The University of Salford

School of the Built Environment

Developing an Assessment Model for the Adoption of Building Information Modelling to Reduce the Cost of Change Orders in the Jordanian Construction Industry

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Abstract

The cost of change orders is a major challenge facing the Jordanian construction industry. Change orders can be defined as modifications to the contract documents through adding, modifying or deducting something in the original agreement. Change orders might be a change in the work, a change in the quality of the work or in the construction schedule, or other forms of change that affect the nature of the project. Many studies have examined the causes of change orders, and a variety of solutions have been proposed as a way of minimising their effects, yet the cost of change orders continues to increase. However, the potential of the use of Building Information Modelling (BIM) as a tool which to minimise the cost of change orders has not been explored. In addition, there is an existing knowledge gap, in terms of current understanding of BIM across Jordanian construction industry, and key factors derive it. The literature review indicates that there has been a significant failure to use BIM in construction projects and that there is thus a considerable difference between the uptake of BIM in developed countries and what is going in Jordan. The aim of the current research is therefore to develop a model for assessing the adoption of Building Information Modelling (BIM) by Jordanian construction organizations as a means of minimising the costs of change orders.

To achieve this aim, a critical review of the literature on change orders and BIM was undertaken. This explored the causes of change orders and their impact, levels of awareness of BIM, the benefits of BIM, barriers to the adoption of BIM, and the effects of implementing BIM in terms of reducing the costs of change orders. The research took a positivist, realist, and value-free approach, and the researcher thus used mixed methods, combining semi-structured interviews and a questionnaire to collect the data required. In the first stage, 17 experts participated in semi-structured interviews as a means of investigating the major causes of change orders, as well as levels of awareness of BIM and its benefits, and of factors which both restricted and drove its use in Jordan. The outcomes of the interviews provided the basis for the design of the questionnaire, and this was distributed across the Jordanian construction industry, resulting in 155 responses received.

The questionnaire answers were analysed descriptively and statistically by the Severity Index, factor analysis and correlation tests. The causes of change orders in the Jordanian construction industry were further categorised into three main groups, namely client-related causes, engineering causes and causes arising from the circumstances of the project. Changes initiated by clients and design errors were found to be the major causes of change orders which are responsible for cost overruns. It was also found that there are significant shortcomings in levels of awareness and knowledge of BIM both among individuals and across the construction sector. Moreover, it was found that there are several barriers to the adoption of BIM in the Jordanian construction industry. These barriers are clustered in four main groups: financial, human, communication and project procurement. The main barriers to the use of BIM are the costs of BIM software and the cost of training.

The research concluded that there is a significant positive relationship between the use of BIM and reductions in the cost of change orders in the Jordanian construction industry. This means that the costs of change orders will decrease significantly if BIM is used, and supports a case for using BIM as a means of reducing the costs of change orders in the Jordanian construction industry. Finally, House of Quality and ISM (Interpretive Structural Modelling) were used to validate this approach. In the first step of validation, House of Quality was used to investigate the relationship between the causes of change orders and the functions and features of BIM, which validated the positive effects of using BIM in terms of reducing the costs of change orders by minimizing the main causes of change orders. In the second step, the ISM model was used to build the final model of the factors which obstruct the adoption of BIM in the Jordanian construction industry. This model categorized seven levels of barriers to the adoption of BIM, with those at level seven being the main barriers. This showed that the costs of BIM software and training are the main barriers to the adoption of BIM in the Jordanian construction industry.

Table of Contents

List of Tables

List of Figures

Declaration

This thesis is presented as an original contribution to earn a Doctorate of Philosophy degree at the University of Salford. The work has not been previously submitted to meet the requirements for an award at any higher education institution under my name or that of any other individuals. To the best of my knowledge, the thesis contains no materials previously published or written by another person except where due reference is made and acknowledged.

Ala'a Alshdiefat

Dedication

I dedicate my humble efforts in this thesis to:

My Parents, who have always been the source of my inspiration and my strength;

My Grandfather, who supported me in doing this PhD;

My Brother and my Sisters, for their continuous support and love;

My Friends, for their unfailing encouragement.

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I would like to dedicate this work to my beloved mother and father. I am profoundly thankful for your support, efforts and sacrifices, and all you have done for me throughout my life. Your prayers for me are what have sustained me thus far. I would like to thank my grandfather for his support and effort, which enabled me to complete my PhD journey; words cannot express the debt I owe you. I extend my sincere appreciation to my brother and my sisters for your love, encouragement, support and patience. I also extend my sincere love and thanks to all my friends, colleagues and other members of my family for your support during my journey. In particular, I would like to express my appreciation to my friend Dr. Yaser Labib for your unstinting efforts in helping me throughout my research and my life in Manchester. Finally, my deepest gratitude goes to the staff of the Research Office in the School of the Built Environment at the University of Salford for your support over these years, and especially to Moira, Jill, and Tracy. You have always been kind and patient in responding to my requests and making sure things go well.

Glossary of terms and abbreviations

2D- Two Dimensions

3D- Three Dimensions

BAC- The Building and Construction Authority

BEIIC- Built Environment Innovation and Industry Council

BIM - Building Information Modelling

BOQ- Bill OF Quantity

BPM- Business Process Management System

BS- British Standards

CAD- Computer Aided Design

CIDB- The Malaysian Construction Industry Development Board

CMAA- Construction Management Association of America

COMS- Change Orders Management System

ECS- Engineering Consulting Service

FIDIC - International Federation of Consulting Engineering

GCC- Gulf Cooperation Council

GDP - Gross Domestic Product

ICE- Institute of Civil Engineering

ICT- Information Communication Technology

IFC- Industrial Foundation Classes

JD – Jordanian Dinars

JMPWH- Jordanian’s Ministry of Public Work and Housing

KBS- Knowledge-Based System

MICMAC- (Cross-Impact Matrix Multiplication Applied to Classification)

RFI- Request for Information

RM- Reachability Matrix

SSIM- Structural Self-Interaction Matrix

UK- United Kingdome

USACE- United State Army Corps of Engineers

CHAPTRE ONE: INTRODUCTION

1.1 Overview of the research topic

The construction industry is dynamic, complex and fragmented in nature, as shown in Figure 1.1, and this frequently causes many problems. Globally, the construction industry is considered one of the major sectors that affect social and economic development (Winch, 2010). Recently, the construction industry has been facing greater challenges such cost overrun, delay, and duplication works. Change orders are one of the challenges that construction projects face. According to Halwatura and Ranasinghe (2013), changes occur in every construction project. Similarly, Sun and Meng (2009) argue that cost overruns and delays in completion are the most frequent effects of change orders in construction projects. Such claims highlight a significant problem in the construction industry that needs critical examination before it can be resolved.

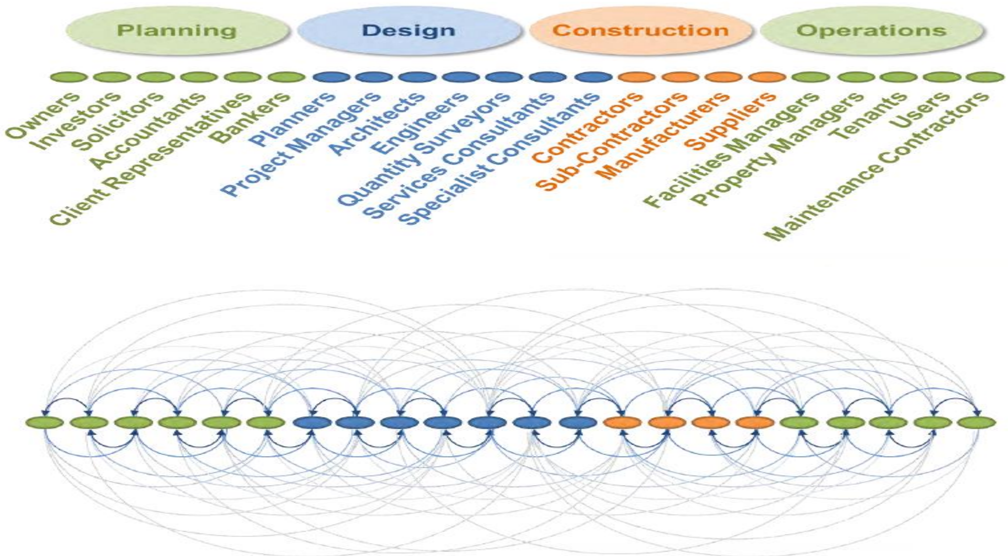


Figure 1.1: The fragmented nature of the construction industry and the pathways for sharing information (Montague and Slattery, 2013)

A 'change order' is defined as a modification to a construction contract, and the resultant impact on costs and time must be mutually agreed by the owner and the contractor (Sundar, 2013). Change orders can occur in construction projects for a variety of reasons. Several studies have investigated the causes of change orders in construction projects. For example, Alnuaimi et al. (2010) classified the causes of change orders into four categories: client-related, consultant-related, contractor-related, and others, and within each of these categories there are many specific causes. The impact of change orders extends beyond work on the project itself to affect all project parties; they increase the total cost of the project, delay the completion date, and lead to conflict between the project parties. According to Isaac and Navon (2009), the effect of change orders can be clearly seen after their implementation in the project.

Building Information Modelling (BIM) is defined, according to Arayici and Aouad (2010), as the use of Information Communication Technology (ICT) technologies to manage a construction project over the whole building lifecycle in order to improve the safety and productivity of the environment for occupants, improve the efficiency of the construction process, and to ensure that the project has the least possible environmental impact. BIM is considered to be the ‘medicine’ for the interdisciplinary inefficiencies in the construction industry (Coates et al., 2010), as shown in Figure 1.2. This is because BIM offers a wide range of benefits for the construction industry, according to Autodesk (2011) BIM eliminates the problems associated with traditional approaches through an intelligence model that creates and manages the building project faster, more economically, and with less environmental impacts. Azhar et al. (2008) also point out that it facilitates collaboration within project teams, which will lead to reduced costs, greater profitability, better time management and improved relations between the project parties. BIM eliminates change orders and Requests For Information (RFIs), which occur in construction projects because of missing information in construction documents, since all the parties involved in developing the model will be able to check for all possible problems and conflicts (Kuehmeier, 2008). The benefits of using BIM in a construction project are thus very considerable, and in particular include reducing the costs of change orders as well as the overall cost of the project.

Figure 1.2: A vision of BIM (Montague and Slattery, 2013)

However, using BIM in construction projects is not straightforward, and there are many factors which obstruct its adoption. A number of studies have examined the barriers to the adoption of BIM in the construction industry. For example, Arayici et al. (2012) identify three main factors which affect the implementation of BIM: financial restrictions, the suitability of projects for the BIM approach, and the selection of staff who could be trained to use BIM tools. Similarly, Rogers (2013) found that the main barriers to the adoption BIM in Malaysian Engineering Consulting Service (ECS) companies are financial considerations, human resources, the change process and legal factors.

In conclusion, it is clear that the cost of change orders is a significant problem in construction projects, and that they increase project costs overall. Using BIM could significantly minimize change orders and improve the quality of the project, as well as reducing its total costs and duration. Yet using BIM is not straightforward, as there are a number of barriers to the adoption of BIM in construction projects. The purpose of this research is therefore to identify the relationships between change orders and BIM in the Jordanian construction industry, which will clarify how far the use of BIM can minimize the cost of change orders. In addition to this, the research has developed a model for assessing the adoption of BIM in Jordan, which will enable change orders to be managed effectively and ultimately lead to a reduction of cost overruns in construction projects.

1.2 Jordanian construction industry

Formally, Jordan is known as the Hashemite Kingdom of Jordan. It has a range of geographic features, from the desert plateau in the east to the Jordan valley in the west, with a range of small hills in between (Ali and Al Nsairat, 2009). It is bordered, as shown in Figure 1.3, by Syria to the north, Iraq to the east, the Kingdom of Saudi Arabia to the east and the south, and both the West Bank (Palestine) and Israel to the west. The total area of Jordan is 89,318 km^2, and the total population is 9,559,000 (Department of Statistics, 2015). Jordan’s economy is highly dependent on remittances received from nationals working in the Gulf Arab countries, exports to the Arab region, and unconditional grants received due to its strategic geopolitical location (Abugattas-Majluf, 2012).

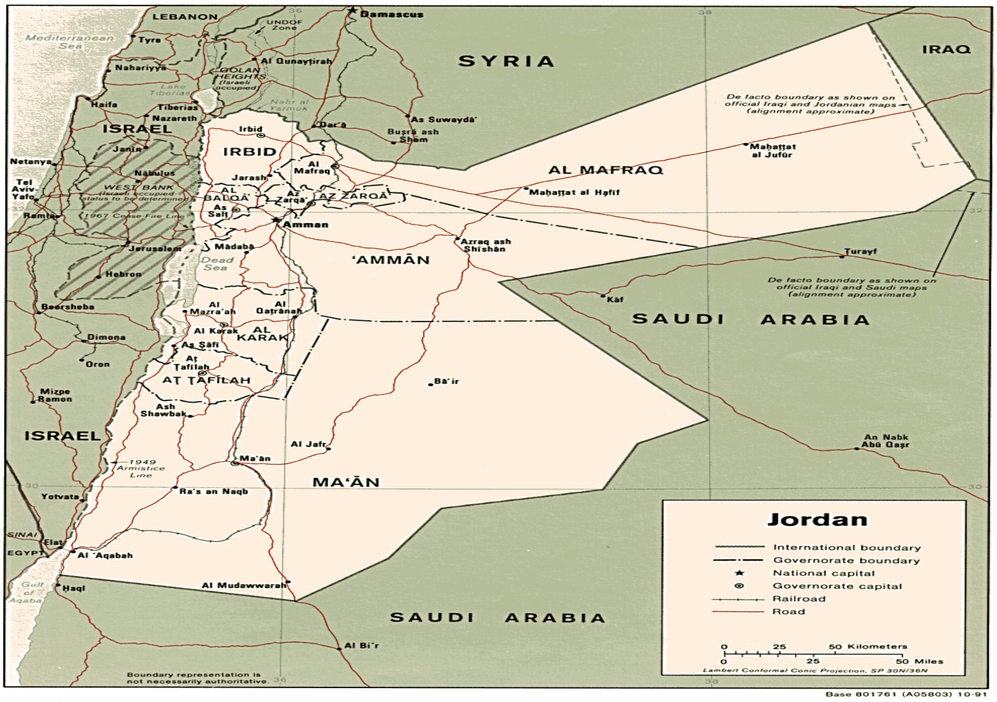


Figure 1.3: Map of Jordan

Construction is one of Jordan's most important economic sectors, and it is sensitive to changes in economic activities as well as to social and demographic factors (Ministry of Planning and International Cooperation, 2013). The construction industry is one of Jordan's largest production activities and occupies a key position in the national economy, contributing to economic development and to the country's Gross Domestic Product (GDP). Alkilani et al. (2013) estimated that the Jordanian construction sector accounted for 5% to 8% of GDP over the period 1994 to 2010, and employed 20% of the total workforce in 2013.

Investment in the construction sector accounted for 4.7%, 4.9%, 4.7% and 4.4% of GDP at current prices in 2013, 2014, 2015 and 2016 respectively, and amounted to 1,195.8 million Jordanian Dinars – around 1686.62 million dollars ($) - in 2016 (Department of Statistics, 2016). The Jordanian government also contributes to the development of the construction industry in several ways (Al Momani, 2000), and has invested 5 billion dollars in capital projects since 2012 (Jordanian Construction Contractors' Association, 2014). The private sector is considered to be the second pillar of the Jordanian construction sector. In 2015, the Jordanian Construction Contractors' Association reported that the private sector invested 767 million JD -1081.82 million $- in 2015, while the public sector invested 697 million JD -983.08 million $- , which means that investment in the Jordanian construction industry by the private sector was higher than that of the public sector. However, the Jordanian construction industry faces major challenges such as cost overrun and delay in completion. Thus, new ways of thinking and practices will therefore have a positive effect on the construction industry and support economic development.

1.3 Definition of the problem and justification for the research

As discussed above, there is a need to develop the Jordanian construction industry because of its great importance. It is therefore essential to resolve the major problems facing the construction industry if it is to develop and progress. In this context, there have been several studies of the costs of change orders as one of the main problems facing the construction sector. A study carried out in Jordan by Al-Momani (1996) found that by the time a project is completed, the actual costs exceed the original cost by 30%, while change orders result in cost overruns of 8.3%. Moreover, Swies (2008) found that change orders initiated by clients are regarded as one of the five major factors which cause delays in the Jordanian construction industry. Also, Sweis et al. (2013) concluded that change orders in construction projects in Jordan are considered to be one of the major factors that cause cost overruns. The anti-corruption commission investigate change orders in Jordanian public sector, the study was aim to investigate the volume of change orders, determine the causes of change orders and provide recommendations to minimise it. To achieve this aim several methods were applied as review the applied regulations that managing change orders, conducted interviews with experts they are working in public or private sector, review change orders' documents in formal associations, and conducted brain-storm sessions. The study results indicated that between 2008 and 2012 the committee of the Ministry of Public Works and Housing issued 531 change orders, with a total cost of 291 million Jordanian Dinars, and this figure does not include change orders issued by the Engineer, the Secretary General and the Competent Minister (posts working under the Ministry). The value of change orders represents 17% of the total cost of projects, which is 1,720 million Jordanian Dinars (Anti-Corruption Commission, 2013). That means that the cost of change orders increased from 8.3% in 1996 to 17% in 2013.

There is thus an ineffectiveness of the proposed solutions to the problem of change orders. The proposed solutions depend on recommendations and modification clauses in construction contracts, and do not take into consideration developments in information technology such as Building Information Modelling. For example, the Anti-Corruption Commission (2013) issued recommendations which included modifying some clauses in the conditions in Jordanian contracts, checking quantities during the design phase, developing a database in the Ministry of Public Works and Housing to hold data about change orders, and designing an efficient process to improve communication between project parties. The relevant literature on the Jordanian construction sector indicates that there are very serious problems in relation to the cost of change orders, which suggests that there is an obvious opportunity to reduce the cost of change orders in the Jordanian construction industry through information technology (Al Jaloudi, 2012, Assbeihat and Sweis, 2015, Msallam et al., 2015, Swies, 2008, Sweis et al., 2013, Anti-Corruption Commission, 2013). It is clear that there is a significant problem in the Jordanian construction industry, and the focus of this research is on resolving this problem and thus developing the construction industry.

Many researchers have discussed BIM as an appropriate tool for improving communication between project parties which would offer great benefits in construction projects such as minimizing changes, conflicts and errors. BIM can make a significant contribution to reducing the cost of projects, as well as reducing change orders, and several studies support this claim. According to Lu et al. (2014), the implementation of BIM contributes to saving of 6.92% of the total cost of a project. Similarly, Kuehnmeier (2008) concludes that using BIM can eliminate the change orders and RFIs (Requests for Information) which happen in construction projects. Such findings suggest that BIM is a suitable solution to the problem of change orders in the Jordanian construction industry. However, the question arises as to whether the Jordanian construction industry is at an appropriate level of maturity for the adoption of BIM. For example, Al Awad (2015) found that there is a great gap between the awareness and use of BIM in Jordan and what is happening in the construction industry in the west. Al Awad (2015) found that the use of BIM by small and medium enterprises (SMEs) in the Jordanian construction industry was zero. This means that Jordanian construction firms tend to use other applications in their work, and this is borne out by Hamad’s (2014) findings that the majority of Jordanian construction firms rely on 2D CAD. Furthermore, in a survey conducted by Building SMART ME in 2010, Jordan had the lowest use of BIM in compare to six Gulf Cooperation Council (GCC) countries by 7% of total respondents (Building Smart. 2011). A critical review of the literature on the use of BIM in the Jordanian construction industry shows that most firms still depend on 2D CAD and are not using BIM. Moreover, the level of awareness and knowledge of BIM is low, as is clearly reflected by the fact that there are no SMEs which are using BIM. When this situation is considered in relation to the problem identified above, however, then a possible solution becomes apparent. This research will therefore explore the adoption of BIM as a way to reduce the cost of change orders in the Jordanian construction industry.

In conclusion, the literature on change orders and BIM in the Jordanian construction industry has indicated a clear opportunity for reducing the cost of change orders through utilizing BIM, or in other words that BIM is a 'medicine' for reducing change orders and their costs. The literature shows no evidence of any practical implementation of BIM in Jordanian construction projects. Therefore a thorough investigation will be conducted to provide a model for assessing the adoption of BIM in the Jordanian construction industry as a means of reducing the costs of change orders.

1.4 Research questions

Research questions "define an investigation, set boundaries, provide direction and act as a frame of reference for assessing the research work" (Neuman, 2006). This research proposes an intelligent model for assessing the adoption of BIM in the Jordanian construction industry as a means of reducing the costs of change orders. Therefore, in the light of the issues identified above, the following research questions will be used to guide the research process:

1.4.1 Research question 1

Very little is known about the use of BIM in the construction sector in Jordan to reduce the cost of change orders, as there has been a minimal amount of research on this topic. The available literature on the use of BIM is generally related to other countries such as the UK. Therefore the first research question is:

- **Is BIM able to minimize the cost of change orders in the Jordanian construction industry?**

1.4.2 Research question 2

The literature shows that implementing BIM in the construction industry provides great benefits. This has made a range of countries try to encourage the adoption of BIM, as well as issue regulations to achieve this. However, the implementation of BIM in the construction industry faces many difficulties, and so significant barriers and obstacles must be overcome if this is to be done successfully. Therefore the second research question is:

- **What are the root causes of the minimal adoption of BIM in the Jordanian construction industry?**

1.4.3 Research question 3

Because of the perception of BIM in the Jordanian construction industry, the environment of that industry and the barriers to the adoption of BIM, as well as perceptions of the adoption of BIM as a means of reducing the cost of changes, the third research question is:

- **How can the impact of BIM be assessed in the Jordanian construction industry?**

1.5 Research aim

The aim of the research is to develop a model for assessing the adoption of Building Information Modelling (BIM) in Jordanian construction organizations to minimize the costs of change orders.

