TQM in the phases of the construction project.

a) The inputs criteria of BIM include:

1- Coordination between elements and plans (CEP)

2- 3D Modeling (Visual Verification) (3DM)

3- creating a common database (CCD)

4- Availability of Information (AI)

5- Accuracy and Possibility of Modification (APM)

6- Compilation or Classification (CC)

b) The inputs criteria of TQM include:

1- Cost reduction (CR)

2-Time reduction (TR)

3- Improve Employee Performance (IEP)

4- Coordination improvement (CI)

5- Negative risk reduction (NRR)

6- Scope clarification (SC)

7- Increase customer satisfaction (ICS)

8-Greater process control (GIC)

Table 7-2 Results and Discussions and The Impact of BIM Criteria on TQM

Input	Phase	Output	Results and Discussions

3D Modeling (Visual Verification) (3DM)	Briefing	Coordination improvement (CI), Scope clarification (SC)	The BIM improving the owner's perception leads to understanding or imagining the final form of the project that will improving the TQM by Fact-Based Decision Making: Teams collect data and process statistics to ensure that work meets specifications.
Coordination between elements and plans (CEP) and Accuracy and Possibility of Modification (APM)	Designing	Increase customer satisfaction (ICS) and Scope clarification (SC)	The BIM improving the full understanding of the project requirements and desires in the early stages an efficient mechanism that guarantees coordination between the plans in case of design changes that will improving the total quality management by focuses on planning and designing the product in accordance with the customer requirements and satisfaction level in terms of quality, service delivery method and price
Availability of Information (AI) and creating a common database (CCD)	Tendering	Cost reduction (CR), Time reduction (TR) and Negative risk reduction (NRR)	The BIM improving The high efficiency of the costing process for various reasons, including the automatic counting of construction quantities. This results in accuracy and low error rates that will improve the TQM by Increased competitiveness, depending on the accuracy in quantity surveying and the accurate cost and time are calculated to increase the companies' ability to compete

Availability of Information (AI)	Construction and Commissioning	Improve Employee Performance (IEP)	The BIM provides all the information the contractor needs to implement the project that will improve the TQM by total employee involvement: All employees participate in working toward common goals.
Coordination between elements and plans (CEP)	Construction and Commissioning	Negative risk reduction (NRR) and Greater process control (GIC)).	The BIM provides high coordination between the various functions and services of the project, and high communication channels between the project parties that will improve the TQM by Integrated System: A shared vision, including knowledge of and commitment to principles of quality, keep everyone in a company connected.
Accuracy and Possibility of Modification (APM), creating a common database (CCD) and Compilation or Classification (CC)	Construction and Commissioning	Coordination improvement (CI)	The BIM provides collision and overlap points between functions are often not discovered except at the implementation stage, which results in an increase in processing time that can be avoided in advance, which in turn affects the duration and the total cost of the project that will improve the TQM by Continuous Improvement: Every employee should always be thinking about how to better perform their job.

7.2.2.3 The effect of applying BIM systems on reducing change orders and executing inquiries.

This research studied the possibility of using BIM systems through parametric models in reducing change orders resulting from errors, omissions and poor perception, and reducing the executing agency’s inquiries.

The case study was presented as a means of comparing the traditional work approach with the use of the parametric model with its smart elements within a virtual electronic environment simulating reality.

It was found that change orders and inquiries from the implementing agency often arise during the design phase, due to poor coordination and communication between the parties involved in the design process. This poor coordination is a result of two reasons and they are:

- The method of exchanging and transferring information at the design stage.
- The technology used to complete the blueprints, which is ideal when it ensures effective collaboration to transfer information between the project team.

Therefore, one of the objectives of this study was to measure the impact of the implementing agency's inquiries and change orders resulting from errors, omissions and poor perception on the cost and time of the project. This effect was quantitatively measured through an accredited case study in this research, which concluded that addressing the contractor's inquiries and change orders resulting from errors, omissions and poor perception before reaching the implementation stage and the automated management of changes during the implementation stage would raise the work efficiency by avoiding an increase in the time of the aforementioned project by 48% and avoiding an increase in the cost amounting to about 3% of the project cost.

The research has also reached the best methods to ensure cooperation, coordination and communication between the project parties in its various specializations through the application of building information modeling systems, which is the central database that contains project information. This is done through BIM systems software that is based on the principle of spatio-temporal simulation of all components of the building and ensures the optimal interdependence of its elements through its parametric capability and its ability to detect potential conflicts.