1.6 Research objectives

The research objectives explain the purpose of the research and define what the research tries to achieve (Zikmund et al., 2010). The specific objectives of this research are therefore:

1. To identify the main causes of change orders in the Jordanian construction industry which are responsible for cost overruns;
2. To explore current perceptions of BIM within the Jordanian construction industry;
3. To identify the barriers to the adoption of BIM within the Jordanian construction industry;
4. To develop an approach to the adoption of BIM in the Jordanian construction industry in order to assess how far the utilization of BIM can minimize the costs of change orders:
5. To validate and provide recommendations for the model which has been developed.

1.7 Research scope

The construction industry is quite broad in scope, and has many stakeholders, disciplines, systems, participants, tools, materials and practices. It is therefore unrealistic to include all the features of the construction industry in one study. Likewise, change orders and BIM are broad topics, and have many different aspects, and so it is beyond the scope of this research to consider in detail every issue related to change orders and BIM. In an attempt to establish a context within which it is possible to achieve the aim and objectives of the research, the scope of the research is presented as follows:

1. The construction industry has many sectors, including buildings, transportation and infrastructure. The building sector is the main sector in the Jordanian construction industry, and had the highest investment of all construction sectors over the period 2010 to 2015 (JCCA Report, 2015). This research therefore focuses on building projects in the Jordanian construction industry.

2. Cost overruns represent one of the main challenges facing construction projects. Many factors lead to increases in the cost of projects, such as increases in the cost of materials, accidents, changes, claims and others. It has been found that the cost of change orders is a significant problem in Jordan. At the same time, many studies have explored ways of minimizing the costs of change orders by controlling and minimizing the causes of change orders. None of these proposals have considered BIM as a possible solution, and the cost of change orders keeps on increasing. Therefore, this research concentrates on reducing the cost of change orders by identifying the major causes of change orders, and focuses on BIM as an appropriate way of minimizing the costs of change orders.

3. The private sector is a vital pillar of the Jordanian construction industry. According to the Jordanian Construction Contractors' Association report (2015), in 2015 (767) million JD was invested by the private sector, while the public sector invested 697 million JD. Furthermore, several researchers have focused on public sector in their researches such as Assbeihat and Sweis, 2015, Msallam et al., 2015, Sweis et al., 2013, and the Anti-Corruption Commission, 2013. While few studies have focused on private sector. This research therefore examines only the private sector. In addition, the research focuses on large organizations, and medium and small organizations are not included.

4. A variety of people and roles have some kind of link to the research topics, but due to the limited time available for the research and data collection, the research examines only those who are directly involved in the construction industry, i.e. clients, engineers (designers,

architects and consultants), contractors, project management firms, government, educational organizations and regulatory bodies.

1.8 Overview of the research methodology

The research methodology helps the researcher to produce useful data through effective data collection in order to achieve the aim and objectives of the research, and thus to draw meaningful research conclusions that contribute to existing knowledge. The current research therefore adopts Saunders et al.'s (2016) onion model. A research strategy is the way that the researcher has chosen to find answers to the research questions, and is influenced by the research philosophy and research approach, which could be quantitative, qualitative, or a mixture of the two (Saunders et al., 2016). This research has used a mixed method combining qualitative and quantitative tools, i.e. interviews and a questionnaire, in order to collect meaningful data. The data was collected in two phases. The first phase was a case study (semi-structured interview) with 17 experts from the Jordanian construction industry. The second phase was a survey (questionnaire), in response to which 155 completed forms were received from people working in the Jordanian construction sector. The target population in both phases included clients, engineers (designers, architects and consultants), contractors, representatives of government, academic organizations, regulatory bodies and project management firms. House of Quality and Interpretive Structural Modelling (ISM) techniques were used to validate the analysis of the data which had been collected. In this stage, a focus group interview was conducted with seven professionals from the Jordanian construction industry. Table 1.1 shows the methods used in the research to answer the research questions and achieve the research objectives.

Table 1.1: Methods used in the research

Objectives	Research questions	Literature review	Interview	Questionnaire	House of Quality	ISM
1. To identify the main causes of change orders in the Jordanian construction industry which are responsible for cost overruns;	is BIM able to minimize the cost of change orders in the Jordanian construction industry?	S	P			
2. To explore current perceptions of BIM within the Jordanian construction industry;		S	P			
3. To identify the barriers to the adoption of BIM within the Jordanian construction industry;	what are the root causes of the minimal adoption of BIM in the Jordanian construction industry?	S	P			
4. To develop an approach to the adoption of BIM in the Jordanian construction industry in order to assess how far the utilization of BIM can minimize the costs of change orders:	how can the impact of BIM be assessed in the Jordanian construction industry?		P	P		
5. To validate and provide recommendations for the strategic model which has been developed.					P	P

* P: primary data, S: secondary data

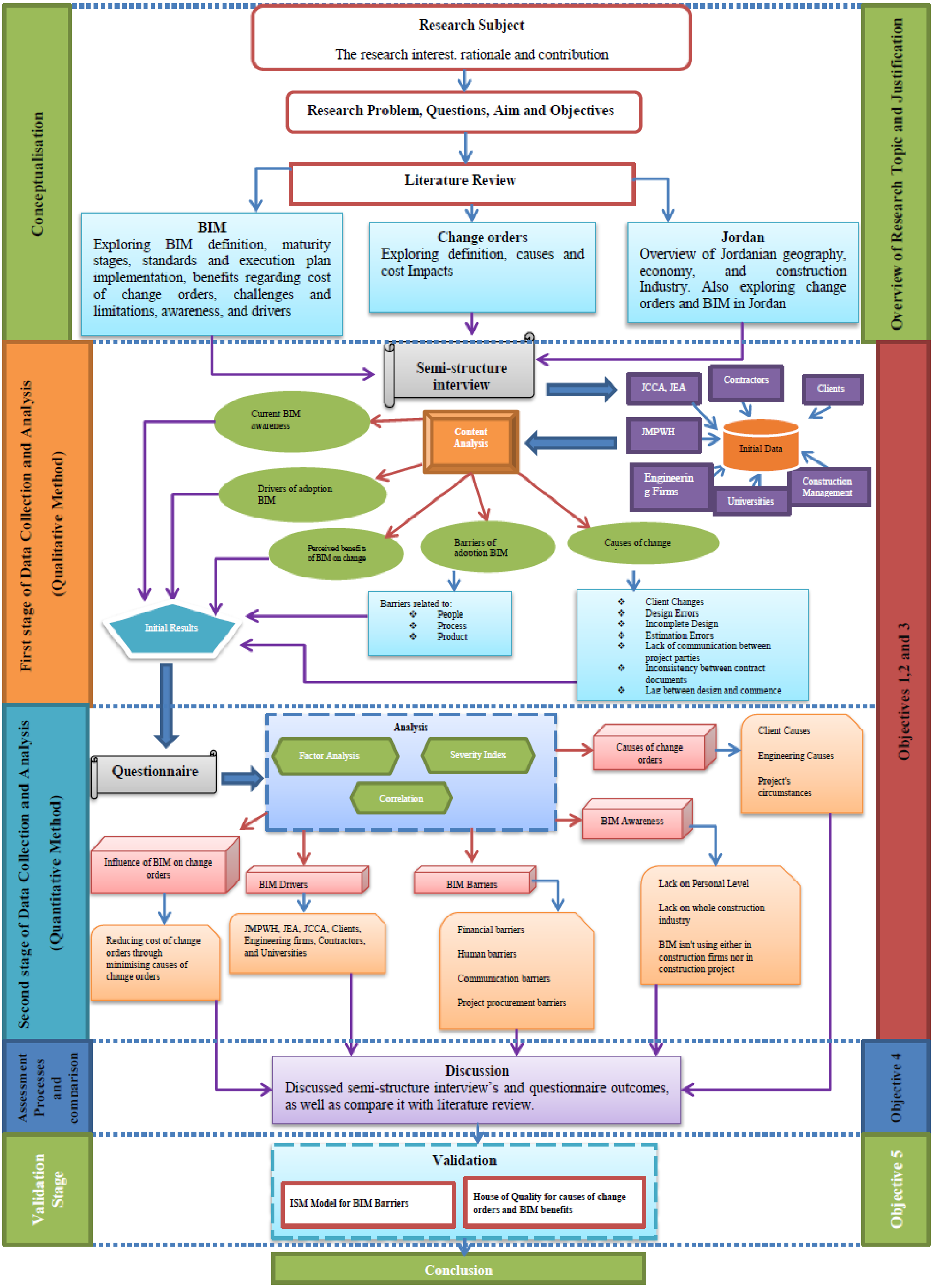


Figure 1.4: The research process

1.9 Contribution to knowledge

This research arose from an increasing interest in minimizing the costs of change orders in the Jordanian construction industry and the great effectiveness of BIM in reducing change orders. A critical review of the relevant research that has been undertaken in Jordan shows that there is a need for research in this area. The literature review also shows that the methods so far proposed for minimizing change orders do not consider BIM as a possible solution for this problem, and that limited research has been done into levels of awareness and perceptions of BIM. The current research will therefore propose an appropriate solution to a significant problem in the Jordanian construction industry, and is also likely to offer the following academic and practical contributions:

1. This research critically assesses, reviews and synthesizes current knowledge relating to the adoption of BIM, change orders, and the effects of BIM on change orders in construction projects.

2. This research is the first comprehensive academic investigation into the adoption of BIM as a means of reducing the costs of change orders in the Jordanian construction industry. It will therefore provide a practical basis on which managers can develop and implement effective initiatives. Furthermore, the findings of the research has contributed to the development of the Jordanian construction industry by providing an appropriate solution to a significant problem.

3. This research will also serve as a basis for further research in the area of the implementation of BIM in the Jordanian construction industry.

1.10 Thesis structure

This thesis consists of eight chapters. The features of each chapter are as follows:

1.10.1 Introduction

The first chapter in this thesis starts with an overview of the research topic, then presents a brief background to Jordan, as well as to the Jordanian construction industry. After that the research problems are explored and the motivation for undertaking this research is presented, which is followed by a statement of the research questions and the aim and objectives of the research. Both the scope of the research and the contribution it makes to knowledge are then outlined. The chapter closes by presenting an overview in tabular form of the research methodology adopted and how the methods used fulfil the research objectives.

1.10.2. Literature Review

This chapter presents a critical discussion of two major topics. The first of these is change orders and their definition, their causes and their impact on construction projects. This draws on an in-depth investigation of the literature related to change orders in the Jordanian construction industry. The second topic is Building Information Modelling, which is defined and then discussed in terms of levels of maturity, its benefits, the barriers to its implementation, its impact on change orders in construction projects, and the environment of the Jordanian construction industry. The literature review helped the researcher gain a comprehensive theoretical understanding of the research topic, as well as to develop the questions used for data collection.

1.10.3. Methodology

The methodology chapter presents the procedures for collecting data to answer the research questions and achieve the research aim and objectives. The methodology is based on Saunders et al.’s (2016) onion model, and an explanation is given of the choices available in terms of underlying philosophy, approach and strategies, as well as the time horizon. A detailed justification of the qualitative and quantitative data collection techniques and analysis procedures is provided in this chapter. The chapter closes with a full account of the methods used for assessing the reliability and validity of the findings.

1.10.4. Initial Data Collection

This chapter describes the first stage of data collection and analysis. Qualitative data was collected by means of semi-structured interviews with seventeen experts from the Jordanian construction industry, which focused on defining the current situation of change orders in the Jordanian construction industry, as well as the main causes that are responsible for cost overruns. The interviews also investigated the current level of awareness of BIM in the Jordanian construction sector, the barriers to the adoption of BIM, and the perceived benefits of BIM in terms of reducing the costs of change orders, and explored the factors which could promote the adoption of BIM in Jordan. The results gained from this were used as a basis for designing the questionnaire used in the second phase of data collection.

1.10.5. Questionnaire Analysis and Results

Chapter 5 describes the second phase of data collection. A questionnaire was distributed across the Jordanian construction industry to collect data from a representative sample of professionals working in the construction sector. 155 responses were received, and these were analysed descriptively and statistically. The chapter first gives general information about the respondents' backgrounds, and then presents descriptive results obtained by using the Severity Index technique, as well as statistical analysis based on factor analysis and correlation tests.

1.10.6. Discussion: the Development of the Assessment Model

This chapter offers a critical discussion and comparison of the results obtained from the interview and the questionnaire, and also draws on the literature review chapter. It was found that the causes of change orders fall into three main groups: engineering causes, causes related to the client, and causes related to the circumstances of the project. The chapter also presents findings related to BIM in the Jordanian construction industry. These findings identify the level of awareness of BIM, and indicate that the barriers to the adoption of BIM can be categorized into four groups, each of which contains many barriers. They also give insights into the relationship between BIM and the causes of change orders, as well as the factors which could lead to the adoption of BIM in the Jordanian construction industry.

1.10.7. Validation

The validation chapter describes the methods used for validating the findings of the focus group interview with professionals in the Jordanian construction industry. It explains the House of Quality technique, which is the first step in the validation process, and which identifies how the use of BIM can minimize the causes of change orders in Jordanian construction projects, and allows a comparison between the effectiveness of BIM and current (traditional) practices. The second part of the chapter presents Interpretive Structural Modelling (ISM). The ISM model assigns the barriers to the adoption of BIM to different levels according to their power and importance in the Jordanian construction sector. The ISM technique involves a structural self-iteration matrix, a reachability matrix, a reachability set, an antecedent set, reachability with dependence and independence powers, iterations to classify levels, and MICMAC.

1.10.8. Conclusion

This is the last chapter of the thesis, and presents the overall results of the research, starting with an overview of the research, and then the reviewed research objectives and the methods used to accomplish these objectives. It then discusses the contribution to knowledge made by the research. The last sections consider the limitations of the research and present recommendations for future research.

1.11Conclusion

This introduction chapter presents an outline of this research. It starts with an overview of the research topic, which highlights the importance of the construction industry for developing the national economy of Jordan, and briefly introduces the problem of change orders in the construction sector, as well as the potential of BIM for improving and developing the construction industry. It then provides a brief sketch of Jordan and the Jordanian construction industry, outlines the motivation for the research and identifies the gaps which this research is designed to fill. Several studies have found that the cost of change orders is a significant problem in the Jordanian construction industry. Many proposals have been made relating to ways of minimizing change orders, yet the cost of change orders is still increasing. At the same time, a critical review of the literature on BIM indicates that it offers significant benefits for construction projects, as it provides a range of functions which can improve the quality of a project and reduce costs and time. These benefits will result in minimizing the costs of change orders by reducing the need for change. However, there is little literature on the Jordanian construction industry which discusses BIM, and none of it mentions the ability of BIM to minimize the cost of change orders. Yet this is precisely where research is needed in order to develop the Jordanian construction industry and resolve the significant problems which arise from change orders. Three questions need to be asked to fill this gap, and these questions guided the researcher in formulating a precise aim and objectives for the research, which were presented after the research justification.

The construction industry is a broad field and has many disciplines, stakeholders and participants. Similarly, both change orders and BIM have many features. It is thus difficult to focus on all the issues which may be of interest in one thesis. This research therefore concentrates on the adoption of BIM as a means of minimizing the cost of change orders in building projects in the Jordanian private sector. This selection of building projects and the private sector is prompted by the massive investment which they have attracted in comparison to other areas of the Jordanian construction industry. This focus is reflected in the research objectives and is clearly explained in the discussion of the scope of the research (see 1. 7 above). The contribution which this thesis makes to the research is also presented. For example, it will help to resolve a significant problemin the Jordanian construction industry. The next section of this chapter illustrates the methodology adopted to fulfil the research aim and objectives. In this research, Saunders et al.'s (2016) onion model is used to answer the research questions. A mixed method involving both qualitative and quantitative tools (semi-structured interviews and a questionnaire) was used to collect valid and reliable data. This data was analysed descriptively and statistically to support the development of an effective approach to the adoption of BIM in the Jordanian construction industry in order to minimize the cost of change orders. The final section presents the structure of this thesis in eight chapters: introduction, literature review, methodology, initial data collection (interview), questionnaire, discussion, validation and conclusion.

CHAPTRE TWO: LITERATURE REVIEW

2.1 Introduction

To focus on the research topic and investigate the area critically, particular attention should be paid to change orders and the BIM literature. Recently, change orders have attracted a lot of discussion in construction management. The success of a construction project is influenced by controlling change orders and minimising their causes and impacts (Desai et al, 2015). Change orders thus have a significant influence on the successful delivery of a project, and the effectiveness and efficiency of the way changes are controlled is a critical factor for project accomplishment. At the same time, the importance of BIM in the construction industry has dramatically increased due to the great benefits it offers in terms of improving the quality of projects, controlling costs and improving the coordination between project parties. Furthermore, many researchers have suggested BIM as a suitable tool for the construction sector: according to Mihindu and Arayici (2008), "many projects have gained maximum benefits from BIM by using it in design and development, construction, environmental planning, code and safety checking, and optimisation". The focus of this research is to evaluate BIM as a means of reducing the cost of change orders in the Jordanian construction industry.

Many researchers have tried to define change orders. According to Sundar (2013), a change order is a modification to a construction contract, and the resultant impacts on cost and time must be mutually agreed upon by the owner and the contractor. Consequently, change orders are alterations in contract documents in the form of additions, deletions or modifications in relation to any aspect of the project and which impact on project cost and time. Changes in construction projects occur for many reasons, such as changes to the scope of the project requested by the client or design errors by the consultant (Alnuaimi et al., 2010). A critical review of the causes of change orders in the construction industry as a whole will thus provide a good starting point for identifying the causes of change orders in the Jordanian construction industry, and will furthermore be compared with any other factors leading to change orders which are particularly related to the Jordanian construction industry.

Change orders have significant impacts on construction projects. Several studies conclude that change orders increase project costs, delay completion, reduce project quality and can lead to disputes. Arun and Rao (2007) mention changes, defects and corrections in design as sources of both of cost and time overruns. Moreover, according to Serage and Olaufa (2007), in most cases contract modification increases the project cost by between 5% and 10%. In Jordan, cost overruns are a major consequence of change orders. Cost overruns caused by change orders increased from 8.3% of total project costs in 1996 to more than 17% in 2013 (Al-Momani, 1996., Anti-Corruption Commission, 2013). So, an in-depth investigation of the impact of change orders will therefore identify the causes of the changes.

Finally, it is evident that change orders are widespread and have undesirable impacts on construction projects. Furthermore, the Jordanian construction industry is suffering because of change orders, and a number of researchers have investigated both the causes of change orders and their effects (Al Momani, 2000, Sweis et al., 2013, Msallam et al., 2015). On the other hand, it obviously can be mined the effects of BIM in the construction industry that could be used in the Jordanian construction industry to minimise the costs of change orders. This research will therefore focus on the adoption of BIM in the Jordanian construction industry as a means of minimising the cost overruns arising from change orders. An in-depth review of the literature on change orders and BIM will be undertaken as a means of identifying the causes and impacts of change orders, as well as the importance of BIM and the benefits it can offer and the challenges it faces. The findings from this literature review will help to formulate interview questions for investigating change orders and BIM in the private Jordanian construction sector, focusing in particular on those reasons for change orders which are the main causes of cost overruns. The interview results will in turn be used to design a questionnaire that will be distributed across the Jordanian construction industry.

The questionnaire will help to develop a detailed understanding of the major causes of change orders which are responsible for cost overruns, give a clear picture of the current status of BIM in Jordan, and identify factors which may influence the adoption of BIM as a means of reducing the costs of change orders. After that, House of Quality technique will be implemented to clarify the effectiveness of BIM as a means of minimising the costs of change orders. Finally, ISM will be used to assess the barriers to BIM, thus providing a basis for developing important guidelines for the adoption of BIM in the Jordanian construction industry.

2.2. Change Orders in Construction Industry

2.2.1 Definitions of change order

To explore change orders in the construction industry, it is essential to determine what the meaning of this term is. Many organisations and researchers have defined change orders in construction projects. The different definitions reflect the point of view of each researcher, i.e. what they consider to be the necessary and sufficient pre-conditions for change orders. However, some definitions describe change orders as ‘variation orders’. According to Charoenngam et al. (2003), change orders are referred to as ‘variation orders’ in Institute of Civil Engineering (ICE) conditions, also the term ‘variation order’ is used by The International Federation of Consulting Engineering (FIDIC). Thus ‘change orders’ and ‘variation orders’ are the same in the construction industry. They also added that change orders must be made in writing, or in the case of oral instructions should be subsequently confirmed in writing.

The International Federation of Consulting Engineering (FIDIC) (2010) defines change orders as "changes to the quantities of any item of work included in the Contract, quality and other characteristics of any item of work, changes to the levels, positions and/or dimensions of any part of the Works, omission of any work unless it is to be carried out by others, any additional work or services necessary for the permanent works, or changes to the sequence or timing of the execution of the works". The Construction Management Association of America (CMAA) (1993) describes a change order as an agreement between the parties to a project in terms of additions, deductions or modifications to the contract documents that specify both the time and cost of the change and describe the nature of change to the work. Jackson and Carlson (2010) clarified the legal meaning of a change order as a modification of the construction contract by the client and the contractor after the bid has been accepted and the contract executed. Change orders could therefore be summarised as modifications to the contract documents through adding, modifying or deducting something in the original agreement. Change orders might be a change in the work, a change in the quality of the work or in the construction schedule, or other forms of change that affect the nature of project.

2.2.2 Types of change order

Change orders in the construction industry are classified according to the time the order is issued, the reason for the change and the impact of the change. Motawa et al. (2007) distinguish between proactive and reactive change orders in relation to timing. Reactive change orders relate to remedial action undertaken by the project team when change occurs, while proactive change orders have to do with efforts by the team to prevent disruptive change or minimise its impact. Distinctions can also be made between elective and required, discretionary and nondiscretionary and preferential and regulatory change orders. This classification relates to the need for a change order. For example some change orders might not be absolutely essential for a project, and the project could be executed without them, whereas others may be vital if the project is to achieve its purpose. Changes can also be categorised as beneficial, neutral or disruptive, depending on their effects. Therefore the impact of change orders is not negative in all cases, but depends on the nature of the change and how it might affect the project. In this research, a critical examination of the literature on change orders in the Jordanian construction industry has been undertaken to clarify the effect of change orders on construction projects.

Another classification of change orders makes distinctions according to who is responsible for change in a construction project. Assbeihat and Sweis (2015) define three types of change order. Formal or directed change is initiated by the owner or his representative in accordance with the change clause in the contract. Constructive change occurs when problems arise due to design errors, which are considered to be the responsibility of the client. Scope change has to do with things outside the scope of the contract, and is executed only after a complete redefinition of the scope of the project and re-negotiation of the contract. This classification thus takes as its starting point the project stakeholder who is responsible for the change.

In summary, the literature review identifies different types of change order in the construction industry, based on criteria such as the time of the change, its impact, the need for change or who is responsible for the need arising. This research will focus on minimising the cost of change orders in Jordanian construction projects through the adoption of BIM. It will start by determining the core causes of change orders, identify the impact of BIM on the causes of change orders by using House of Quality, and then use ISM to classify major barriers to the adoption of BIM. This approach to reducing cost overruns arising from change can be seen as a proactive process that aims to solve change order problems before they happen. This research therefore focuses on proactive change orders in the Jordanian construction industry.

2.2.3 Causes of change orders

Recently, changes have became common in construction projects, and this situation has spurred researchers to explore change orders critically both to determine their causes and to minimise their negative impact. Developing a wide understanding of the root causes of change orders is the key success factor for an effective analysis of changes. In this research, the causes of change orders will be determined firstly through a review of relevant research in the construction industry. The causes of change orders in building projects in the Jordanian private sector have been determined through interviews with professionals from the construction sector, and the results have been used to formulate a questionnaire that gathered data from a large sample in the construction sector. Understanding the causes of change orders provided basis for exploring the effects of the adoption of BIM in terms of minimising cost overruns arising from change in Jordan.

The purpose of making changes varies from one project to another. Some researchers believe that changes are initiated to improve a project, introducing additional features which have advantageous effects. According to Boot (2004), changes are undertaken to improve the quality of the project, better operation of the project facility, enhance the characteristics of the building and its operation or to introduce new dimensions or ideas. In contrast, researchers such as Gunhan et al. (2007), Ibn-Homaid (2011), Ijaola and Iyagba (2012), Assbeihat and Sweis (2015) and Alnuaimi et al. (2010) found that changes in construction projects occur to rectify errors in design or to adapt to new requirements or needs, or because of others factors which have an undesirable impact on the cost or time of the project. The current situation of change orders in building projects in the Jordanian private sector has been critically examined to determine whether it is positive or negative, and the researcher then explored the causes of change orders.

The literature review indicates that change orders have been categorised in many different ways. Some research groups the root causes of change orders into four categories: Alnuaimi et al. (2010), for example, classify change orders as client-related, consultant-related, contractor-related and ‘other’. Here the source of the change is the underlying factor. Gunhan et al. (2007) identify five categories: owner-directed changes, code-compliance issues, errors and omissions in contract documents, unexpected or changed conditions and ‘other’. This research will adopt the model proposed by Alnuaimi et al. (2010), so the reasons for changes in the Jordanian private sector have been grouped into four categories, namely client causes, engineer causes, contractor causes and ‘other’.

2.2.3.1 Change orders initiated by the client

During the life of a project, many changes can be initiated by the client. Change orders are required to ensure that the project progresses according to the client’s wishes. According to Gunhan et al. (2007), change orders in construction projects initiated by the owner are normal and happen in most projects. Clients have a right to make changes in their projects according to standard contract provisions. They have a right to initiate changes in order to ensure that the work performed meets needs.

There are several reasons why clients may make changes. Alaryan et al. (2014) conclude that the top two reasons for change orders in the Kuwaiti construction industry are changes of plan and changes of the project scope by the owner. Ibn-Homaid (2011) argues that additions, reductions or enhancements in relation to client requirements are the most frequent cause of change orders. Similarly, Ijaola and Iyagba (2012) identify 23 causes of change orders in Nigeria, in a survey which found that additional works and design modifications required by owners were the most fundamental. It is thus clear that clients may issue change orders specifying additional requirements in order to adapt to circumstances or needs, or the omission or modification of specific elements of a construction project for the same reasons.

The literature review indicates that clients are seen as the main initiators of change orders in building projects. Al-jishi and Marzoug (2008) found that clients are responsible for most change orders. Similarly, Issac and Navon (2008) conclude that the primary causes of change orders are owner-initiated changes. Mohammed et al. (2010) support these conclusions in research which found that changes to plans and the use of different materials are the first and second most important causes of change orders.

A study by Desai et al. (2015) concludes that clients are responsible for the first and second most important underlying reasons for change orders in construction projects in the central Gujarat region. These changes are necessary because of the client’s financial situation and a need to change to the scope of the project respectively. Alnuaimi et al. (2010) also found that the main cause of change orders in public construction projects in Oman is modifications and additions to the design by the client. Perkins (2009) examines the causes of change orders during the construction phase in the United States, concluding that additions or reductions to specifications by the owner, the action of third parties beyond the control of the owner or the contractor and delays in supplying equipment and access by the owner, along with other factors, constituted a significant percentage of the causes of change orders.

Clients may ask for change at any time during the life of a project. The design phase is considered to be the main period when the client might request many changes, and this is confirmed by several studies (Wu et al., 2004, Williams et al., 2003, Chan and Kumaraswamy, 1997). These have to do with changes in the client's expectations, update necessities, financial difficulties experienced by the client and pressure to complete the project. In addition, the studies concluded that late changes by clients relate to delays in reviews and approvals and to inappropriate interference in the design and execution of the project.

It can be concluded from this discussion that clients are the major source of change orders in the construction industry. Clients may ask for changes in their projects through adding, deleting or modifying specific items. Amongst other factors, the root causes of these changes relate to unrealistic expectations, adapting to new situations which might require adding or rejecting elements, or delays in taking proper decisions. These causes will be taken into consideration during the research. The research asked Jordanian participants if clients in the Jordanian private sector are responsible for change orders, as well asking them to identify the most important reasons for clients’ desire for changes. It also try to ascertain whether there are factors which are specific to the Jordanian construction industry.

2.2.3.2 Change orders initiated by the engineer

The second set of causes of change orders are those related to the engineer, and these have been investigated in several studies. It is essential to review these in order to determine whether or not these factors are present in the Jordanian construction industry.

Causes related to the engineer take many forms, according to Otim et al. (2012) incomplete design documents lead to many mistakes in execution, and subsequently to mandatory change orders to correct these mistakes. Inconsistency between contract documents such as structural and mechanical drawings – both of which are the responsibility of the engineer - could cause many changes during the construction process. Perkins (2009) concluded that discrepancies between design and specification are one of main causes of change orders. Changes could also be a result of changing the design of a project. Mohammed et al. (2010) also ranked changes in design by the consultant as the third major cause of change orders. There seems to be a general consensus that changes in design, incomplete design and inconsistencies between contract documents are responsible for many changes in construction projects. It is thus very important to keep these in mind in any attempt to reduce change orders.

Several studies have concluded that changes in construction projects are mainly attributable to design errors. According to Olsen (2012), design errors are responsible for the majority of changes. Hanna et al. (2004) also found that design errors are an important cause of change orders, and could be eliminated during the design phase. Similarly, Madni et al., 2001, Hsieh et al., 2004 and Wu et al., 2004 also found that both errors and omissions in design are the major causes of change orders during the construction stage. They additionally identified human errors on the part of the structural engineer, the architect and building service engineering as one underlying factor in these changes. Sun and Meng (2009) suggest that a misunderstanding of the client's requirements can lead to mistaken assumptions about key aspects of the project that result in faults in the design at a later stage. All in all, it seems that design error is the major cause of changes in construction projects in this category. This suggests that a concern for improving project design and minimising the number of errors will have the positive effect of reducing change orders in the construction industry.

Changes in a construction project might be a result of mistakes in estimation calculations. In the context of Sri Lanka, Halwatura and Ranasinghe (2013) concluded that estimation errors were the major cause of change orders in road construction projects. Estimation errors could therefore be categorised as a further main cause of change orders initiated by the engineer.

In conclusion, this in-depth examination has identified the engineer as one of the major sources of change orders. The underlying causes could be design errors, incomplete designs, changes in design, inconsistency between contract documents, estimation errors and others. According to many studies, such errors arise from human mistakes, misunderstanding client requirements, confusion in the design and other factors. These results have been formed the basis for studying the causes of change orders in the Jordanian construction industry related to the engineer. It also seek to identify the root causes of these errors in order to propose an efficient way of minimising changes and reducing their cost through the implementation of BIM.

2. 2.3.3 Change orders initiated by the contractor

Following the categories relating to the client and the engineer, the third category of causes of change orders in construction projects is related to the contractor. The contractor is responsible for executing construction projects according to the design, standards and specifications by managing and planning the whole process. Any mistake or shortcoming in the contractor’s work could cause changes in the construction project. Alnuaimi et al. (2010) found that poor project management on the part of the contractor is a cause of change orders in public construction projects in Oman, but this was not a major cause of changes. Chan and Kumaraswamy (1997) and Assaf and Al-Hejji (2006) identified a contractor’s poor management and supervision as a vital cause of changes in construction projects. Specifically, they found inadequate managerial skills, lack of experience and inappropriate management structure to be the underlying weaknesses. The quality of the contractor’s work can therefore be considered an important factor in relation to change orders. Other factors in this category include poor workmanship, which reflects adversely on the project and leads to delays and cost overruns (Al Jaloudi, 2012) and is a common cause of unplanned changes and reworks (Love and Li, 2000, Wu et al., 2004). This category is related to the quality of work carried out by the contractor, which should be of a specific level in accordance with the standards and specifications, and with no reworks or changes. Poor workmanship might be a result of using unskilled labour, or a contractor’s limited experience. According to Al Jaloudi (2012), lack of experience on the part of the contractor or of skilled manpower are two contractor-related factors could lead to change orders.

Other researchers have identified many causes of change orders in construction projects related to the contractor. According to Alnuaimi et al. (2010), the misuse of change instructions by the contractor is a cause of change orders. Furthermore, Al Jaloudi (2012) found that the change orders could also result from the contractor's lack involvement in the design phase, the unavailability of equipment required for a new situation, financial problems experienced by the contractor, lack of familiarity with local regulations and conditions, and a lack of communication with other project parties. A study by Ekhator (2016) found that the main contractor-related causes of change orders in residential building projects in Lagos State in Nigeria were poor project management, poor site management and supervision, and poor schedule planning. Overall, it appears that the contractor is a major factor in changes in construction projects in a variety of ways.

In conclusion, the in-depth review of the literature has identified the contractor as the third main third source of change orders in construction projects. Several underlying factors can be seen as causes of change orders, including poor management, poor workmanship and financial problems. In this research, the interview has been draw on the findings of the literature review to determine the main causes of change orders in the Jordanian construction industry. The researcher asked participants to identify any major contractor-related causes which have a significant impact on Jordanian construction projects.

2. 2.3.4 Change orders initiated by others

The final category is 'other' causes of change orders in construction projects. Sometimes the client or his representative issues change orders as a result of work which is not the responsibility of any of the project parties. Causes in this category cannot be ascribed to the clients, the engineer or the contractor, which means that some external factor is affecting the project and creating changes. The climate or weather is one such factor that affects construction projects and could lead to changes. Unusual weather conditions are an example of this (Al Jaloudi, 2012). El-Rayes and Moselhi (2001), Al-Momani (2000) and Yogeswaran et al. (1998) point out that weather conditions cannot be predicted, which minimises the effectiveness of advance planning. Consequently, delays and changes occur as a result of climate and weather conditions. The literature thus indicates a strong correlation between climate and weather conditions and changes in construction projects.

Different site conditions may also lead to change orders in construction projects. Different site conditions are seen as major causes of change orders in the construction industry in numerous studies. Halwatura and Ranasinghe (2013) found unforeseen conditions to be one of the top causes of change orders. Perkins (2009) also concluded that different site conditions are very important cause of change orders. It can thus be concluded that different site conditions play a major part in changes in construction projects. Hsieh et al. (2004) and Wu et al. (2004) explain how the development of project design options depends on site and ground conditions. If any unusual conditions are not discovered during the site investigation, the project design will be undermined. Corrective action will thus be required to adapt to the new situation, and most of these actions will involve design changes.

There are many external factors which push towards changes in construction projects. Over the life of a project, changes in the availability of material and equipment, in economic conditions and in regulations can have a massive impact on the project. In this regard, Frimpong et al. (2003) found ‘escalation of material cost’ to be one of five main causes of project changes and cost increases in Ghana. Memon et al. (2014) found that the lack of availability of equipment is a major cause of change orders in the Malaysian Public Works Department (PWD). However, Alaryan et al. (2014) concluded that change in materials is not a major cause of changes. Change in material or the availability of material varies from one project to another. Williams (2000) explained that changes in construction projects might be necessitated by changes in government regulations and legislation in areas such as health and safety, planning and employment. Similarly, Wu et al. (2004) also found that legislative or policy changes and political pressure were two of the main external causes of changes in construction projects.

To summarise, the ‘other’ category of the causes of change relates to external factors rather than the client, engineer or contractor. This category includes different site conditions, climate and weather conditions, change in local regulations, the unavailability of materials and equipment, and economic conditions. The interviews therefore be designed to elicit information about such factors as causes of change orders to determine their importance in the Jordanian construction industry.

2.2.4 The impact of change orders

Changes in construction projects occur for different reasons. The impact of these changes is broad, and affects the project parties, i.e. the client, engineer and contractor, as well as the project itself. They also vary from one project to another. The effect of a change order can be clearly seen after its implementation in the project, and becomes clearer at the end of the project process (Isaac and Navon, 2009, Whelton, 2002). It can be seen that selecting other options or making modifications is a very difficult decision, and could have a serious impact on cost and time at a later stage. A several studies for the influence of change orders in construction project have done to clarify the results of changes on construction project as whole, and in particular the Jordanian construction industry. The current research focuses specifically on the cost impact of change orders in the Jordanian construction industry, drawing on a critical review of the literature and informed by the finding that cost overruns are the major impact of change orders that should be minimised. The research was seek to establish links between the effects of changes and their underlying causes as a basis for reducing these causes through the adoption of BIM and thus minimising cost impacts. The relationship between the implementation of BIM and the causes of change orders will be validated by House of Quality, and ISM will be used to determine the main barriers as a basis for adopting BIM in the most suitable way.

The impacts of change orders on construction projects can be direct or indirect. The indirect impact of changes includes disputes and claims, reduced productivity, changes in cash flow, an increased risk of co-ordination failures and errors, lower morale, and so on (Hanna et al., 1999). At the same time, a change order might have a beneficial effect on a project if the change is positive. However, the majority of changes result in disrupted work flows, delays and cost overruns (Sun and Meng, 2009). Alnuaimi et al. (2010) concluded that the contractor gained the greatest benefit from change orders due to increased work and unit rates without any competition from other contractors. The benefits for the consultant are increases in work with guaranteed payments, and increased income arising from design modifications. The client as the third party also benefits from change orders in that the project is delivered with minimum problems. However; Alnuaimi et al. (2010) also felt that the consultant benefits from change orders because of the low level of risk in his work as well as from guaranteed payments. In another study, Ijaola and Iyagba (2012) also concluded that the contractor is the main beneficiary of changes. As a result of changes to the plan, there is an increase in the duration of the work and unit measurement. The consultant also benefits from being able to claim for redesign and from the increase in the timeframe of the project. The client, finally, will get what he/she desired. These studies clearly show that change orders have great benefits for all the parties, with the contractor gaining the most, followed by the engineer and then by the client. In the initial data collection and the interviews, the current research will seek to determine whether change orders have a positive or negative impact in the Jordanian construction industry.

On other hand, many researchers have concluded that the major impacts of changes are cost overruns and delays in completion. According to Sun and Meng (2009), cost overruns and delays in completion are the most frequent effects of change orders in construction projects. Ijaola and Iyagba (2012) found that delays in completion and cost overruns are the second and third most significant impacts of change orders in Nigerian public projects. Increased costs arise for many reasons. For example, Halwatura and Ranasinghe (2013) suggest that the contractor tends to charge higher rate for change items, which affects the client by increasing the overall project cost. In the context of Hong Kong, Won et al. (2009) found that changes to infrastructure projects lead to an increase in debris, which have to be removed at a cost of time and money. It can thus be seen that increases in costs and time are the major negative impacts of change orders on construction projects. The current research will focus on the cost impact of change orders in the Jordanian construction industry, especially in the private sector, and it will be suggested that this can be minimised by implementing BIM.

Several studies have tried to evaluate cost and time impacts of change orders. Charoenngam et al. (2003) conclude that change orders increase project costs by an average of 7%, as well as delaying completion by 30%, while Finke (1998) estimates that the impact of change orders increases costs by between 5% and 10% in most construction projects. Ibbs et al. (1998) estimate that the overall cost of change orders in the construction industry in the United States is $26 billion per annum, and may be as high as $50 billion if the expenditure on legal disputes and claims is factored in. These studies, together with others in the construction industry, indicate that change orders have a massive negative impacts on the costs and duration of a project which should be minimised.

Yet change orders have impacts beyond cost and time overruns. In this regard, Alnuaimi et al. (2010) conclude that the top five impacts of change orders in construction projects in Oman are delays in completion, increased claims and disputes, cost overruns, negative effects on labour morale and performance, and a decrease in contractors' profits as a result of having to implement change orders. In addition, Taylor et al. (2012) conclude that change orders in the construction industry can cause frustration for project parties and result in lower performance quality. Sun and Meng (2009), drawing on many studies, also list several negative impacts of change orders, such as the fact that reworks incur cost increases in the form of the labour and materials wasted on the initial work, as well as the cost of the labour and equipment required to undo that existing work. They could also lead to further disruptions as a result of having to accelerate work to make up for the delay caused by the change. This acceleration of process will be reason for lost floats of original schedule for some tasks during acceleration processes. Changes in a construction project may also lead to reduced productivity. According to Sun and Meng (2009), change orders have a significant negative impact on productivity, and there is a negative correlation between the number of changes and project productivity.

This section has shown that changes have massive effects on construction projects. The literature indicates that the impact of changes can be positive or negative. The contractor is the stakeholder who generally benefits most from changes, followed by the engineer and the client respectively. Both the contractor and the engineer can earn more money and get extra time, while the client gets the project as desired. However, several studies also find that changes in the construction industry have negative effects, which may include cost overruns, delays in completion, disputes and claims, a decline in labour performance and morale, reductions in contractors' profits and reworks. These impacts have to do with the complex nature of change orders, which means that construction teams have to deal with a huge quantity of information which has to be sent, checked, revised, approved, requested, clarified, transmitted or submitted, and so on (Charoenngam et al., 2003).

The current research will concentrate on the impact of cost overruns in the Jordanian construction industry, drawing on many studies to be presented in the next section. A critical review of these studies will indicate that cost overruns are the major outcome of change, which should be minimised. The researcher will therefore propose the adoption of BIM as a means of minimising cost overruns.

2.2.5 Review the suggested solutions for reducing change orders

Change orders have become common in most construction projects. Many studies have investigated change orders in different construction sectors, as well as proposing different ways of managing and reducing change orders. Exploring these proposed solutions will improve the researcher's knowledge of previous attempts to reduce change orders in the construction industry.

Isaac and Navon (2009) developed a model that identifies the impacts of changes in building projects at the project design and planning stage, before implementation, and focuses on the client objectives of cost, schedule and performance. The model draws on available sources of information about the project in order to identify the impacts of changes. The model, which is applied in four stages, uses the case study method to identify the impacts of changes in a building project, using Microsoft Excel and Analytica as a decision analysis tool. However, this model concentrates on changes initiated by the client, and may not be effective in clarifying the impact of changes arising for other reasons such as clashes in drawings.

Isaac and Navon (2009) also discuss other models which have been developed to control and reduce change orders in the construction industry. For example, Karim and Adeli (1999) proposed the use of CONSCOM, which is an object-oriented information model for construction scheduling, cost optimisation and change order management. The model generates several construction plan scenarios that support change management. However, this can be done only by implementing change in the design and scheduling of the project, and Isaac and Navon (2009) conclude that the model cannot facilitate an analysis of the effects of changes before their implementation. Hegazy et al. (2001) propose a model which involves recording each component in the project together with a list of all the other components that are affected when this specific component is changed. Isaac and Navon (2009) point out that this model requires information to be entered manually, which is very time-consuming. Moreover, it cannot help determine the need for a change before it happens, which means that it is unlikely to reduce the cost of change orders. A tool proposed by Motawa et al. (2006)

depends on previous projects for developing a fuzzy model that can estimate, in the early stages of a project, the probability of a change result, and predict the effect of the change on the project parameters. According to Isaac and Navon (2009), however, this model is not able to facilitate an analysis of the impact of a specific change once it has been proposed.

In another attempt to control change orders, Arain and Pheng (2006) present a knowledge-based system (KBS) developed for reducing changes in educational building projects in Singapore. KBS consist of two major components; a knowledge-base and a control selection element. The system is based on data collected from 80 educational buildings. The results suggest that the model may assist in improving the design of educational building. The KBS provides a fast response to queries relating to the causes, effects and control of changes, as well as being able to display in-depth details relating to the changes that could help decision makers to select the most appropriate controls for managing the changes. This model is therefore effective for educational projects, but may not be effective for other types of project. It could be useful for educational building projects in Jordan due to similarities in the general requirements of the education system. However, it would not be applicable to the Jordanian private sector.

Charoenngam et al. (2003) also propose a change order management system (COMS) to manage change orders by using the internet. The main advantages of this system are that it distributes information in a timely, remote and accurate way to manage the change order process. However, it still depends on traditional methods of solving change order problems such as estimating the cost and time of changes through meetings, which does not achieve the objectives of automation. Furthermore, this system requires the construction parties to check new documents regularly in order to update the project information manually, which could result in errors.

In another study, Yitmen and Soujeri (2010) developed an artificial neural network model to manage change orders. The model includes two main components; the first to identify the adverse impacts of change orders on project performance, and the second focusing on identifying the probability of disputes. While this model is effective in estimating the effects of change orders on project performance and their ability to cause disputes, it cannot determine the reasons for change orders, which in the context of the Jordanian construction industry would help to minimise problems at an early stage of the construction life cycle, as well as reducing their negative impacts on project costs and time.