7.2.2.4 The effect of applying BIM systems on estimating building costs

Obtaining accurate estimated costs requires obtaining accurate quantities of building elements. Therefore, the research evaluated the methods of calculating quantities by comparing the traditional methods based on two-dimensional diagrams and the smart methods based on BIM models. The comparison was made using two of the most popular software commonly used to calculate quantities, the first of which is Microsoft Excel which was adapted to calculate the quantities of the housing building of the doctors and nurses. The second program that was used is classified within the BIM software which is the Revit program, because it has a great reputation for use among BIM systems software. Three main elements of the building have been compared which are the shear walls, foundations and architectural partitions. The researcher has developed several criteria for comparing and evaluating the approved software based on user requirements. These criteria included the availability of information for the various needs required for the process of calculating quantities, accuracy and the possibility of classification or grouping according to a specific scale, studying the possibility of visual verification of the components of the building whose quantities were calculated, and finally researching the possibility of each program to produce final reports for the quantities of building elements.

The research concluded that there are advantages and limitations for each program in the process of calculating construction quantities. The Excel program, which is based on manual extraction of quantities, whether from electronic or paper charts, is characterized by consuming a large part of the time and prone to human error and omission. For example, working on plans that are not correctly scaled, or neglecting to deduct or repeating some openings, or mistakenly calculating the heights of the walls due to the lack of a correct perception of them, and other errors that could affect the accuracy of the calculated quantities and thus the construction costs. Dealing with changes in construction and plans, and their reflection on the calculated quantities, will affect their accuracy, especially since it is done by repeated manual paralysis. Also, classifying the quantities of building elements and assembling them according to a specific standard is important in the cost estimation process, which is often done by traditional methods before starting to calculate the quantities according to one or more criteria specified by the user, which makes it difficult to change to another criteria in order to calculate the quantities. In addition to the absence of a link between the plans and the calculated quantities, which makes the process of visual verification not possible by traditional methods.

By using BIM systems software, the quantities are automatically extracted once the building is modeled, which holds the designer responsible for the correct modeling to obtain the correct quantities. The Revit program is characterized by the ability to collect, sort and filter the quantities of building elements according to any criteria specified by the user and at any time. Knowing that there are some building elements whose properties cannot be shown or group their quantity according to the levels, which is one of the important criteria for classifying quantities, which confirms the necessity of linking with tools added to the program (such as the Sky-BIM –Tocoman tools) that groups building elements according to the levels. Also, by using the Revit program, we can visually verify the components of the building whose quantities are calculated by providing a direct automatic link between quantities and elements, which provides optimal management of changes in construction and contributes to providing immediate costs for the proposed alternatives at the design stage.

It was found that BIM models are the best and most accurate for calculating quantities, even if developed software is used to deal with two-dimensional diagrams (such as Autodesk Quantity Takeoff – On-Screen Takeoff). It provides more efficient and accurate amounts of current traditional software. However, it is noted that when evaluating the efficiency of the program in terms of the effort expended, it is found that the level of effort is greater, and requires experience and training to reach the correct modeling of the elements compared to software based on two-dimensional diagrams, in which the main effort is focused primarily on the quantity calculation stage.

7.2.2.5 Summary

The case study was able to find the extent to which the BIM application contributes to addressing the lack of necessary information, alteration orders resulting from errors/oversights, poor perception before reaching implementation phase and the automatic management of alteration throughout the implementing phase. This will increase the efficiency of applying TQM concepts in engineering projects in the Kingdom of Saudi Arabia, which is achieved by avoiding an increase in time and cost of the project, focus on customer satisfaction, and increase coordination between project elements and plans.

Furthermore, the degree of contribution of Revit, one of the BIM systems programs, is identified. It adapts the smart 3D model in computing quantities quickly and accurately as the quantities are extracted automatically when the modeling process is completed, or by using an Excel program that relies on 2D plans, which requires more effort in calculating the quantities that are consider semi-manual and this leaves room for error.

CHAPTER VIII

8. Conclusions and Recommendations

The research relied on the BIM systems that have been applied to the case study. It presented the comparison assisted in understanding and determining if the use of BIM systems would increase the efficiency of applying TQM concepts or not in the implementation phase through quantifiable performance indicators within the project, such as lack of information needed for the implementation process, alteration orders, and estimating construction costs.

In addition to that literature review and constructive interviews to gather the information needed. The data gathered was analyzed through descriptive and analytical approaches, the SPSS program, the RI, and the mean values, which were achievable by distributing questionnaires to engineering firms and companies.

7.1 Conclusions

Total Quality Management (TQM) represents the management method for continuous success through client satisfaction. By applying the concepts of TQM, operators or project owners are able to adhere to time schedule, meet all the clients' demands, increase revenues, minimize expenses, and accomplish safety protocols. They are also able to maintain management and reliability within the fundamental constraints, which are time, cost and quality of a project. To increase the efficiency of applying TQM concepts in construction projects, this research aimed to determine, whether or not, the use of BIM systems would help.