Jongeling and Olofsson (2007) propose an integrated model which connects 3D geometry with 4D and 5D. This is integrated with a work schedule that coordinates changes over the duration of the project. Furthermore, the automation provided by 5D technologies extends beyond design changes. ArchiCAD also automates and coordinates the creation of documents, schedules, bills, and estimated quantities through its integrated 'Virtual building' model based on BIM. This study thus demonstrates the efficiency of BIM for managing and reducing change orders in the construction industry, as well as their negative impacts on costs. It can be concluded that the adoption of BIM in the management of Jordanian construction projects will have a positive impact by minimising the number of change orders, thus reducing cost overruns, delays in completion and other problems.

Other researchers take a similar approach in their proposals for minimising change orders in construction projects. For example, Alnuaimin et al. (2010) suggest seven steps to manage change orders in construction projects in Oman as follows:

1. Develop a standard manual with a checklist for project design to regulate all stages and steps, including the feasibility study, design, tendering, tender evaluation and the award of the project;
2. Establish a specialized national technical unit to evaluate overall construction practices in Oman; also establish a manual of construction procedures;
3. Develop a national database system, to be made available to all project parties, about soil, weather conditions and underground services;
4. Review the registration of consultant firms and contractors from time to time in order to check their current technical and financial capabilities;
5. Clients should prepare well-defined briefing documents about their needs before entering the design phase;
6. Clients should hire experienced technical staff who can help and advise top management in decision-making in a timely manner;
7. The government should plan projects in a way that does not lead to contractors being overloaded by the number of projects they have taken on, and therefore being short of qualified staff, especially engineers.

These recommendations for reducing change orders vary from those which have been made in the specific context of public construction projects in Nigeria. According to Ijaola and Iyagba (2012), the five essential steps in managing change orders effectively are first of all that that “a specialized quantity surveyor/cost controller and project manager should be assigned to large construction project(s)”. Then a standard document should be developed to establish the stages/steps from the start of the project until completion and close-out, a common learning database system should be shared among all governmental units, no design engineer should be allowed to practice without having a professional license, and finally, the general conditions should be reviewed and updated regularly. Desai et al. (2015) also provide different remedies for minimising change orders in the central Gujarat region as follows: there should be a review of grey areas in the contract document, negotiation and timely approval of change orders, checking and review of design changes for feasibility, and consideration should be given to the indirect effects of change order pricing.

To conclude, this critical review of the literature on proposals for reducing change orders in the construction industry has examined several studies with many models. The models presented have been thoroughly investigated in order to examine their ability to minimise cost overruns efficiently in the Jordanian construction industry. The results indicated different weaknesses in each model which might reduce efficiency in reducing the costs of change orders in Jordan. However, the integrated system proposed by Jongeling and Olofsson (2007) demonstrates the greatest effectiveness in minimising change orders over the project life cycle, which suggests that implementing BIM may be successful in decreasing the cost of change orders in the Jordanian construction industry. Besides, many researchers have suggested recommendations and steps for reducing change orders in construction projects. However, these recommendations vary from one project to another in accordance with the special environments and circumstances for which they are designed, which suggests that they may not be successful in minimising the costs of change orders in the Jordanian construction industry.

2.2.6 Change orders in the Jordanian construction industry

A critical examination of the available literature on the Jordanian construction industry has been undertaken to develop an initial understanding of the causes and consequences of change orders in this context and as a starting point for exploring any solutions which have been proposed. The findings will be combined with those from the literature discussed so far to provide the researcher with a fuller knowledge of all the issues relevant to change orders in the Jordanian construction industry. This in turn will form a basis for designing interview questions to be used for collecting initial data about the major causes of change orders, and then a questionnaire to elicit responses from a large sample of people involved in the Jordanian construction sector. A proposal will then be formulated for the adoption of BIM in the Jordanian construction industry in order to minimise the causes of change orders, as well as their resulting cost overruns.

Change orders are widespread and clearly noticeable in the Jordanian construction industry. Many studies have identified change orders as problem in Jordanian construction projects, and they cause delays and cost overruns. A study by Al-Momani (1996) to predict the construction costs of public school buildings indicated that, by the time a project is completed, the actual cost exceeds the forecast cost by 30%, whilst change orders result in an 8.3% cost overrun. Similarly, Alshdiefat (2013) found that claims in construction projects have become normal and expected, with most building projects in Jordan suffering from cost overruns and delays in completion; according to the results of this research, change orders are the main cause of these claims. Sweis et al. (2013) also found that change orders in construction projects in Jordan are considered to be one of the major factors that cause cost overruns. Such findings highlight the negative impact of change orders, and especially cost overruns, on Jordanian construction projects. The current research will focus on the influence of costs in order to propose a suitable solution based on the adoption of BIM in order to minimise cost overruns arising from change orders.

Between 2008 and 2012, 531 change orders were issued by the committee of the Ministry of Public Works and Housing, and this figure does not include change orders issued by the Engineer, the Secretary General and the Competent Minister (which are posts reporting to the Ministry). The total cost was 291 million Jordanian Dinars. The cost of these change orders amounts to 17% of the total cost of the projects, which is 1,720 million Jordanian Dinars (Anti-Corruption Commission, 2013). The literature thus views change orders in Jordanian as the main problem impacting on the cost, duration and others aspects of projects in the Jordanian construction industry. What is more, it has been found that the total costs of change orders have escalated dramatically, from 8.3% of total project costs in 1996 to more than 17%

in 2013. Such figures highlight a critical issue facing the Jordanian construction industry, which is the challenge of controlling and minimising change orders in order to improve and develop the construction sector.

The causes of change orders have been investigated by many studies in different sectors in the Jordanian construction industry. Al-Momani (2000) concludes that the main causes of delays include changes initiated by designers, client requirements, the weather, site conditions, late deliveries and economic conditions. Swies (2008) found that change orders from clients are considered one of the five major factors causing delays in the Jordanian construction industry. Moreover, Swies (2013) concluded that governmental delays and design changes are the major causes of time overruns in construction projects. This implies that systematic steps must be taken to accelerate the approval process of the government (these can be achieved by reforms and modified regulations). In addition, more attention needs to be paid during the design phase to minimising the probability of change orders. Overall, client changes and design changes seem to be the major causes of change orders in Jordanian construction projects.

Al Jaloudi (2012) classified 49 causes of changes in four categories, namely ‘client’, ‘consultant’, ‘contractor’ and ‘other’, in water and wastewater projects in Jordan. The five main causes of changes identified are conflict between contract documents, errors and omissions in design, unforeseen problems, differing site conditions and inadequate design. The study emphasizes that the effects of changes in water and waste water projects in Jordan are great in terms of cost overruns and delays in completion. The engineer is thus seen as the major source of changes in this study, as he is considered to be responsible for three of the five major causes of change orders in such projects. The Anti-Corruption Commission (2013) also studied the causes of change orders in public projects. Their study indicated that change orders had led to an incredible increase in the total cost of many projects, totalling over 100% of the original cost. It was concluded that there are 13 causes of change orders, with the main ones being design errors and errors in material estimation, changes to the project scope and objectives, and a lack of communication between the project parties. These results indicate that both clients and engineers are responsible for major changes in construction projects.

Another study was conducted by Assbeihat and Sweis (2015) to determine the major causes of change orders in public projects, finding that the client is responsible for three of the top five primary causes of change orders. The major cause of change in public projects is the owner requiring design modifications, followed by the owner requiring additional works, and the fifth cause is 'insufficient coordination among the parties by the owner'. The third major cause identified in this study is 'ambiguities and mistakes in specifications and drawings', while the fourth is 'modifications in materials specifications'. These results show that, in public projects, clients are the major source of changes in construction projects, and that they can cause changes in different ways.

Msallam et al. (2015) grouped change orders in highway projects into four categories: client, consultant, contractor and ‘other’, outlining the main causes of change orders related to each category. The main causes of change orders related to the client are changes to plans, changes in schedule and financial problems encountered by the client. Ambiguity in the design details, inadequate design, inconsistencies between contract documents and weakness in coordination are the four major causes related to consultants. Several causes are ascribed to contractors, including unfamiliarity with local conditions and lack of communication. The last category includes safety considerations, socio-cultural factors and unforeseen problems. These researchers also found that the major impacts of change orders in Jordanian highway projects are delays in completion, cost overruns and overhead expenses. Overall, this exploration of the causes of change orders in the Jordanian construction industry concluded that the causes of changes in construction projects can be classified according to their source, i.e. the client, the engineer, the contractor and ‘other’. It also found that change orders in the Jordanian construction industry have many negative effects, such as cost overruns and delays in completion.

Several other studies have identified change orders as a major problem in the Jordanian construction industry, and researchers have gone on to propose ways of reducing the number of changes as well as their impact. For example, Al-Momani (1996) suggests that complete drawings and bid documents, combined with consistency in specifications and cost control systems should be sufficient for improving productivity in the construction industries as a whole. Recently, Al Jaloudi (2012) has proposed a framework for controlling changes. The steps cover the different project phases, i.e. conceptual, design and construction, and recommendations include selecting a contractor with appropriate experience for the type of construction, selecting an experienced design firm, developing a fully detailed design, to be set out in drawings and specifications, providing a reasonable period for the design phase and reviewing the contract documents by owner. These suggestions are made as a way of minimising change orders in the Jordanian construction industry.

The Anti-Corruption Commission, (2013) has also made recommendations for controlling and reducing change orders in public projects. The overall proposal is divided into two parts; the first of which is contractual, while the second relates to work process. Both parts include recommendations that push towards minimising changes in construction projects, so reducing the cost of change orders. It should be noted that none of the recommendations reviewed here propose the use of Information Technology.

To conclude this review, it can be seen that change orders in the Jordanian construction industry are a major issue which causes cost overruns, delays in completions and other problems. Several studies investigate change orders in different sectors of the Jordanian construction industry, for example Al-Momani (1996) in public projects, Al Jaloudi (2012) in water and waste water projects and Msallam et al. (2015) in highway projects. In addition, the Anti-Corruption Commission has explored change orders in public projects, coming to the alarming conclusion that change orders can result in final costs exceeding the original cost by more than 100%. However, there are no findings which relate clearly to change orders in building projects in the Jordanian private sector, even though this sector has recently attracted the most capital investment (Jordanian Construction Contractor Association, 2015). Furthermore, the recommendations for minimising change are unlikely to be sufficiently effective because they depend on modifications to the construction contract, and do not consider drawing upon developments in information technology such as building information modelling, and this must be considered a weakness in any remedy proposed for the issues surrounding change orders. This is against a background in which the number of change orders in the construction industry as a whole is still on the increase, having risen from 8.3% of total project costs in 1996 to more than 17% in 2013, which means that there is an ambiguity in effectiveness of proposed solutions in order to control change orders.

This research will therefore focus on the adoption of BIM as an Information Technology solution for minimising change orders in building projects in the Jordanian private construction industry. The exploration has emphasised major causes, and the relationship between the causes of change orders and BIM will be explained, and then validate by implementing House of Quality. This will be followed by determining the major barriers to the adoption of BIM in the Jordanian construction industry, using ISM.

2.3 BIM in construction Industry

2.3.1 Definition BIM

A discussion of Building Information Modelling (BIM) must start by clarifying the meaning of BIM in the construction industry. It is very important to know what BIM is in order to assess the current level of awareness of this tool in the Jordanian construction industry. Many researchers have defined BIM, but according to different criteria. The term 'building information modelling' first emerged in 2003 (Saxon, 2013). According to the National BIM Standard (2010), a Building Information Model is "a digital representation of the physical and functional characteristics of a facility and a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle; defined as existing from earliest conception to demolition". Arayici and Aouad (2010) define BIM as the use of Information Communication Technology (ICT) to manage the process of the building life cycle to handle a project with improved safety and productivity, to improve project efficiency during the building life cycle and to ensure the least possible environmental impacts from its existence. BIM thus uses Information Communication Technology (ICT) to develop a model of a building in order to facilitate the sharing of information between the project parties so that they have a strong and reliable base for decisions. The virtual representation of the physical and functional characteristics of the building enables them to improve the way construction processes are managed and to execute projects with high levels of quality, safety and efficiency, and with fewer environmental effects. Although a thorough search of the literature found several definitions of BIM, the one which is most appropriate in the context of the Jordanian construction industry and for the aim of minimising the cost of change orders is the National BIM Standard definition.

2.3.2 The importance of BIM

There has recently been a tremendous increase in the awareness of the importance of BIM within the construction industry. A number of studies have investigated BIM in the construction industry, and many countries have started to adopt BIM. According to the BIM Industry Working Group (2011), there are on-going national deployments of BIM across the USA, in Scandinavia and Europe as a whole, and in the Far East. Recognition of BIM is becoming common around the world. The adoption of BIM is supported by various bodies and groups in the construction sector, including governments and clients, and there are a variety of reasons for this. The Efficiency and Reform Group (2011) suggests that governments have supported BIM as a way of improving collaboration and reducing fragmentation in the construction industry. Furthermore, clients are requiring the implemention of BIM in their projects, which is pushing many construction firms to invest in BIM technologies for use at different project stages, from bidding, pre-construction, construction and post-construction (Hergunsel, 2011). It is thus clear that the importance of BIM in the construction industry across the world is pushing different parties toward BIM, including governments, construction firms and clients. What is more, the importance of BIM in the AEC industry is spurring leaders and managers to seek a fuller understanding and look to academics and professionals for specific research to support the further development of BIM (Gerber et al, 2010) and its implementation in construction projects. Against this background, the current research will critically investigate the causes of change orders in the Jordanian construction industry that lead to cost overruns, and then seek to determine how the adoption of BIM can minimise these causes and reduce cost overruns, as well as validating this by House of Quality. In addition, the level of awareness of BIM and barriers to its adoption in the Jordanian construction industry will be explored through interviews with experts in that industry and a survey distributed across the sector. Finally, ISM will be employed in this research to identify core barriers to the adoption BIM in Jordan.

2.3.3 The BIM concept - information encapsulated in the BIM model

The concept of BIM has been examined in order to determine how it can be used to maximum effect in practice. Ballesty (2007) describes the difference between 2D CAD and BIM. 2D CAD describes a building in two dimensions in the form of plans, elevations and sections. 2D drawings are graphical entities such as lines, circles and arches. This means that any modifications in one document requires other documents to be updated in order to avoid errors. In contrast, BIM describes a building in model form, and the intelligent contextual semantic of the BIM model is represented in elements and systems like spaces, walls and beams. Eastman et al. (2008) define BIM as an object base, and the object-based format allows queries, transfers, updating and the management of individual project objects from among a potentially heterogeneous set of applications. There is thus a huge difference, for while 2D CAD explains a construction project in two dimensions, BIM represents it in a model. Errors and changes in 2D CAD are more frequent, due to mistakes in updating drawings and lack of coordination between disciplines. Smith (2007) suggests that BIM provides a virtual model of a building in order to avoid problems. Consequently, Kymmel (2008) is confident that this virtual model of the building makes it possible to make any adjustments or modifications before construction starts, which could minimise changes and errors in construction projects. BIM is thus an appropriate way of reducing the cost of change orders in the Jordanian construction industry through minimising changes and errors.

Thompson and Miner (2007) explain the BIM concept as connecting and storing project data in a single online system, as shown in Figure 2.1. This makes it possible to execute the project in a virtual environment. Both time (scheduling) and cost dimensions can be added to the model, and so the cost and time benefits of different options can be assessed. Moreover, Fischer and Kunz (2006) argue that developing a model like this will allow stakeholders to contribute at earlier phases in the project and offer their experience and knowledge at the design stage.

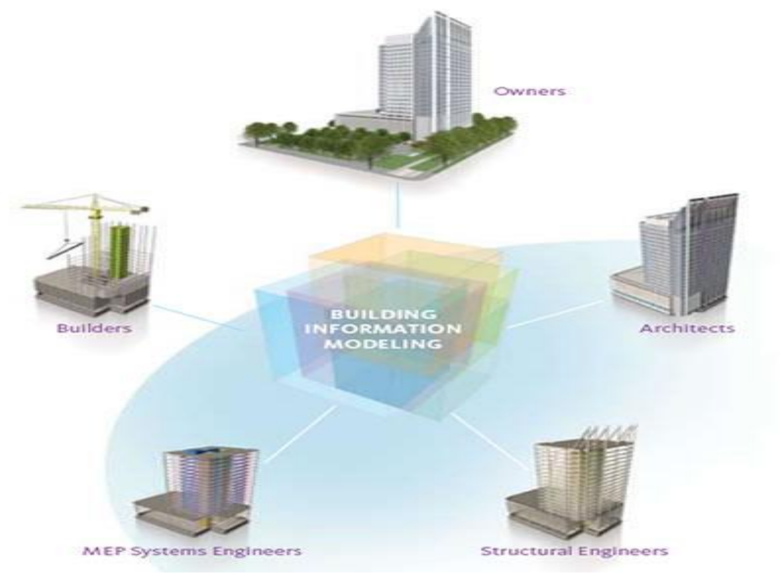


Figure 2.1: Conceptual diagram to describe the Building Information Modelling concept (Haron et al, 2009)

Sebastian (2011) distinguishes between two aspects of the BIM concept, namely an intelligent building model and an integrated collaboration approach, which is designed to facilitate open information sharing and integration. These intersect with the BIM framework and technology produce several aspects, as illustrated in Figure 2.2.

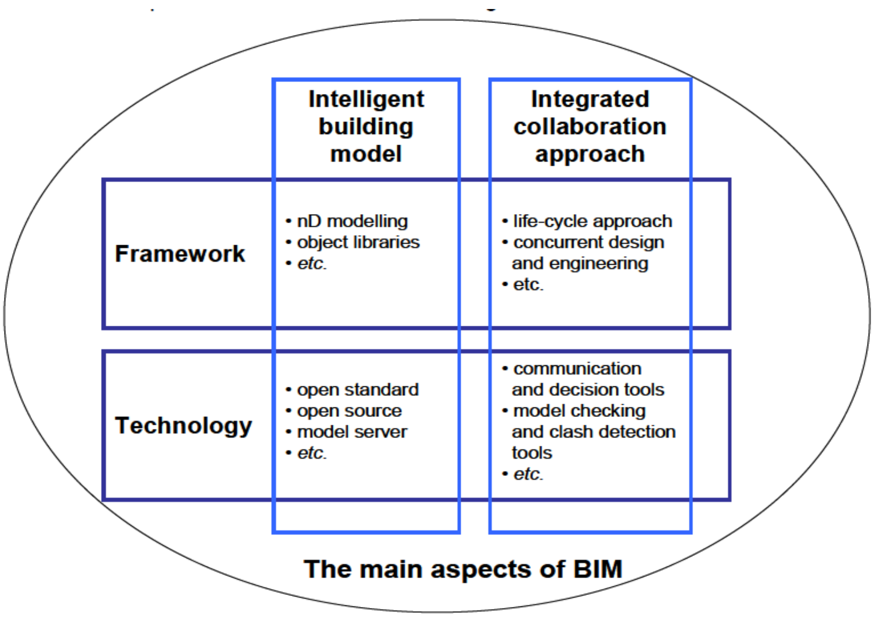


Figure 2.2: The main aspects of Building Information Modelling (Sebastian, 2011)

This interrelation produces several new aspects that offer benefits for construction projects. For example; the interrelation between the intelligent building model and the framework enables multi-dimensional modelling that can include three-dimensional models, time (the fourth dimension) and cost (fifth dimension). Furthermore, the intersection between the integrated collaboration approach and the framework will result in innovative products with a dynamic life-cycle approach. Dynamic life-cycle management goes beyond simply minimising costs to maximize the total benefits that can be gained. Moreover, the integrated collaboration approach and the technology support decisions through construction processes based on the open communication platform for project data, as well as making it possible to check for clashes in the design, which helps to eliminate problems and design errors at an early stage in the project life cycle. Amongst other things, BIM can thus minimise errors, improve quality and highlight clashes. Above all, it offers an appropriate solution to the problem of cost overruns arising from change orders in the Jordanian construction industry.

2.3.4 BIM at the maturity stage of implementation

The review of the BIM literature reveals a need to establish a shared definition of BIM as a basis for identifying the characteristics of its maturity level of end-use. Succar (2009) identified the maturity stages of BIM as those stages which provide a systematic framework for the implementation of BIM from the three perspectives of technology, people and process. Improvements in one of these aspects will result in a significant improvement in BIM capability. Significant efforts have been made to characterise the maturity level of BIM in the construction industry. According to UK-Gov (2011a), the maturity level of BIM comprises three levels, Level 0, Level 1, Level 2, and Level 3, as illustrated in Figure 2.3. Khosrowshahi and Arayici (2012) also suggest three levels, as shown in Figure 2.4. These levels are object-based modelling, model-based collaboration and network-based integration. It is very important to clarify the features of the maturity level in order to assess how far it is achievable in the Jordanian construction industry. This research will use these classifications to investigate the current state of BIM implementation and awareness in the Jordanian construction industry. Furthermore, it will examine the barriers to achieving the next level of BIM maturity.

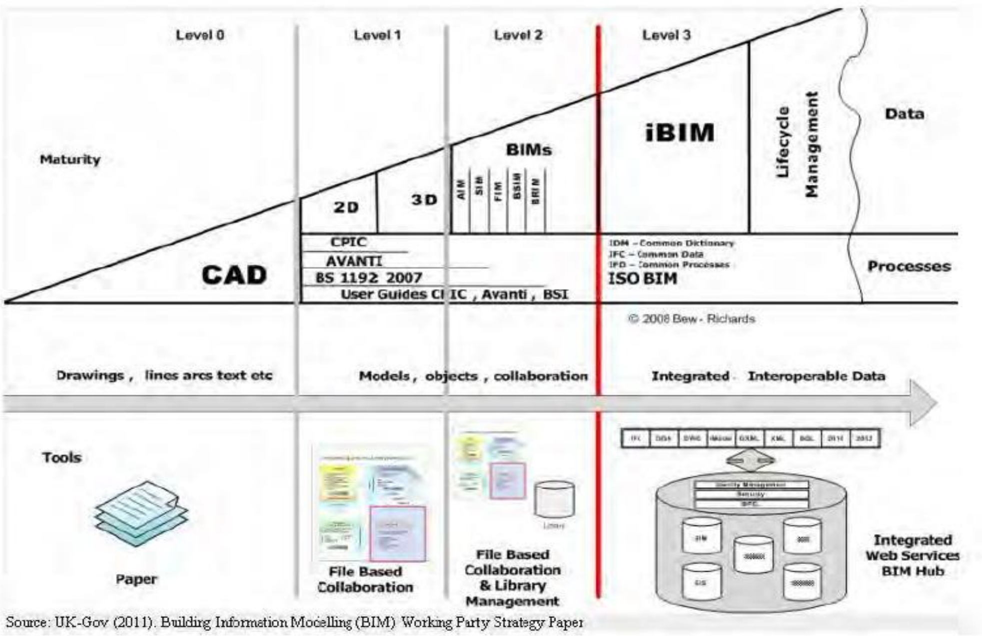


Figure 2.3: The Bew-Richards BIM maturity model (UK-GOV, 2011a)

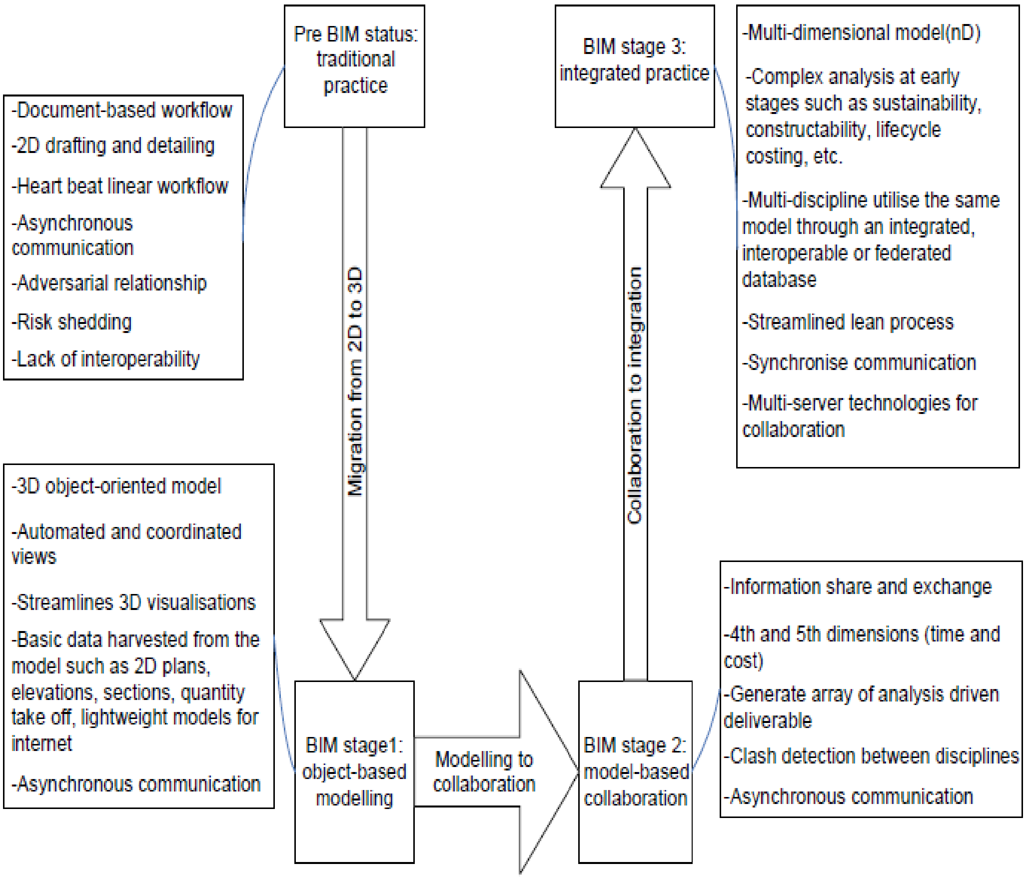


Figure 2.4: Stages of maturity in BIM implementation (Khosrowshahi and Arayici, 2012)

2.3.4.1 Pre-BIM stage (Level 0)

At this level, BIM is not implemented in a construction project. There are many obstacles to the implementation of BIM in cases where the industry depends on traditional practices. At this stage, as presented in Figure 2.4, construction firms depend on 2D CAD for drafting and detailing, with a lack of interoperability and collaboration between different disciplines. According to Khosrowshahi and Arayici (2012), the traditional construction process depends on paperwork in the form of drawings and written documents, which increases the probability of human error. Such poor information management processes will lead to clashes and inconsistencies between the different components of a project, functional inefficiency, weak understanding of the planned construction and the inaccurate development of components. Moreover, the knowledge obtained once the project is completed is not well organised and is buried in detail, so it is hard to use and to comply with best practice and knowledge derived from other projects. This means that BIM is still facing massive challenges, and this is why it can be said that the construction sector is currently at the pre-BIM stage.

2. 3.4.2 Object-based modelling (Level 1)

This level constitutes the first level of BIM maturity, and is characterised by the move from 2D to object-based modelling and 3D. This stage of maturity, as presented in Figure 2.4, streamlines 3D visualizations, automates and coordinates views, harvests basic data from the model and offers asynchronous communication. BIM models real architectural elements and is still mono-disciplinary, depending mainly on CAD (Khosrowshahi and Arayici, 2012). CAD is managed in a format of two or three dimensions using BS1192:2007 and a file-based collaboration tool, providing a common data environment, and possibly some standard data structures and formats. This level of BIM maturity thus depends on 3D CAD as the core element, which facilitates the production of the required information, automates views and offers visualization.

2. 3.4.3 Model-based collaboration (Level 2)

Level 2 of BIM maturity is characterised by the move from object-based modelling to collaboration between different disciplines. As seen in Figure 2.4, this level of maturity is able to utilise many approaches, including the time approach (4D) and the cost approach (5D). Additionally, construction teams are able to identify clashes between disciplines in this stage that will minimise problems and changes in the construction project. Khosrowshahi and Arayici (2012) explain that "while the building has highly complex process due to design and managing of building, the streamflow of data and smooth communication as well collaboration between project's parties are the remedy of that". Managing the three-dimensional model environment in terms of different resources depends on file-based collaboration and library management (Rogers, 2013; UK-Gov, 2011a). Level 2 of BIM maturity facilitates construction practices minimising problems in construction projects by moving the project on from the object-model-based stage to one which accommodates a wider range of collaboration between different disciplines and highlights the dimensions of cost and time, as well as potential clashes.

2. 3.4.4 Network-based integration (Level 3)

This is the highest level of BIM maturity, and signifies a move from a collaboration to an integration model. This makes it possible to carry out a complex analysis of a construction project at an early stage in the project life cycle. Additionally, multi-dimensional models are used in this maturity stage. Models in this stage become interdisciplinary nD models, allowing complex analyses at early stages of virtual design and construction (Lee et al., 2005). Khosrowshahi and Arayici (2012) believe that the integration level is a reflection of the real BIM philosophy, the benefits of virtual workflows are increasing due to dissolve substantially and players interact in real time throughout the project life cycle. Furthermore, this stage of BIM maturity represents the full integration of interoperability between disciplines by using a collaborative web server and 'web services' that are compliant with IFC standards (Rogers, 2013; UK-Gov, 2011a). To sum up, the integration level of BIM maturity is the highest level of maturity in the construction industry, and contains many features. During this stage complex analyses can be carried out at an early stage, which significantly minimises problems in construction projects and improves time, costs and quality control. Multi-dimensional models are used in this stage which offer efficient interoperability between several disciplines.

2.3.5 Processes of BIM implementation in construction business practices

The transition to BIM can be achieved by integrating BIM into the business process model of construction practices. This means that the effects of integrating BIM with construction processes can be measured. A clear understanding of an applicable process reengineering framework to support the construction process is required. If that is the case, implementing BIM to improve the construction process will be smooth, and will deliver significant advantages in construction projects. Jordani (2008) suggests reforming business processes to achieve meaningful change during the construction process. In the context of the UK, Arayici and Aouad (2010) propose building life-cycle processes for BIM implementation. They first analysed the construction life process framework in the UK, as illustrated in Table 2.1. This was then integrated with BIM through linkage between the proposed process framework and the BIM integrated process, as shown in Table 2.2. Specific names are also provided for the models created at different stages of the design process with reference to the Senate Properties (2007) documentation (Arayici and Aouad, 2010). The processes proposed are designed to offer smooth and seamless integration with the real environment.

Table 2.1: A proposed construction life-cycle process framework in the UK (Arayici and Aouad, 2010)

Process protocol (UK)
Phase 0. Demonstrating the Need Phase 1: Conception of Need
Phase 2: Outline Feasibility Phase 3: Substantive Feasibility and Outline Financial Authority Phase 4: Outline Conceptual Design
Phase 5: Full Conceptual Design
Phase 6: Coordinated Design, Procurement and Full Financial Authority
Phase 7: Production Management
Phase 8: Construction
Phase 9: Operation and Maintenance

Table 2.2: A process framework for a BIM-integrated construction lifecycle (Arayici and Aouad, 2010)

BIM-integrated construction life-cycle process	
Requirements model, Site BIM, Inventory BIM	Space requirements, structural requirements, site requirements
Spatial group BIM, Spatial BIM	Environmental impact, energy simulations, visualisation and environmental integration, MEP/structural alternatives
Preliminary building element BIM (Pre BIM)	Building elements, licensing and permits requirements
BE – BIM: Quantity take-off phase	True investment, MEP simulation, calling for sub-contractor tenders
BE – BIM : Construction phase	Detail design, pre-fabrication, product planning
As-built BIM	Building construction and site management, facility management, space and occupancy management, renovations and extensions, demolitions
Environmentally integrated BIM	BIM handover, product training, future planning

These tables indicate how BIM can be integrated with construction business processes to improve and even revolutionise construction practices in the UK. They also provide labels showing a specific BIM stage for each step in the construction process. This integration of BIM and construction business processes could be replicated in the Jordanian construction industry. However, effecting this transition will not run smoothly due to the special environment of the Jordanian construction industry. This research will therefore explore the level of understanding of BIM in the Jordanian construction industry, as well as the barriers to the adoption of BIM, as an initial step before proposing a process for integrating BIM into Jordanian construction business practices.

2.3.6 Developing strategies to minimise the impact on business practices

BIM is a technology for the construction industry which aims to manage construction phases efficiently. However, implementing BIM in the construction industry could have negative effects on construction business processes. According to Kirby (2007), delays may occur during the implementation of BIM that lead to delay starting of construction project. These may be caused by potential disruptions and difficulties in workflow transitions, while a lack of adequate staff staff is also a factor in many of these circumstances. Therefore, it is very important that organisations adopting BIM technologies should be able to resolve these issues. For this reason, Arayici and Aouad (2010) propose deriving strategies from within the organisation. They propose several steps in the three main phases of the BIM implementation process (preparation, rolling out and post-implementation), with focus points for each phase, as presented in Table 2.3.

Table 2.3: The BIM implementation process and focus points (Arayici and Aouad, 2010)

Phase	Steps involved	Focus points
Preparation	a) Planning for the change	
	b) Business process management	Effects on the Business Process (BP)
	c) Implementation checklist	
	d) Implementation plan	Minimising the anticipated effects on the BP
	e) Initial training	In particular for higher management and those who are affected the most
	f) Training plan for next phase	
Rolling out	g) Change management	
	h) Adequate hardware and software	
	i) Implementation	
	j) Training for all staff	
	k) Pilot the first few projects	Performance of the BP

	l) Minor adjustments	Rectifying the BP
Post-implementation	m) Update the implementation plan	
	n) Post-implementation checklist	Any future activities and plans
	o) Assess adequacy of training	
	p) Evaluate pilots to develop further recommendations	
	q) Confirm increased business intelligence and performance	Optimizing the BP

2.3.6.1 Preparation phase

In this phase, firms have to analyse the effects of the new technology on the business process and prepare initiatives to minimise difficulties during and after implementation. Using a business process management system (BPM), an implementation checklist and initial training can minimise many of the problems. For example, having highly skilled people will lead to the efficient implementation of BIM, as well as overcoming barriers to BIM and avoiding adverse effects on construction work.

2. 3.6.2 Rollout phase

Firms already use change management processes for the implementation of all systems and training programmes, and for conducting business assessments of outcomes using live pilot projects and new technologies, and these are appropriate for the rollout phase. This involves a complete assessment of the business processes which may require reengineering, and measuring their efficiency, effectiveness and performance through a pilot project and then rectifying any issues that may be identified.

2. 3.6.3 Post-implementation phase

The final phase includes analysing the efficiency, effectiveness and performance of the new system and processes. This will help firms to evaluate the current status and to develop plans for new business opportunities that the business could target (Kirby, 2007).

To conclude, this critical review of the adoption of BIM in the construction industry has found that it could have adverse effects on construction business processes, such as delays in starting construction. Developing appropriate strategies will minimise these impacts and improve the adoption process. The strategies proposed relate to the three main phases of preparation, rolling out and post-implementation. A thorough investigation concluded that BIM has not been implemented in the Jordanian construction industry. This means that construction firms should pay particular attention to the preparation phase in order to minimise the negative effects of adopting BIM. This research will focus on the barriers to the adoption of BIM identified in the Jordanian construction industry, as well as clarifying the effects of implementing BIM on the cost of change orders in the Jordanian construction industry. Since the adoption of BIM could lead to undesirable results such as delays in starting construction, identifying barriers to BIM and trying to overcome them will have a positive effect on the process of adoption, and may also reduce any adverse results of the adoption of BIM in the Jordanian construction industry.

2.3.7 The components of building information modelling

Critical examination of BIM in the construction industry has suggested that a wide range of benefits could be earned when it is implemented. These benefits spur construction industry players to adopt BIM in their projects. However, implementing BIM effectively in the construction industry requires changes in the way work is done at almost every level, involving a switch from traditional processes to integrated and intelligence-based processes (Kiviniemi, 2013). Consequently, the adoption of BIM in the construction industry involves technology, process and people. The following review examines these three main components of BIM in the construction industry.

2.3.7.1 Technology

The first component of BIM is technology, to which the different project parties look with different expectations. Gu and London (2010) found designers see BIM as an extension of CAD, while contractors and project managers expect BIM to help in analysis, scheduling and cash-flow modelling. Cooperative Research Centre (CRC) for Construction Innovation (2005) sees BIM as a parametric digital model using smart objects to store project data on the physical and functional characteristics of a building. BIM as a technology thus presents a different face according to the discipline using it. To fulfil these different expectations, it is very important to define the capabilities of BIM as a technology in the construction industry. In this regard, Rogers (2013), drawing on Eastman et al. (2011) and Underwood and Isikdag (2009), lists some of the capabilities of BIM, as illustrated in Table 2.4. The table shows the significant benefits BIM can offer a construction project against headings showing its functional features and areas of application.

Table 2.4: The capabilities and applications of BIM (source; Rogers, 2013; Eastman et al., 2011, Underwood and Isikdag, 2009)

Functions and Areas of Application	Extended Description
Early/Conceptual Design	Can include photo-realistic visualisations to support design process, planning applications and communication with non-expert stakeholders and the general public. These can be virtual walk-throughs and not just static images. Can be extended to include operational user testing, e.g. projected customer flows in shopping centres or patient movements in hospitals. Visualisations are commonly used for sales and marketing purposes.
3D and Parametric Modelling	Individual components can be modelled and appraised, and linked into their respective systems. E.g. a variable air volume damper can be individually assessed and then incorporated and assessed as part of overall HVAC system. The HVAC system can then be incorporated into the entire building model and assessed in conjunction with other services, structural or architectural assets. 3D models provide for the (semi)-automated provision of coordinated services drawings. This enables visual verification of design concepts and can be extended to automatically model human space requirements for access – particularly beneficial for maintenance works in plant rooms.
Acoustics and Lighting	Interactive, parametric 3D models enable the interrogation and modelling of spaces and surfaces for acoustic and lighting design development.
4D - Assembly and Operation	Scheduling and sequencing of site activities. Can be extended to include site logistics and temporary works planning. Materials delivery sequencing can be planned, e.g. site deliveries in congested inner cities.
5D - Estimating and Cost	Estimating and cost management. Scenario and value management activities can be included.
6D - Procurement/ Supply Chain	Can include e-procurement and integration of supply chain. Includes interaction with component and materials suppliers. Can include design information, such as lift or escalator manufacturers, shop fabrication drawings that can be included for 'as-built' record drawings.

6D - Facilities Management	Planned and preventative maintenance can be automatically scheduled, complete with requisite information (e.g. supplier details). Can be linked directly to inventory management systems. Reactive maintenance can be aided by modelling remedying works complete with all supplier information.
6D - Operations/ Facilities Usage	Models can be integrated with space usage applications to enable optimised facilities occupation services such as room bookings or business/operational process changes. Real-time monitoring of building usage, including energy usage, integrated with building management systems (BMS).
Structural Analysis	Complex structural calculations can be performed to verify, validate and test proposed designs.
Clash Detection using BIM Objects in Design and Construction Stages	Automated clash-detection capability identifies where two or more components or objects interfere. Tolerances can be established to allow for build/constructability.
BIM-based Collaboration and Collaborative Environments	Sharing of single-source, unified data enables a new level of accurate collaboration by design team members. Transferring the BIM model(s) to the cloud enables real-time collaboration by remotely located design team members. Incorporated document management system enables command of version and revision control systems.
Applications for Code Checking against National Regulations	BIM models can be automatically verified, validated and tested against national building code regulations.
Applications for the Green Building Concept (i.e. design of energy-efficient buildings); Applications for Sustainable Design	Design optimisation capabilities can allow designs to be optimised for energy efficiency or environmental sustainability. Analysis tools enable modelling of solar gain, thermal mass and hydraulic flow. Facilitates introduction of sustainable fabrics and technologies as their utility and efficacy can be better predicted. Can include technologies such as ground-source heat pumps or material replacement such as rammed earth construction. Pollutants and toxins can be recorded and managed, including control of hazardous substances during refurbishment or eventual demolition. Proposed designs can be automatically checked against accreditation

	systems such as BREEAM and LEED.
BIM and Geospatial Information Systems	Can include site technologies for setting out works and components. RFID systems integrated for component location capabilities.
Creating BIM Geometries through Spatial Information Acquisition	Point cloud technology enables retrospective development of 3D BIM models.
Integration of BI – GI Models	ERP (enterprise resource planning) and MRP (manufacturing resource planning) integration with BIM are logical extensions. BIM models can drive manufacturing systems, e.g. ductwork or structural steel shop manufacturing. Entire business process can be managed and quality assured through ERP system.
The Role of BIM in 3D City Models	Utilities such as power and drainage can be modelled and assessed within their civic setting. This enables providers and authorities to better manage urban development. Traffic flows can be modelled to improve integration and traffic planning; transport networks can be improved at master and regional plan level. Emergency response and security/policing requirements can be visually or numerically assessed and enhanced.

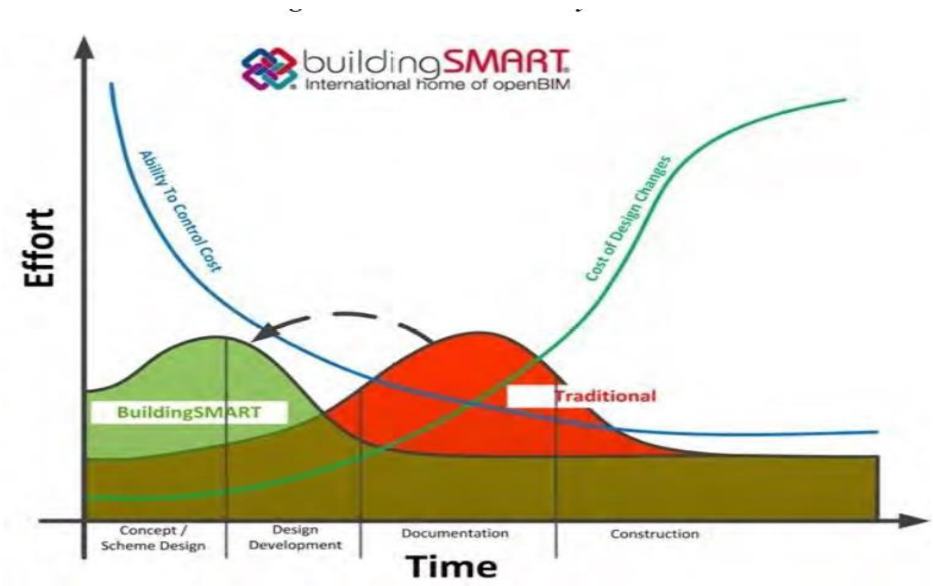
Construction projects involve a huge amount of data. The key characteristics which need to be recorded are parameters representing the minimum of each component, such as height, length, width, depth, material properties and element properties (Building SMART (2012d). The important value of these parameters in BIM linked with object, according to Dwyer (2012) the value of parametric data concept is essential for the object. He also points out that parametric objects are typically based on a set of rules that define their performance and appearance, and allow for a range of unique instances of the object. Parametric modelling also maintains the relationships between different objects in order to feed data from one to the other.

It is clear that a significant amount of data is stored and integrated within the BIM model. The efficient integration of this data has great benefits for a construction project. In Jordan, change orders are a major challenge facing the construction industry, and many projects have suffered from cost overruns. Therefore, the researcher will examine the effect of implementing BIM and the number of change orders in Jordanian construction projects. Furthermore, House of

Quality will determine the correlation between BIM capabilities and the major causes of change orders in Jordan, as well as the ability of BIM to reduce the cost of change orders.

2. 3.7.2 Process

Process is the second component of BIM, and contributes to the transition from traditional processes which depend on 2D CAD to an integrated model. This demands enormous change to current processes. According to Gu and London (2010), the adoption of BIM requires a change in existing work processes. Both collaboration and integration across disciplines are essential for the development of an integrated model, i.e. a collaborative setting where the parties contribute to a single shared model. Brewer et al. (2010) argue that building information modelling is not solely a technical initiative, as the BIM software comprises elements which are interoperable and integrated with each other. This means that all parties must be educated and assessed for their suitability, and that an appropriate culture must be developed. Therefore, approved protocols and standard processes are needed to assign responsibilities and carry out design and validation. This change in processes can be represented by the MacLeamy curve (2007), as illustrated in Figure 2.5.