For further comprehension and understanding of BIM application in projects, the case study analysis was conducted on the student residence building at King Khalid University in Saudi Arabia. The analysis compared the 3D plans generated by Revit and the basic 2D plans generated by AutoCAD. The results indicated the contribution of BIM application in addressing: the lack of necessary information, orders of alterations caused by errors and oversights, poor perception before reaching the implementation stage, and the automatic management of alterations during the implementation phase. These factors raise the effectiveness of applying TQM concepts in engineering projects by avoiding increases in time and budget constraints, focusing on customer satisfaction, and increasing coordination between elements and plans.

The research outcomes proved that companies applying BIM concepts are capable of adhering to project schedule, cost and customer satisfaction unlike those companies that do not apply BIM in their projects and that higher managements are incapable of committing to the application of TQM concepts when BIM is not used in the construction projects. This implies that construction projects in the Kingdom of Saudi Arabia still suffer from setbacks in the application of the concepts of TQM and suffer from a lack of administrative, scientific and technical applications.

Furthermore, modeling structures using BIM programs automatically enables the project to link the project components (plans, tables of quantities and properties) through a single model, which makes the possibility of oversight and human error unimaginable. Such a process leads to better coordination between project plans and influences the optimal management of modifications, which proves the alternative hypothesis that there is a significant relationship in the application of TQM and BIM simultaneously that affects the success of construction project implementation in Saudi Arabia.

The overall results revealed that applying the TQM concepts when implementing construction projects is inadequate and incomplete and the higher management could not commit to applying TQM concepts within projects. The majority of the respondents judged that within the construction divisions, accomplishing the administrative, scientific and technical abilities while applying TQM is weak and insufficient. The results showed the relative importance for the ability of the administration to commit using TQM during the application of BIM was (0.717), while the ability of the administration to commit to using TQM without BIM application was (0.552). This revealed that construction projects in Saudi Arabia still suffer from setbacks in applying TQM concepts, and suffer from a lack of administrative, scientific and technical applications, which proves the alternative hypothesis that there is a significant relationship in the application of TQM and BIM simultaneously that affects the success of construction project implementation in Saudi Arabia.

7.7 Recommendations and Future Works

The majority of the respondents judged that within the construction divisions, accomplishing the administrative, scientific and technical abilities while applying TQM is weak and insufficient. This study proposes that the organizations lack a sufficient committee to manipulate the TQM concepts.

Additionally, using BIM programs to model structures automatically links the project components (plans, tables of quantities and properties) through a single model, which makes the possibility of error unimaginable. This process leads to better coordination between project plans and influences the optimal management of modifications. BIM technology has great potential to control the construction industry as a whole. Yet, it is still under development and requires more time and work to avoid the flaws mentioned previously, and to develop its numerous tools. Nonetheless, with the continuous development in the computer industry and associated technologies, BIM might just succeed in starting a new era for the construction industry (Wortmann et al., 2017).

The researcher proposes a set of recommendations, including:

1. Searching for current projects and the current methods of costs and their times using the current methods and the methods that are, in addition to the costs of the latest modern technologies and their impact on the return on investment.

2. The search for an equal strategy in all systems in accordance with the rules, legislation, general rules and general rules, and with the sequence of work

3. Researching the impact of engineering contracts and project delivery methods

4. Study models of systems on the investment stage of the building, its tickets and the benefits accruing to the owner through the six-dimensional model

5. Finding the correct methods in modeling to obtain the correct quantities of the following components.

6. Develop manual work

7. Research in graphic evaluation, calculating quantities, by linking with BIM, estimating costs, which will reduce the difference between contractors when submitting proposals, since the available modeled information will communicate the design better and reduce misunderstandings for projects and the project as a whole.

8. Devoting part of the company's financial plans, training for competencies, and applying this methodology

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APPENDICES

Appendix A

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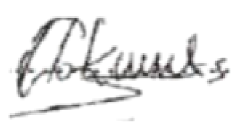

Prof. Dr. Hüseyin Gökçekuş

Appendix B

Ethics Letter

YAKIN DOĞU ÜNİVERSİTESİ

BİLİMSEL ARAŞTIRMALAR ETİK KURULU

01.02.2023

Dear Mohammad Abazid

Your application titled **“Implementation of Total Quality Management and the Integration of Building Information Modeling in the Construction Management Sector in Saudi Arabia”** with the application number NEU/AS/2023/174 has been evaluated by the Scientific Research Ethics Committee and granted approval. You can start your research on the condition that you will abide by the information provided in your application form.

Prof. Dr. Aşkın KİRAZ

Coordinator of the Scientific Research Ethics Committee