Source: (MacLeamy, 2007)

Figure 2.5: The MacLeamy curve for the fundamental nature of the change in operational processes in relation to BIM (MacLeamy, 2007)

The MacLeamy curve shows that with the adoption of BIM, the entire design process is brought to the front of the project and executed earlier and with a higher level of completion than it traditionally has been. This will significantly improve cost control over the project life cycle, as well decreasing the cost of design changes. To be successful, the adoption of BIM involves improving communication and changing traditional processes. Change in traditional processes in the construction industry is required for successful BIM adoption. Significant benefits will not be achieved if processes are not adapted. In the Jordanian context, a thorough investigation is required to define current processes and their likely effects on the adoption of BIM.

2. 3.7.3 People

People have to adapt if BIM is to be implemented successfully. According to Rogers (2013), many studies have shown that the capabilities of human resources have to be changed to match new technologies or operational processes. In this context, Eastman et al. (2011) conclude that team members and technical staff need suitable training to be able to use BIM and to continue to contribute in the changing work environment, so it may be necessary to provide team members with experience of new processes and procedure. Any significant change in work will require technical support and training. People are the third component of BIM, and it is essential that they are developed if it is to achieve its full potential. A ‘BIM model manager’ is one of the new roles that result from adapting human resources to work with BIM technology. The model manager is responsible for team activities such as managing access, availability, coordination, configuration, consistency and change (Eastman et al., 2011). People are the major pillar that should be focused on for the effective adoption of BIM in the construction industry. People need to improve their skills, knowledge and awareness of BIM, which can be achieved through training sessions and the use of BIM standards and protocols, and they need to learn from successful implementation in previous projects. This research will explore issues related to the human factor for the adoption of BIM in the Jordanian construction industry. Amongst other things, these include levels of awareness and the availability of skilled and trained staff. This will provide a clear picture of the current readiness of people for the adoption BIM in Jordan.

2.3.8 Awareness of BIM

BIM heralds a new era in construction processes, effectively shifting the construction industry to a higher level of integration and collaboration between project parties. However, real knowledge and understating of BIM has still to develop to the full. A number of studies have indicated that a lack of knowledge and awareness of BIM is a major barrier to its effective adoption. In Jordan, the awareness level of BIM in the private sector has not been clearly established because there has been little research. The current research will therefore focus on exploring awareness of BIM in the Jordanian private construction industry.

Many studies across the world have examined the level of awareness of BIM in the construction industry. The findings generally indicate that there is a lack of research with the aim of determining knowledge and awareness of BIM. According to Newton and Chileshe (2012), there are only a limited number of studies that have explored the current level of awareness, knowledge and use of BIM in construction organisations in South Australia, which suggests a weakness in the understanding of BIM and a lack of interest. Similarly, Ibrahim and Bishir (2012) argue that there is a need for more studies to explore the level of awareness and knowledge of BIM in the Nigerian construction industry in order to promote the adoption BIM as well as increase awareness, as the results indicate that the public and the private sectors have not taken any steps to train or retrain their staff to use BIM applications. These conclusions paint a similar picture to the current situation of BIM in the Jordanian construction industry, in which there has been a lack of successful BIM implementation.

In order to investigate the level of awareness of BIM, Newton and Chileshe (2012) asked participants about BIM terminology, finding that only 3.45% of the participants in their survey had any significant understanding. Similarly, lack of understanding and awareness of BIM has been identified as a major barrier to more widespread adoption of BIM in Australia by many researchers. These results testify to the low level of understanding of BIM within the construction industry. This research will therefore ask interviewees about their knowledge of BIM terminology in order to determine their understanding. In another study, Adebimpe and Moses (2016) also found a low level of awareness among experts in the Nigerian construction industry. To enhance the awareness level they suggested focusing on the benefits of BIM, as well as increasing governmental support for implementing BIM and organising training courses in both the private and the public sectors. Chewlos et al. (2001) also concluded that private clients were not mandating the use of BIM in their projects because of their low level of awareness and knowledge of BIM. However, they believe that the technologies currently in use are enough, and that there is a lack of educational facilities to support the implementation of BIM, which is one of the main barriers to BIM. In India, a survey conducted by the collaboration of three institutions, the Indian built environment sector, the RICS School of the Built Environment and KPMG, found that 22% of participants are currently using BIM, 27% have a good knowledge of BIM and are considering adopting it, while 43% of respondents are 'just aware' and 8% are unaware of BIM (Chougule and Konnur, 2015). The International BIM Report 2016 reported that almost half of the participants from the Czech Republic were aware of BIM , but only 13% were using it. The results indicated a need to put the use of BIM into legislation for public procurement and to prepare standards for BIM libraries and outputs (Pospíšilová, 2016).

Overall, these studies indicate that a weak understanding of BIM in a country leads to delayed adoption in that country. However, awareness of BIM is the key factor for its successful adoption in the construction industry. Nevertheless, the initiatives suggested to improve the rate of adoption of BIM start with improving awareness levels through training courses, focusing on the benefits of BIM, and government support through legislation. As a result, and due to the paucity of research carried out in the Jordanian private construction sector, this research will concentrate on determining the awareness level of BIM, as well as ascertaining participants' understanding of BIM, using interviews and a questionnaire. It will then investigate how far the current level of awareness constitutes a barrier to the adoption of BIM in the Jordanian construction industry.

2.3.9 The benefits of BIM

Building Information Modelling is an intelligence tool has a wide range of benefits. Many researchers have explored the advantages of using BIM in the construction industry. This section will focus on these studies in order to identify the benefits which could be gained if BIM were adopted in the Jordanian construction industry. Building Information Modelling has great positive effects on construction projects throughout the project life cycle. Substantial impacts of implementing BIM may be gained at all the stages of the construction process (Eadie et al., 2013). The benefits of BIM can be apparent both in the short or the long term. Therefore, Sahil (2016) categorised the benefits of BIM under these headings, short and long-term. The benefits in the short term, i.e. those which are immediately apparent, are a reduction in conflicts, a better understanding among team members of the ideas underlying the design, enhanced project quality, a decrease in Requests For Information (RFIs) and better predictions of construction costs. Benefits over the longer term are fewer claims and less litigation, reductions in the construction costs, increased profits, a reduction in the project duration and attracting new business. Lu et al. (2014), drawing on a number of studies, summarised the benefits of BIM as better communication, collaboration from the start, error-free completion of the work, less rework, better predictability, cost savings and improved productivity. It can be seen clearly that a wide range of benefits accrue from BIM in construction projects that directly affect costs, time, quality and so on. These benefits may improve the Jordanian construction industry if it adopts BIM, as well as minimising the cost of change orders.

The virtual 3D model of BIM is of particular importance in that it supports understanding about the project. Lee et al. (2003) found that 98% of the industry finds it difficult to understand 2D. This clarifies the root of many problems in construction projects, as well as explaining the great number of change orders. Kymmel (2008) concludes that the 3D model is the main advantage of BIM because the virtual model helps foster close collaboration between project parties at an early stage on most aspects of planning, design and construction. That confers significant benefits in the planning and construction phases of building projects, and facilitates greater understanding of the project. What is more, Eastman et al. (2008) suggest that the virtual model discovers design errors and omissions, as well as detecting clashes. At the same time, the virtual model can generate both 2D and 3D drawings, and is highly effective in eliminating errors at an early stage in the project life cycle. In short, the 3D model significantly supports communication and collaboration between the project parties, which will have a direct influence on minimising changes in construction projects by identifying clashes and errors at an early stage in the project life cycle, i.e. before construction begins.

Building Information Modelling provides a single shared database that allows construction parties to integrate and collaborate efficiently. The data stored in the model can initiate a learning cycle, a deeper understanding of the building dynamics and constant improvement throughout the facility life cycle (Carbonari et al., 2015). Additionally, BIM is an intelligent facility which automatically updates the model once a change is made, which will enable decision makers to make appropriate decisions based on real-time data about the building use and behaviour. It can clearly be concluded that the single database is one of the most beneficial features of BIM in that it pushes towards integration and collaboration between the project parties. This could dramatically minimise problems in the Jordanian construction industry, especially those arising from changes, through the significant integration and communication which it facilitates between project parties.

A project's cost and time are also significantly affected by BIM. Implementing BIM in a construction project leads to a reduction of the total cost because it minimises changes, reworking and so on. What is more, BIM minimises the total duration of construction by efficiently controlling the project schedule and sequencing tasks. In this regard, Azhar et al. (2008) conclude that collaboration within project teams through BIM leads to reduced costs, improved profitability, better time management and improved relationships between the project parties. Carbonari et al. (2015) also report other studies which indicate that implementing BIM in construction projects positively affects costs and time and reduces errors, omissions and reworking, and that companies which are fully committed to BIM report a return on investment of over 25%. Kymmel et al. (2008) add that the 4D model (construction schedule) can be further developed once the initial schedule is available, and the construction sequence can be simulated. Hence, as concluded in several studies, BIM can significantly minimise both the cost and duration of construction projects, which could help to minimise cost overruns and delays in completion in the Jordanian construction industry. Many other researchers have highlighted a great number of benefits which can accrue from BIM. For example Kuehmeier (2008) lists the following: conflict resolution, the ability to adjust costs as changes occur, speeding up the design and construction process, reductions in the ultimate cost, single entry, alternates, design optimization, conflicts identification and resolution, improvements in constructability, better construction sequencing and scheduling, life cycle evaluation and the ability to conduct operational simulations.

In conclusion, it has been seen that BIM is tremendously effective for construction projects, offering a wide variety of advantages. In view of the fact that the Jordanian construction industry is suffering from many problems such as the high cost of change orders and delays in completion, implementing BIM may be the best way to reduce cost overruns arising from change orders. This research will therefore investigate the cause of change orders in the

Jordanian construction industry, the current level of awareness of BIM, as well as the barriers to its use, collecting data through interviews and then a questionnaire based on the results to be distributed across the construction industry. The questionnaire data will be analysed by means of the Severity Index, factor analysis and correlation tests in order to determine how far the introduction of BIM will be able to minimise the cost of change orders by reducing their main causes in the Jordanian private construction sector. The House of Quality will be also be used to determine the effectiveness of BIM in dealing with change orders.

2.3.10 The effects of implementing BIM on costs and change orders

As discussed previously, Building Information Modelling has great benefits for construction projects. This section presents a review of studies which explore the benefits of BIM for reducing the cost of change orders in construction projects, as well as the cost of construction projects. The findings give an indication of what will happen to the cost of change orders in the Jordanian construction industry if it in adopts BIM.

Firstly, BIM is an intelligent system which gives stakeholders a great chance to integrate and collaborate at an early stage of the project life cycle, and contributes effectively to the overall improvement of construction projects. The effects of proper integration between the project parties on the project's costs are identified by Laiserin (2008). He concluded that implementing BIM will assist in improving aspects of the business process. Improving one or more aspects of an existing process will affect the project in terms of enhanced accuracy, consistency, communication, integration and coordination, which leads to savings of between 10% and 30% of project costs. In the same way, Lu et al. (2014) found that the implementation of BIM contributes to savings of 6.92% of a project's total cost. In one case it was also found that using BIM tools and a collaborative approach to project delivery was able to save $9 million and six months in project time as compared with the traditional process (Manning and Messner, 2008). This review of the literature therefore shows that implementing BIM in construction projects can significantly contribute to minimising the total cost of projects by enabling effective integration and collaboration between project parties, as well as the efficient planning, design and operation of projects. These advantages of BIM will significantly motivate the Jordanian construction sector to adopt BIM in order to reduce both the costs and time of projects.

These reductions in project costs arising from the implementation of BIM come about by reducing various problems in the construction industry such as changes. According to Kuehmeier (2008), the driving theory behind BIM is the elimination of change orders and RFIs (Requests for Information), which arise in construction projects as a result of missing information in the construction documents, since all parties involved in creating the model will check for all possible problems and conflicts. Manning and Messner (2008) concluded that updating plan views, quantities, sections and scope will contribute to controlling costs because they will decrease change orders during the construction process. It is evident that the effect of BIM on change orders in construction projects is achieved by minimising the causes of changes such as design errors, which in turn reduces cost overruns. It can therefore be concluded that the adoption of BIM in the Jordanian private construction sector will reduce cost overruns that arise from change orders.

Various studies have tried to quantify the impact of BIM on project costs and change orders, i.e. how far costs and time are reduced by minimising changes and RFIs, and identifying clashes at an early stage in the project life cycle, before the start of construction. For example, in a study by Azhar et al. (2008) which drew on the results of research based on 32 major projects that used BIM, the Stanford University Centre for Integrated Facilities' Engineering (CIFE, 2007) found that the benefits include:

- Elimination of unbudgeted changes by 40%
- Savings of up to 10% of the contract value through the detection of clashes
- Estimating costs to an accuracy of within 3%
- Reductions of up to 80% in the time required for generating cost estimates
- Reduction of the project duration by 7%.

Another study by Autodesk (2009) examined the results achieved when the Gilbane building company started using BIM software, and found that they had been able to:

- Identify and resolve thousands of design clashes before construction
- Decrease the number of RFIs and change orders by up to 70%
- Save clients more than $1 million on typical projects
- Accelerate project schedules by as much as 10%.

Moreover, according to Kuehmeier (2008), the benefits of BIM which were obtained by an architectural design firm (a global innovator in BIM methodologies) are:

- A decrease of 40% in unbudgeted changes
- Cost estimate accuracy of 3%
- Less than 1% increase in costs
- Bids within 2.5% of actual construction costs
- 60% fewer Requests for Information (RFIs)
- An 80% reduction in the time taken to generate a cost estimate
- Overall savings of 10% of the contract sum through clash detection (coordination)
- A 7% reduction in the schedule cost
- 10 to 20 times the return on investment arising from the life cycle analysis performed by BIM.

Khanzode et al. (2008) found that the number of Request for Information (RFIs) was only 2 out of the 233 identified in a project they investigated; moreover, there were no change orders and the project was completed and operational with all MEP (Mechanical, Electrical, and Plumbing) systems installed. Similarly, Kuehmeier (2008) reported that before implementing BIM in a steel factory project, the total number of RFIs in the steel fabricator had been over 300 in the first three months, whereas all the RFIs were answered after using BIM.

This critical review of studies related to the effects of BIM on the costs of construction projects and the change orders generated has shown that implementing BIM has a highly significantly ability to minimise the number of change orders and the overall cost of projects. It also indicates that BIM is able to eliminate changes in construction projects to a very large extent, reduce RFIs by more than 60%, improve cost estimation, identify clashes before the start of construction, and so on. These and other issues that are influenced by BIM are considered to be the root causes of change orders in construction projects. The researcher therefore aims to adopt BIM in the Jordanian construction industry as a means of reducing the cost of change orders by minimising their causes. In first stage, the researcher will use interviews to investigate the main causes of change orders, which are responsible for significant cost overruns. Then a questionnaire developed from the interview results will be distributed online to a large sample of participants in the Jordanian construction industry to further explore the causes of change orders in Jordan and the impact which BIM has on them.

Finally, House of Quality will be used to validate the relationship between the causes of change orders and BIM in the Jordanian construction industry, as well as to determine the ability of BIM to reduce cost overruns in construction projects by eliminating the main causes of change orders.

2.3.11 Barriers to BIM

Despite the many benefits gained from using BIM, the implementation of BIM in the construction industry will not happen overnight. The adoption of BIM faces many challenges in the construction industry. The major barriers to the adoption of BIM vary from one country to another, depending on the special characteristics, environment and the nature of the construction sector of each country. A thorough investigation of the barriers to the adoption of BIM identified in a number of studies will provide a basis for exploring the feasibility of adopting BIM in the Jordanian construction industry. The major barriers to the adoption of BIM will first be determined, and then possible ways of overcoming these barriers will be examined. A critical literature review indicates that these barriers can be categorised into three main groups related to product, process and people.

2.3.11.1 Barriers related to product

There are many barriers to the adoption of BIM in the construction industry that are related to products.

2.3.11.1.1 Financial considerations

The adoption of BIM requires construction firms to purchase software and hardware, and to train their staff. The financial impact of adopting BIM varies from firm to firm, depending on the current financial status of the firm. According to Autodesk (2011) and Eastman et al. (2011), implementing BIM requires new software as well as new or upgraded hardware to run the processing-intensive software. What is more, software packages need to be updated periodically, which incurs extra costs (Lee et al, 2012). The costs of adopting BIM thus comprise several elements, and several studies have concluded that the overall cost is a barrier to the adoption of BIM in the construction industry.

Eadie et al. (2013) report that many researchers conclude that the front-end costs of implementing BIM act as a significant barrier to the adoption of BIM in the construction industry. Furthermore, they found that the cost of software and the cost of training constitute the fourth and fifth major barriers to adoption in the UK by large contractors. Abubakar et al. (2014) conclude that the cost of training is the most significant barrier in Nigeria. These findings testify to the importance of financial issues for the adoption of BIM in the construction industry. Hosseini et al. (2016) found that the initial cost of adoption is the fourth major barrier in developing countries. This investigation of financial issues has thus concluded that the costs of software, hardware and training are thwarting the adoption of BIM. In view of the fact that Jordan is currently a developing country, this research will critically explore the financial issues that hinder the adoption of BIM in the Jordanian construction industry, as well as using ISM to categorise these barriers on the basis of their independence and dependence.

2.3.11.1.2 Different perspectives on BIM products

BIM is an intelligent technology that is used to facilitate improvements in the construction industry. However, stakeholders view BIM from different perspectives, which obstruct its adoption BIM in construction projects. According to Gu et al. (2008 and 2010), opinions of BIM technology depend on the particular actor. For example, design professionals see BIM as an extension of CAD, while contractors and project managers view it as a more intelligent document management system. Furthermore, the NBS National BIM Report (2014) concluded that BIM may encounter problems arising from project parties' feeling that BIM is not applicable or appropriate to the nature of project work, and the report classifies this as one of five major barriers. Regardless of the fact that BIM is an efficient tool for supporting and improving the construction industry, the way it is viewed by construction participants plays an essential part in deciding whether it will be adopted: the view of the engineer varies from that of the client or contractor. This research will seek to identify participants' views by assessing their levels of knowledge and awareness of BIM.

2.3.11.1.3 Interoperability

The collaborative nature of the construction industry requires effective collaboration and exchange of information between project parties. BIM is particularly good for sharing data and promoting collaboration between project parties. To realise the full benefits of this, Pniewski (2011) argues that the BIM software packages used by different project participants should be 'interoperable'. Interoperability is defined by the (IEEE Standards Board cited in Eadie et al., 2013) as "the ability of two or more systems or components to exchange information and to use the information that has been exchanged". However, current systems in the construction industry suffer from weaknesses in interoperability. Thompson and Miner (2007) consider developing interoperability in existing systems and the creation of multi-accurate models to fulfil different purposes to be the main challenges for BIM technology development. Many BIM applications on the market accommodate separate software packages for architectural, structural and MEP purposes. On the other hand, several software companies have tried to produce comprehensive BIM packages that include several applications (Eadie et al., 2013). To be effective, interoperable applications should be able to exchange data without introducing the possibility of human error by requiring data duplication at the interface (Moon et al., 2011). In conclusion, it is clear that interoperability is essential for the successful adoption BIM in the construction industry in order to improve the exchange of information between project parties. Nevertheless, due to the wide scope of the construction industry and the great number of BIM applications in use, interoperability between applications must be considered one of the major barriers to the adoption of BIM in the construction industry.

2.3.11.2 Barriers related to the BIM process

As in the case of the product, there are many process-related barriers to the adoption of BIM in construction projects. The following have been identified in the in-depth review of the literature on barriers to BIM.

2.3.11.2.1 Changing work processes

Traditional processes depend on paper and documents as the most important means of exchanging information in construction projects. However, BIM was introduced to improve information exchange. Therefore the switch from traditional communication to BIM requires a significant improvement in communication between the project parties. According to Lindblad (2013), BIM is far more than just a tool designed as an interface for information exchange at different phases in a project and for different actors. BIM is fundamentally a single integrated model for the whole life cycle of a project, and needs to be part of a collaborative setting where different participants are able to contribute (Gu and London, 2010). A substantial change in communication practices is required: if BIM is to deliver full benefits in the construction industry, the various construction parties must communicate effectively.

Furthermore, to maximise the benefits of implementing BIM, traditional ways of working must be substantially changed (Arayici et al., 2009), and this is emphasised by studies such as that of Gu and London (2010). Several other studies have also concluded that current weaknesses in communication between project parties are obstructing the adoption of BIM, as are current working practices in the construction industry. For example, in the Canadian construction industry, Forgues et al. (2014) found that professionals are working individually, and that there is a lack of communication and coordination between disciplines, which are major barriers to the adoption of BIM. It has also been pointed out that some organisations might decide not to implement BIM because it requires changes in their traditional business practices and a move from a fragmented to a collaborative way of working (Taylor and Levitt, 2007). To summarise, the critical exploration of the literature which has dealt with barriers to the adoption of BIM shows that traditional communication and work practices in the construction industry can be an obstacle to the adoption of BIM. The researcher will therefore seek to find out whether current methods of communication and coordination among construction project parties in the Jordanian construction industry function as a barrier to the adoption of BIM.

2.3.11.2.2 Legal issues

Using BIM effectively in the construction industry requires certain legal issues related to BIM to be clarified. This could be a major barrier if there is a lack of rules for organising and supporting the adoption of BIM. A review of the legal issues related to BIM was undertaken in order to evaluate the current situation in relation to BIM in the Jordanian construction industry, and its potential to hinder the adoption of BIM.

A lack of codes and standards that should facilitate the implementation of BIM in construction projects constitutes a barrier to the effective use of BIM, and this conclusion has been supported by a number of studies. For example, Chan (2014) concluded that the absence of standards is the fourth key barrier to the adoption of BIM in China. Likewise, Hosseini et al. (2016) considered the absence of standards to be one of the major obstructions to BIM in developing countries. Such findings indicate that it is essential to ensure that there are certain standards and codes for implementing BIM in construction projects, as a lack of these prevents the effective adoption of BIM.

The question of ownership of the model is another legal problem. Lindblad (2013) points out that the client who pays the design costs might feel entitled to own the model, although it is the designer and other participants who have provided property information, which requires protection, and so they believe they own intellectual property. The UK BIM Industry Working Group (2011) suggests that the ownership of copyright should reside with the author rather than the individual who commissions the work. Chao-Duivis (2009), on the other hand, argues that the ownership of copyright should be analogous to the output of conventional teamwork, because the model is shared work. Ownership in relation to BIM is thus a complicated issue in the construction industry, and one which could hinder the adoption of BIM. The current research will seek to clarify who owns the BIM model in the Jordanian construction industry.

Contractual agreements are also a legal issue. Limitations in contracts will obstruct the adoption of BIM in the construction sector since BIM requires new roles and integrated relationships between project parties. Construction parties need the security of a contract which protects the confidential data in the BIM model, and particularly when the BIM model is part of a construction extranet, otherwise they will be exposed to a critical risk (Breetzke and Hawkins, 2009; Christensen et al, 2007; Udom, 2009). Specific clauses must thus be introduced into contracts to manage the implementation of BIM in construction projects, for any loopholes will impede the adoption of BIM. To summarise, legal issues have to do with standards and codes in relation to the ownership of models ownership and to contractual agreements. A lack standards or ambiguity in this area constitutes a major barrier to the adoption of BIM in the construction industry. This research has investigated the current legal situation in relation to BIM in Jordan in order to assess how far it supports the adoption of BIM.

2.3.11.2.3 Lack of demand and interest

BIM has tremendous benefits for construction projects. However, a number of studies have indicated that a lack of interest and demand is a barrier to the implementation of BIM in the construction industry. The project parties may decide not to implement BIM because they believe that there is nothing wrong with the way current processes execute and deliver construction projects, so there is no need to use BIM. According to Yan and Damian (2008), many people are not interested in using BIM, or they believe that current design processes – i.e. without BIM - are enough to design the projects. Likewise, Tse et al. (2005) concluded that the main reason why architects have been hesitant to use BIM is the lack of demand from clients and other project team members, which is confirmed by the view of the majority of architects that “existing entity-based CAD systems could fulfil their drafting and design needs”. Other studies across the world have also found a lack of interest and demand to be a major barrier to the adoption of BIM. For instance; Forgues et al. (2014) found that because clients in the Canadian construction industry do not see the benefits or returns of BIM, they do not ask for it. It is for such reasons that the NBS National BIM Report (2014) categorised client demand as one of the five major barriers to BIM. In the context of China, Chan (2014) concluded that lack of client demand was the fourth obstacle to the adoption of BIM. Similarly, Zuhairi et al. (2014) deemed the lack of requests for BIM by clients to be the second barrier to adoption in the Malaysian construction industry. There is thus considerable consensus on this, and the current research will seek to clarify how far it hinders the adoption of BIM in the Jordanian construction industry.

2.3.11.2.4 Lack of senior management support

Many steps are required to implement BIM in the construction industry, so the support of top management is necessary in order for it to be successful. Top management is responsible for facilitating the adoption of BIM in the construction industry.

However, according to Hosseini et al. (2016), a lack of support from policy makers is the second major barrier to the adoption of BIM in developing countries. Hung and Joo (2011) also confirmed that there was a need for policies and strategies at senior level for fast-tracking practical BIM implementation. Yet in many cases the adoption process has failed as a result of reluctance on the part of top management. According to Gilligan and Kunz (2007), organisations are not utilising Information Technology because senior management thinks that the implementation of new technology requires change in current organisational structure and processes, and that it could jeopardise organisational productivity. This seems to indicate a lack of understanding of how to manage technological change, as strong support from senior management could ease the process of migration in any organisation. Eadie et al. (2013) argue that management support for the adoption of new processes or technologies is necessary if its benefits are to be realised. O'Brien (2000) also concludes that the support of senior management is required because it could give people the confidence they need to implement new technology, especially if they have low self-confidence because of a lack of knowledge of the new technology.

To overcome the obstacle of reluctance on the part of top management, Arayici et al. (2011) suggest that an effective way of implementing BIM and dealing with resistance to change may be to take a bottom-up approach with 'learning by doing' rather than a top-down approach. This suggestion makes it possible to avoid the resistance of top management, where Arayici et al. (2011) believed implementing BIM is related to software and hardware used, process and people. To come back to the current research, it is not clear how the adoption of BIM is supported in the Jordanian construction industry, so the researcher will explore how far the attitudes of top management constitute a barrier to the adoption of BIM.

2.3.11.2.5 Staff resistance

The adoption of BIM in the construction industry is dependent on the personal acceptance of the staff who are to implement it. However, any resistance to BIM on their part will serve as a barrier. Mitchell and Demian (2006) concur that "staff could resist implementing new technology in construction projects". Zuhairi et al. (2014) conclude that a lack of support by team members is the fourth major barrier to the implementation of BIM in the Malaysian construction industry. This reluctance in relation to the adoption of new technology by staff may be linked to the fact that they have had insufficient training, or a feeling that the technology may threaten their employment (Ruikar et al, 2005; Griffiths et al., 2014). The support of staff is essential for the successful adoption of BIM in the construction industry. Yet they may oppose it because they feel that current work practices are enough to achieve good results, with no need for BIM, and that its implementation would cause a shortage of people in the construction industry who have the skills to use BIM, as well as push organisation for recruitment staff they able to do specific works rather than BIM. The current research will therefore investigate staff-related barriers to the adoption of BIM in the Jordanian construction industry and explore ways of overcoming them.

2.3.11.2.6 The requirement for cultural change

The culture of the construction industry is an important factor which impacts on the adoption of BIM. Introducing new processes into an organisation involves changing the culture of the organisation, while the risks and challenges are not only financial, but also have a great deal to do with the flexibility or versatility of the organisation's staff and systems (Eadie et al., 2013). The adoption of BIM thus requires a significant change in the culture of the organisation (Rowlinson et al., 2009; Watson, 2010). This could involve changes in practices and processes, or in staff members' skills and knowledge. According to Jordani (2008) and

Mihindu and Arayici (2008) the implementation of BIM requires far-reaching changes in business practices.

2.3.11.3 Barriers related to people

The third set of barriers to the implementation of BIM in the construction industry have to do with people. BIM requires a certain level of skills, training and awareness. For the successful implementation of BIM in the construction industry, all actors must understand the benefits for their profession (Gu et al. 2008). Training to improve skills is required for all those involved with BIM to enable them to reap these benefits (Arayici et al., 2009). This is because people could obstruct the adoption of BIM due to their lack of ability or awareness in relation to BIM, or for other reasons. This section reviews the literature in this area and identifies a number of barriers related to the people factor.

2.3.11.3.1 The new role of BIM model manager

The environment of BIM encourages collaboration and integration between project parties, and creates new roles and work processes, and these are crucial for the successful adoption of BIM. According to Gu and London (2010), the roles, relationships and work processes of project parties will be affected by the adoption of BIM. Many researchers have therefore suggested that a ‘model manager’ would facilitate the implementation of BIM. Rizal et al. (2011) suggest ‘model manager’ as a new job title in construction projects. The role of the model manager is to deal with the system and project participants. The model manager will improve the skills of stakeholders, manage information flows and provide the technical solutions required for BIM functionalities. However; the model manager will not take a part in decision making related to engineering or design solutions, or to organisational processes, but rather focus on the successful and collaborative use of BIM by all stakeholders. The model manager is thus an essential element for the successful implementation of BIM in construction projects. This research will explore people-related barriers in the Jordanian construction industry. The current state of BIM in Jordan, as illustrated in section (2.3.15), is characterised by a significant lack of BIM awareness and skills, as well as the fact that BIM has not been implemented in construction projects which means this barrier is not vital nowadays, and there are many other barriers which are more important.

2.3.11.3.2 Training individuals

As a new technology, BIM needs proper training and a certain level of skills if it is to be implemented effectively. Inadequacy in one or both of these areas will obstruct the adoption of BIM in the construction industry. Training to use the new technology is sufficient for individuals, since it contributes to changing the work environment (Gu et al., 2008; Arayici et al., 2009). A shortage of skills and a lack of training are correlated to each other, since staff need special training to learn new skills and improve their work. According to Stewart and Mohamed (2003), a lack of the knowledge and skills required to use new technology causes problems in implementing it, as well as contributing to low self-confidence. However this situation can be improved by suitable training provided by the organisation. The critical review of the literature has indicated that many studies consider a lack of trained and skilled staff to be one of the major barriers to the adoption of BIM. Forgues et al. (2014) conclude that the lack in training to develop qualified staff is a major barriers to the implementation of BIM in Canada. Likewise, Chan (2014) found a lack of skilled in-house personal to be the first major barrier to the adoption of BIM in China. In Nigeria, Abubakar et al. (2014) ranked the lack of training as the second main barrier, and Hosseini et al. (2016), explored several studies and concluded that the lack of training is a major cause of delay in the adoption of BIM in developing countries.

It can thus be concluded that training to improve staff skills and encourage them to use BIM is essential for its effective adoption. There is a need to invest in training staff in order to overcome barriers to BIM (NBS, 2014). Fox and Hietanen (2007) concluded that one of the main causes of the unsuccessful implementation of new technology is a lack of training by the organisation for their staff, as training is a vital factor which facilitates the adoption of new Information Technology (IT). A lack of training and a shortage of skilled individuals represents a major challenge for the adoption of BIM, so organisations should focus on training and improving their staff skills in order to reap the benefits of BIM. The current research will investigate the availability of trained and skilled staff, and how far they are able to implement BIM effectively in the Jordanian construction industry. It will also explore how a lack of training hinders the adoption of BIM in Jordan.

2.3.12 BIM standards in construction

Construction projects are unique, and comprise many fragmented activities. BIM standards thus provide a road map to help teams to produce a BIM model which is unique to their project. Implementing BIM requires rules and standards for managing the BIM process in the construction industry. These standards describe best-practice strategic, tactical and operational processes, as well as procedures for managing BIM production. They provide a common basis for collaborative work processes between BIM project participants, as well as describing collaborative working methods (Berard and Karlshoej, 2012). Many countries have issued standards for working with BIM. According to Rogers (2013), several institutions and organisations have issued a range of BIM standards that help firms to organise their resources to operationalise BIM, (AEC (UK), 2012c, Indiana University, 2012, the National Institute - Building Sciences, 2012a, New York City Department of Design and Construction, 2012, Singapore Gov, 2012b, The NBS, 2012b, BIM Task Group 2013). This research will check the availability of Jordanian BIM standards. Standards will also be considered in the discussion of the legal issues relevant to managing the adoption of BIM in the Jordanian construction industry. The question of who should be responsible for issuing BIM standards in Jordan will also be explored.

2.3.13 Drivers of the adoption of BIM in the construction industry

The adoption of BIM in the construction industry is driven by various factors, which have been explored by a number of studies. Government is a vital driver, and should lead the adoption of BIM in the construction industry. In developing countries, the main driver of the adoption of BIM is governmental support (Wong et al, 2011, Alufohai, 2012). Zuhairi et al. (2014) examine the major drivers of adoption in the Malaysian construction industry, concluding that government support and enforcement is the main driver, and pointing out that without this the implementation of BIM would be slow or even static. Other drivers are BIM training programmes, the leadership of senior management, the provision of grant schemes for training in BIM, promotion and awareness-raising, and collaboration with universities. They also found that it is government which has implemented BIM in the construction industry of the UK, Australia, Hong Kong and Singapore. Andy et al.'s study discusses other countries (Finland, Denmark and Norway) in which central government has been the main driver of the adoption of BIM. Such support, if it is sufficiently strong, could create a uniform environment in which BIM is accepted across the nation, as well as an active environment for research and development in BIM. In Singapore, through the Building and Construction Authority (BCA), the government has set a target of getting at least 80% of the construction industry using BIM (Teo et al., 2015). All this gives an indication of the importance of government support for the adoption of BIM in the Jordanian construction industry. Government participation is a major factor driving the adoption of BIM in construction projects. Government involvement takes different forms, such as legislation which forces construction organisations to use BIM (as in the UK), conducting training programs and increasing awareness levels.

BIM may also be adopted because of pressure from a client. Rodgers (2015) and Elmualim and Gilder (2014) conclude that pressure from a client is an important factor in moving organisations from non-adopters to adopters of BIM. Panuwatwanich and Peansupap (2013) also concluded that requests from the client was one of the main drivers for the adoption of BIM in ACE industry, and this was followed by BIM already been used by some of the project team, the provision of adequate technical support and training, and anticipation of large productivity gains. It can be concluded that clients, construction organisations and institutions in the construction industry could contribute significantly to decisions to adopt BIM in the construction industry.

The benefits of BIM could also motivate clients, organisations and other stakeholders to use BIM. According to Eadie et al. (2013), the top BIM drivers are "clash detection, government pressure, competitive pressure, accurate construction sequencing, and cost savings through reduced re-work". Hosseini et al. (2016) found that the major drivers for the adoption of BIM in Iran are increased profits and enhanced competitiveness in the market. Gilkinson et al. (2015) agree that construction firms utilise BIM to prosper in a competitive market. Generally, it can be seen that the benefits of BIM and other factors have a great influence on stakeholder and inspire them to adopt BIM in construction projects. This research examines BIM as a means of reducing the cost of change orders in building projects in the Jordanian private sector, and such drivers may therefore have a significant role to play.

2.3.14 The adoption of BIM across the world

Recently, the great benefits of BIM in construction have encouraged several countries to promote the use of BIM, and significant progress has been noticed in some of these countries. For example; the results of research by McGraw Hill Construction (MHC) (2014) indicated that mandating BIM in some countries like the UK and the USA has caused an unprecedented rise in the adoption of BIM. In addition, it was found that contractors in Europe and North America have reached maturity level in the use of BIM. Kassem et al. (2013) compared the results of studies of BIM adoption in three countries, Australia, the UK and the US. They suggest that these countries have a similar construction culture, have done reasonably wide surveys of BIM adoption, and have noteworthy BIM publications. This research will draw on Kassem et al.'s (2013) research, as well as exploring the status of BIM in Singapore in the same way. The findings should provide a clear picture of the progress which BIM is making in different parts of the world. This image could serve as a basis for suggesting how BIM might be supported in the Jordanian construction industry to reduce the cost of change orders.

In the UK, the results of NBS (2013) research among 1,000 professionals indicated that 48% are 'just aware' of BIM, 31% are 'aware' and using BIM, while 21% are neither 'aware' nor using BIM. These results show a level of awareness which supports the adoption of BIM. The National Building Information Model Standard (NBIMS) has also released the National BIM Standard Version 1 to increase awareness of BIM in the construction industry (NBIMS, 2007). What is more, the UK government has now mandated the adoption of BIM by requiring fully collaborative 3D BIM (with all project and asset information, documentation and data being electronic) as a minimum by 2016 (Government Construction Strategy, Cabinet Office, 2011). These minimum-level standards are known as 'Level 2' competency-file-based collaboration and library management, and comprise a 3D model of structural, architectural, mechanical, electrical and plumbing elements in a single environment which enables the sharing of structural data (MHC, 2014). The UK government has thus taken substantive steps to support the adoption of BIM in the construction sector. In Jordan, the government could also encourage the adoption of BIM of by issuing rules that mandate the use of BIM and increase awareness.

In Singapore, Teo et al. (2015) report that the Building and Construction Authority (BAC) created a Construction Productivity Roadmap in 2010 to enhance productivity in the construction industry up to 2020. One of its strategic thrusts is 'driving the adoption of BIM'. In 2011 the National BIM Steering Committee established a framework to guide the implementation of the BIM Roadmap. The committee led the development of the 'Singapore BIM Guide' and 'BIM Particular Conditions' (BCA, 2013c), as well as providing advice to professionals to support the effective implementation of BIM in construction projects. The BAC (2011) also issued regulations that mandate the submission of architectural, structural, mechanical and electrical plans for building works for approval in the BIM format.

To meet significant demands for skilled BIM manpower, the BAC has worked with several Institutes of Higher Learning (IHIs) to incorporate BIM training into more than 30 academic programmes. Moreover, a BAC BIM fund has been established to provide incentives to construction firms to adopt BIM. The fund covers the costs of training, consultancy services, and hardware and software for business and projects (Teo et al, 2015). These actions constitute a highly focused initiative to develop and improve the Singaporean construction industry by supporting the adoption of BIM. The Singaporean campaign could be used as a model for Jordan to clarify the support required for the successful adoption of BIM in the construction industry.

In Australia, significant targets have been achieved for the adoption of BIM in the construction industry. According to Eadie et al. (2013), the Australian government has made it mandatory for BIM to be used in public projects by 2016. BEIIC (2010) concluded that BIM had been widely adopted in the Australian construction industry, with an estimated impact on the Australian economy to reach 4.8 billion AUD by 2025. In the US, McGraw-Hill Construction (2012) conducted a survey to explore the adoption of BIM across North America, with results which point to massive progress among contractors, engineers and architects over the period 2009 - 2012, as presented in Figure 2.6.

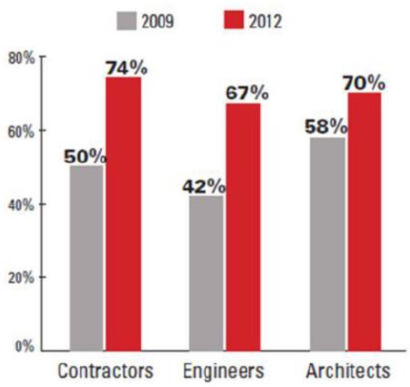


Figure 2.6: BIM adoption rates in the US (adapted from McGraw-Hill Construction (2012), Kassemet al. (2013))

To conclude, this overview of the adoption of BIM in different countries across the world has indicated that significant progress has been made, but this varies from one country to another. The UK, the USA, Australia and Singapore have made significant strides. While, Middle Eastern countries are at the ‘early adoption’ stage - optimistic and aware, but inexperienced in the utilisation of BIM (Building Smart, 2011). Al Awad (2015) suggests that there is a huge gap between Jordan and western countries in terms of the adoption of BIM in the construction industry. The cases discussed above could serve as an example of what could be done to change perceptions and encourage the adoption of BIM in the Jordanian construction industry, thus reducing cost overruns. This research will therefore critically investigate BIM in the Jordanian construction industry in terms of current awareness, status, barriers and drivers for adoption by conducting interviews with professionals and the use of a survey. An ISM model will then be created of barriers to BIM in order to facilitate its adoption in Jordan.

2.3.15 BIM in Jordan

The importance of BIM in the construction industry has increased, with a great many countries accepting and supporting its adoption. However, there is a great gap to be seen between the adoption of BIM in the west and its uptake in the Jordanian construction industry (Al Awad, 2015). This research will therefore critically review the available literature on BIM in Jordan in order to clarify its current status in the construction industry.

In a survey by Building SMART in 2011, it was shown that 25% of participants were familiar with BIM processes, but only 5% were using BIM (BIGPROJECT, 2014 cited in Al Awad, 2015). This gives an initial picture of the BIM environment in Jordan, where a significant number of professionals are not yet aware of BIM. Furthermore, due to the increasing impact of claims on building projects, Hamad (2014) argues that there is a tremendous need to implement BIM in Jordan. Yet he found that only 12.9% of the research sample were aware of BIM, and only 37.1% of firms could create 3D models. These results indicate that the majority of Jordanian construction firms depend on 2D CAD in their work, and clearly indicate a low level of understanding of BIM in the Jordanian construction industry. Therefore, this research will use House of Quality to focus on presenting the benefits of using BIM to reduce cost overruns arising from change orders and on improving the level of awareness of the benefits of BIM in Jordan.

Al Awad (2015) found that that the use of BIM by small and medium enterprises (SMEs) was zero, with AutoCAD packages, emails and web browsers being the most commonly used software. This is paralleled by El-Mashaleh's (2007) findings, which concluded that Jordan will see an aggressive plan to make full use of Information Technology capabilities. There thus appears to be a great reluctance to implement new Information Technology products in Jordan, with the result that the Jordanian construction industry does not derive any benefits from BIM in construction projects.

There have also been few studies which have explored the barriers to BIM in the Jordanian construction industry. Al Awad (2015) investigated the barriers to the adoption of BIM by SMEs related to process, technology and people, which are lack of awareness of BIM, low levels of education, a lack of knowledge and skills, and training and culture. He found that the majority of respondents believed that the public sector (government) should be the main driver for the adoption of BIM. They felt that other drivers should be Jordanian construction associations, clients and large construction companies.

This research will focus on reducing the costs of change orders in the Jordanian private construction sector through the adoption of BIM, and will therefore carry out a critical exploration by means of interviews and a survey in order to ascertain current levels of awareness and understanding of BIM, the challenges facing BIM, and the issue of who should drive the adoption BIM in the private sector. House of Quality will be used to highlight the advantages of adopting BIM for minimising cost overruns arising from change orders in the Jordanian construction industry. This should motivate the construction industry to use BIM and increase their awareness and knowledge. The ISM model will be used to identify significant barriers to the adoption of BIM to enable the construction industry to focus on these barriers to ensure that BIM is adopted effectively.

2.4 Conclusion

This literature review has discussed two main topics, change orders and BIM, and provided the researcher with a significant understanding in both areas. The review indicated that change orders are common in construction projects, and this conclusion is supported by a number of studies. Change orders in the construction industry may be defined as modifications in contract documents as a result of additions, omissions or modifications, and impact on the costs and time of a project. They must be approved by both the owner and the contractor. The review distinguished between many types of change order, based on time, impact, need or response. Proactive change orders are those requiring action by team members in orders to minimise the negative impact of change before it happens, while reactive change orders are those which are used when remedial action is taken only when the change has started to happen. This research focuses on proactive change orders, as the researcher advocates the adoption of BIM in the Jordanian construction industry in order to minimise cost overruns which arise because of change orders. This will be achieved by identifying the main causes of change orders in the Jordanian construction industry, and then House of Quality will be used to identify the relationship between change orders and BIM. This suggests that the adoption of BIM may minimise the causes of change orders. It is argued that identifying the causes of change orders and determining the main barriers to the adoption of BIM in Jordan will help to minimise cost overruns arising from change orders in the Jordanian construction industry.

Examining the causes of change orders in construction projects showed that they can be categorised in different ways. This research adopts the classification proposed by Alnuaimi et al. (2010), which uses the source of the change order as its basis. The classification has four categories: client-related causes, engineer-related causes, contractor-related causes and ‘other’. Clients were identified as a major source of change orders in the construction industry. Clients have the right to issue change orders in their project as per the contract agreement. The focus of change orders initiated by clients were changes in the scope of the project, changes in the client's requirements, changes in design and ‘other’. Engineer-related causes focus on design errors, estimation errors, incomplete designs, inconsistencies between contract documents, a lack of understanding of the client's requirements, and ‘others’. The third category relates to the contractor, and includes poor management, bad work quality and poor workmanship. The last category includes causes of change orders that are due to external factors, and is not related to either of the previous categories. Site conditions, the weather and climate, the availability of labour, equipment and materials, and economic conditions are examples of causes in this category which could lead to changes in construction projects. The causes of change orders identified in the literature will guide the researcher in investigating the causes of change orders in the Jordanian construction industry. For this investigation an interview will be used, and then a questionnaire will be designed on the basis of the interview results and distributed to a large sample in the Jordanian construction sector. Tools used to analyse the results and to identify the major causes of change orders will include the Severity Index (SI), factor analysis and correlation. House of Quality will then be used to determine the relationships between these causes and the implementation of BIM.

The exploration of the effects of change orders concluded that they could be positive or negative. Several studies argue that construction projects gain a lot of benefits from change orders. Firstly, the contractor benefits significantly from an increase his work, project's time execution and unit rate. The engineer also has a good opportunity to increase his income as a result of design modifications and the extension of guaranteed payments. Thirdly, the benefits of change orders for clients lie in getting a project executed according to their wishes with minimum problems. The literature indicates that the client derives the lowest benefits in comparison to other project parties. On the other hand, many researchers consider that change orders have significant negative effects on construction projects, which may be direct or indirect. The indirect effects could be disputes and claims, while the direct effects are cost overruns and delays in completion. This research will focus on the cost overruns arising from change orders, which many studies have shown to be a serious problem in Jordanian construction projects.

Because of the increase in the number of change orders in the construction industry, many researchers have focused on ways both of reducing them and of minimising their negative impact. The in-depth literature review showed that there are different models, recommendations and steps in this area. For example Isaac and Navon (2009) proposed a model for determining the impact of change orders in building projects based on client objectives in terms of cost, time and performance. Karim and Adeli (1999), Hegazy et al. (2001), Motawa et al. (2006), Arain and Pheng (2006), Charoenngam et al. (2003), Yitmen and Soujeri (2010), Alnuaimin et al. (2010), Ijaola and Iyagba (2012) and Desai et al. (2015) propose different models and recommendations for reducing the effects of change orders in construction projects. A review of these models concluded that they will not be fully effective in minimising the cost of change orders in the Jordanian construction industry for a variety of reasons, as mentioned previously. Only one study, by Jongeling and Olofsson (2007), proposes the highly effective method of using BIM in the design and construction phases to reduce change orders in construction projects, and this has been taken as a basis for arguing in the current research that cost overruns arising from change orders in Jordan might also be reduced by implementing BIM. The recommendations made by many other researchers were not suitable for the Jordanian construction because the specific circumstances and environment on which their studies based are very different from Jordan.

The critical review of the relevant literature identified change orders as a major problem facing the Jordanian construction sector. This is why the construction sector suffers from cost overruns, delays in completion, claims and other problems. Cost overruns are the most damaging effect of change orders in Jordan, and their costs increased from 8.3% of total project costs in 1996 to more than 17% in 2013. This means that there is a real challenge for the construction industry. The main causes of change orders in different construction sectors are related to the client, the engineer, the contractor and others. The literature indicates that the causes of change orders in Jordan include changes in client requirements, changes in design, different site conditions, the weather, conflicting specifications in different contract documents, inadequacies or omissions in design, and lack of communication between project parties, among other things.

The review of the Jordanian literature contained many suggestions for reducing change orders. For example; Al-Momani (1996) provides some ideas that could minimise change orders such as providing complete drawings, checking the consistency of specifications, and so on. Al Jaloudi (2012) proposes a framework that includes some recommendations covering the whole of the project life cycle in order to control change orders in water and waste water projects. The Anti-Corruption Commission (2013) presented a solution to the problem of change orders that includes recommendations and processes related to contractual issues and the work process. However, there are no studies which present Information Technology as a solution to the problem of change orders in Jordan. This research will therefore focus on the implementation of BIM as an IT tool which will have a significant effect on reducing change orders in the Jordanian construction industry, as well as the associated cost overruns. The implementation of BIM will require an evaluation of the current level of awareness of BIM in Jordan, as well as investigating the ability of BIM to reduce the causes of change orders. In addition, it is will be necessary to identify barriers to adoption of BIM in Jordan.

The second part of the literatures review revealed a significant focus on BIM in the construction industry because of the benefits it offers in minimising costs and time. The current research therefore proposes the use of BIM in the Jordanian construction industry as a way of minimising the cost of change orders. Many researchers have tried to define BIM. This research draws on the National BIM Standard definition (2010), which sees BIM as a digital representation of a facility's physical and functional characteristics and constitutes a shared knowledge resource as a reliable basis for making decisions over the whole project life cycle. The review has explained the differences between BIM and 2D CAD. Moreover, BIM is able to build the project virtually before actual construction begins, which gives an idea of the feasibility of the project, and can identify errors at an early stage of the project life cycle.

The fundamental concept of BIM lies in the fact that it connects and stores project information in one single model, which allows project parties to participate at an earlier stage in the project and supplement their experience and knowledge in the design phase. Implementing BIM needs to start with an idea of the maturity level of end use. This research draws on UK-Gov (2011a) and Khosrowshahi and Arayici (2012), who identify three BIM maturity levels: Pre-BIM (Level 0), Object-Based Modelling (Level 1), Model-Based Collaboration (Level 2) and Network-Based Integration (Level 3). At the pre-BIM level, the construction firm is not using BIM, but depends on 2D CAD, and there is little collaboration between disciplines. Level (1) of BIM maturity (Object-Based Modelling) depends on 3D CAD, which streamlines 3D visualisations, automates and coordinates views and produces the required data. The Model-based Collaboration level signifies a move to the level of collaboration between disciplines that enables the firm to utilise many approaches which minimise time and costs. The final level of maturity is Network-Based Integration. At this level, complex analyses can be done at an early stage of the project life cycle. This level fully represents the core philosophy of BIM, and allows full interoperability between disciplines by using a collaborative web server. However, the adoption of BIM in the construction industry could have negative effects on the construction business process. Several studies have indicated that adopting BIM may lead to delays in starting construction, potential disruptions and difficulties in workflow transitions. On other hand, construction organisations can develop strategies to solve these problems within the main phases of the BIM implementation process, i.e. preparing, rolling out and post-implementation.

The critical review has also shown that BIM in the construction industry is influenced by technology, process and people. As far as technology is concerned, there are different perspectives on BIM, with the different project parties taking their own particular view. For example; designers see BIM as an extension of CAD, while the contractor expects BIM to help in analysis and cash flow modelling. It is thus very important to be clear about what the capabilities of BIM are as a technology in the construction industry. The capabilities of BIM are its effectiveness for a project as a parametric modelling system that maintains the relationships between various objects which share data. The second factor is process, because the aim of BIM is to move from traditional processes to a collaborative and integrative model. ‘People’ is the final factor, which means that the human resource requires special skills, knowledge and awareness to adopt BIM successfully. Among other things, these can be developed through training courses and the experience of successful BIM project implementation.

The review concluded that improving awareness of BIM is the key factor for successful adoption, but that there is a lack of research on the awareness of BIM in the construction industry, and thus a need for this kind of research. Several studies have found that a lack of awareness is one of the main barriers to the adoption of BIM in South Australia and Nigeria. However, some countries have started improving awareness and knowledge of BIM - for example, in the UK the National Building Information Model Standard (NBIMS) in 2007 released National BIM Standard Version 1. Awareness of BIM can also be improved by training, a focus on its benefits and by governmental support in the form of legislation.

BIM is an intelligent system that confers great benefits over the whole project life cycle. The literature classifies these benefits as short- and long-term. In this regard, a better understanding of the project design is an example of benefits which can accrue in the short term, while a reduction in construction costs can be achieved over a longer period. The virtual model offered by BIM improves project understanding, as well as supporting collaboration between project parties, at the early stage of the project life cycle. Further benefits of BIM in the construction industry are a reduction in errors, minimisation of costs, changes and time, all the advantages of having a single database for the project, conflict resolution, constructability, construction sequencing and scheduling, and many others.

As far as change orders are concerned, the critical investigation of previous studies has shown the great benefits of using BIM both to reduce the number of change orders in construction projects by minimising their causes, as well as to reduce their costs. For example, several studies conclude that implementing BIM reduces changes in construction projects by more than 40% and Requests for Information by more than 60%, and results in bids within 2.5% of the actual construction cost. It can be concluded that these benefits could also be realised in the Jordanian construction industry.

On the other hand, the adoption of BIM in construction projects will not happen overnight, and many barriers to adoption have been identified. The review of the literature concludes that these barriers can be categorised into three main groups, linked to product, process and people. Within each of these groups there are many sub-barriers. The main barriers related to product are financial considerations, different perspectives on BIM, and interoperability. Those linked to process are the need to change work processes, legal issues, a lack of demand and interest, a lack of senior management support, staff resistance, and organisational culture. The last group, related to people, has to do with the new role of the BIM model manager and the training of individuals. These barriers have a major impact on the adoption of BIM in the construction industry. These barriers will be taken into consideration in the context of Jordan, and other barriers might be added depending on the results of the data collection.

The literature review has also explored BIM standards, which specify practice at strategic and operational level, and procedures for managing BIM production. It examined numerous BIM standards across the world, such as those developed in Singapore (Singapore-Gov, 2012b). These were reviewed in terms of applicability to the Jordanian construction industry. There are also many drivers which may influence the adoption of BIM in the construction industry. The literature review indicated that government is a significant driver of BIM in some countries such as the UK. Other studies found that the adoption of BIM can be a result of client pressure, or of the benefits that BIM confers such as clash detection, the accurate sequencing of construction, cost savings and time reduction. Competitive pressures and increased profits may also lead to the adoption of BIM in the construction industry.

The literature review also found various examples of the adoption of BIM in the construction industry from around the world. Four countries were explored because of the similarities in their construction industry and the fact that they had produced significant BIM publications. These countries are the UK, the USA, Australia and Singapore, representing four continents. The examination identified differences in the ways these countries had adopted BIM, as well as in levels of BIM awareness and knowledge. However, all have been successful in adopting BIM in their construction industry, and this constitutes a great contrast to what is going in the Jordanian construction industry.

Finally, a thorough investigation of the Jordanian construction industry indicated that there have been very few publications related to BIM. There is also a significant lack of awareness of BIM in Jordan. At the same time, there has been zero implementation of BIM in small and medium enterprises, and the literature indicates that most construction organisations still rely on 2D CAD, with few organisations being capable of using 3D CAD. The Jordanian government should be driving the adoption of BIM in small and medium enterprises which face barriers such as a lack of awareness of BIM, lack of education, inadequate knowledge and skills, and a lack of training. This research will therefore investigate the causes of change orders, the current status of BIM, and awareness, barriers, drivers, and benefits in the Jordanian construction industry, in order to facilitate the adoption of BIM as a way of reducing the cost of change orders. The methodology to be used for this research will be presented step by step in the next chapter.

CHAPTRE THREE: THE RESEARCH METHODOLOGY

3.1 Introduction

Achieving the aim and objectives of any research requires the utilisation of reliable and suitable methodological research procedures. The procedures must be accompanied by effective data collection methods to generate useful data for analysis and achieve a meaningful research conclusion, which contributes to the existing knowledge. In this research, Chapter 1 gave an overview of the research problem and identified the research aim and objectives. This chapter explains the research methodology. The rationale for the methodology will draw on Saunders et al.'s (2016) 'onion model' (Figure 3.1). This will enable the researcher to achieve the research aim and objectives, as well as to understand and classify available methods and develop the research in a principled way. Selecting appropriate philosophical, ontological and epistemological concepts, and developing a suitable strategy and methods will increase the success and validity of any research (AlKinani, 2013).

Saunders et al.'s (2016) 'onion model' comprises many important layers. It is essential to take these layers into consideration before choosing techniques for data collection and analysis (Saunders et al., 2016). The outer layer is the research philosophy, and the inner layer is data collection and data analysis. Between these two are many layers that guide the research methodology. The research approach follows the research philosophy, and then comes the methodological choices, while the fourth and fifth layers are research strategy and the time horizon respectively.

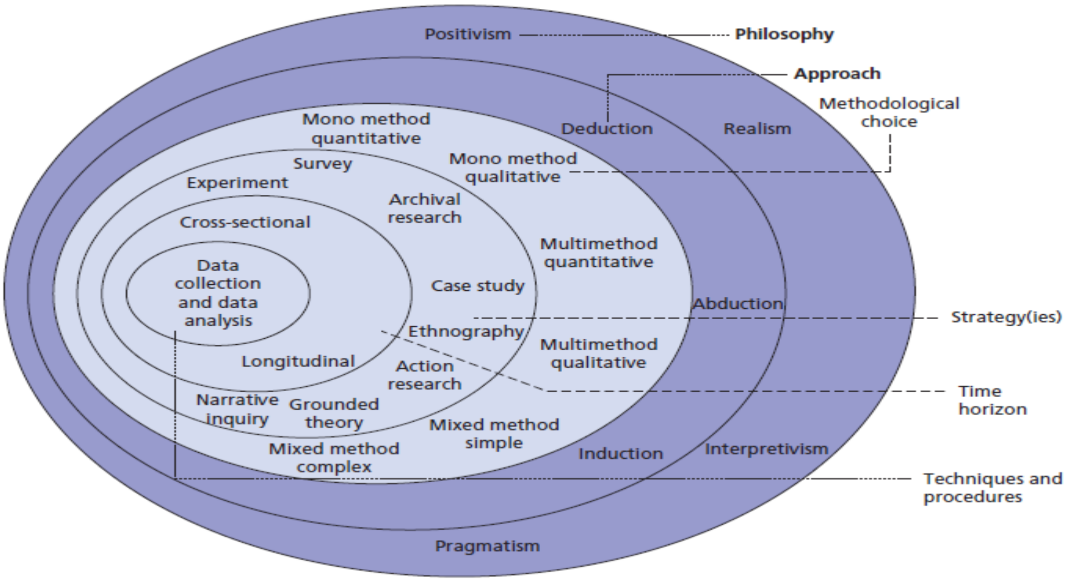


Figure 3.1: The 'Research Onion' model (Saunders et al., 2016)

3.2 Research philosophy

A research philosophy has to do with the development of knowledge and the nature of knowledge, and contains assumptions about how we view the world (Saunders et al., 2016). Khosrowshahi and Arayici (2012) suggest that a research philosophy reflects a researcher's beliefs in the way s/he gathers, analyses and uses data about the problem under investigation. So a research philosophy contains assumptions about how the world is viewed, as well as beliefs about the relationships between knowledge and the processes that lead to the resolution of research problems. According to Saunders et al. (2016), the research process is influenced by three ways of thinking about research philosophy, namely ontology, epistemology and axiology.

3.2.1 Ontology

Ontology is a system of beliefs which is concerned with the nature of knowledge and assumptions. According to Saunders et al. (2016), ontology is concerned with the nature of reality. Logically, ontology precedes epistemology because ontology is the investigation of the nature of reality or existence in general and its categories and their relationships (Lawson, 2004). Ontology covers a spectrum of approaches from objectivism (Realism) to subjectivism. Objectivism assumes that social entities exist in reality to social actors, while subjectivism believes social phenomena are created from the perceptions and consequent actions of social actors; this is a continuous process in that, through the process of social interaction, these social phenomena are in a constant state of revision (Saunders et al., 2016).

This research focuses on the communication of knowledge to develop models for assessing the adoption of BIM in the Jordanian construction industry, with the intention of highlighting its implementation as a way of controlling the costs arising from change orders. This basically requires interaction with people, as well as exploring their perceptions and actions. However, the process of developing a model is dependent on the formulation of hypotheses. These hypotheses are verified empirically by quantitative methods and causal relationships are verified by means of several tests. The researcher is not part of the reality under examination at this stage of the research, and a large sample was used for the questionnaire. This large questionnaire sample provided a basis for developing a deep understanding of the major causes of change orders in the Jordanian construction industry, as well as the current level of awareness of BIM, and of barriers and drivers and their effects on reducing the cost of change orders. It can thus be concluded that the ontological orientation of this research is towards objectivism (realism) rather than subjectivism.

3.2.2 Epistemology

The word epistemology is derived from the Greek words ‘episteme’ (which means knowledge) and ‘logos’ (account). Epistemology thus means the science of knowledge (Johnson and Buberley, 2000). McNeill and Chapman (2005) and Saunders et al. (2016) classify epistemological suppositions into positivism on the one hand and interpretivism on the other. Positivism considers society to be more central than individuals, and generates quantitative data that are used in statistical analyses and graphical representations. These data can be produced by a variety of methods such as surveys (McNeill and Chapman, 2005). Travers (2001) argues that positivism believes that society has to be part of science, and the quantitative approach is used for making logical connections between variables. Interpretative sociology tries to understand the true lives of the people under investigation, while interpretivism is based around the idea that reality can be interpreted and theories can be proposed to define new knowledge (Khosrowshahi and Arayici, 2012). Interpretivism uses the qualitative approach and provides explanations as to how an individual realizes his/her own acts (Travers, 2001).

Many researchers have discussed the differences between positivism and interpretivism from a variety of perspectives. The tables below (Tables 3.1 and 3.2) show the differences between positivism and interpretivism in terms of the assumptions they make, the underlying concepts, and their methods, strengths and weaknesses.

Table 3.1: The strengths and weaknesses of the positivist and interpretivist approaches, (Source: Amaratunga et al., 2002)

Approach	Strengths	Weaknesses
Positivism	can provide wide coverage of a range of situations	methods used tend to be rather inflexible and artificial
	can be fast and economical	not very effective in understanding processes or the significance that people attach to actions
	where statistics are aggregated from large samples, they may be of considerable relevance to policy decisions	not very helpful in generating theories
		because of focus on what is, or what has been recently, makes it hard for policy makers to infer what changes and actions should take place in the future
Interpretivism	data-gathering methods seen as natural rather than artificial	data collection can be tedious and require considerable resources
	able to look at change processes over time	analysis and interpretation of data may be more difficult
	able to understand people's meaning	more difficult to control the pace, progress and end-point of the research process
	able to adjust to new issues and ideas as they emerge	policy makers may give low credibility to results from a qualitative approach. This because that the qualitative researchers are interested in understanding how the people make sense of their world and the experiences they have through understanding the meaning people have constructed (Merriam, 2009), thus they could introduce a bias in their findings.
	contributes to theory generation	

Table 3.2: The differences between positivism and interpretivism, (Source: adapted from Amaratunga et al., 2002 and Weber, 2004)

	Positivism	**Interpretivism**
Concept	social structure and social facts	social construction and meanings
Ontology	person (researcher) and reality are separate	person (researcher) and reality are inseparable (life - world)
Epistemology	objective reality exists beyond the human mind	knowledge of the world is intentionally constituted through a person's life experience
Research Object	research object has inherent qualities that exist independently of the researcher	research object is interpreted in the light of the meaning and structure of a person's (researcher's) life experience
Method	quantitative: hypothesis testing and statistical analysis	qualitative: hypothesis generation, hermeneutics and phenomenology
Theory of Truth	corresponding theory of truth: one-to-one mapping between research statement and reality	truth as intentional fulfilment: interpretations of research object match lived experience of object
Validity	certainty: data truly measures reality	defensible knowledge claims
Reliability	replicability: research results can be reproduced.	interpretive awareness: researchers recognize and address implications of their subjectivity

This research proposes the adoption of BIM in the Jordanian construction industry as a means of controlling the costs arising from change orders. Both qualitative and quantitative approaches are therefore used in order to triangulate information. The first stage of data collection involves eliciting the views of experts on the main causes of change orders, the current level of awareness of BIM, and drivers and barriers. The research focus is thus on what people think and feel about change orders and BIM, and how far they are aware of BIM.

This means that the researcher is part of what is being observed in order to understand and explain phenomena, and the epistemological orientation of this stage of the research is towards interpretivism. The second stage of the data collection is the vital part of the research, and includes designing a questionnaire and distributing it to a large sample, determining causal relationships between factors, and the use of quantitative methods, statistical analysis and free interpretations on the part of the researcher. The conformist part of the positivist approach is underlined by collecting data and analysing it to test hypotheses, as well as to remove the effect of any variable that could cause any misunderstanding of statistical relationships by applying typical rules which apply to whole populations. The philosophy which initially underpins this research is thus interpretivist, while a positivist approach is taken in the second stage. For this reason, and because of the importance of the second stage of data collection, this research towards to positivism philosophy.

3.2.3 Axiology

The third set of philosophical assumptions is axiology. This is a branch of philosophy that studies judgments about value (Saunders et al., 2012). In this regard, Collis and Hussey (2013) state that an assumption has to be made about whether a subject is value-free and unbiased or whether it is value-laden and biased. Axiology is concerned with the value of the research in terms of how far it adds to the sum total of knowledge: if it tests research hypotheses and verifies them by applying quantitative and empirical methods to a particular set of data, it is based on positivist, deductive and objective preferences, and thus considered to be value-free research. Value-laden research, on the other hand, is that which is based on an interpretivist approach, i.e. on qualitative methods and human beliefs (Frankfort-Nachmias et al, 2015). In the current research, the researcher's own values, subjective preferences and biases have played no part in verifying the research hypotheses because of the nature of the research, i.e. the fact that it requires an empirical set of data. This means that in terms of axiology, the research is value-free rather than value-laden, or linked to the researcher's experience and thoughts.

In conclusion, in terms of this discussion of ontology, epistemology and axiology, the current research can be seen as objectivist, positivist and value-free.

3.3 Research approach

A research approach can be defined as how a theory is developed, and the two broad approaches are deductive and inductive. The deductive approach has a close relationship to the positivist philosophy, while the inductive approach tends towards interpretivism (Saunders et al., 2016). Combining the two approaches in research could confer benefits and lead to important results. The current research therefore draws on both approaches, i.e. deductive and inductive.

3.3.1 Deduction

The deductive approach is associated with quantitative research, and draws conclusions based on logic (Ghauri and Grønhaug, 2010). The researcher designs a theory or hypothesis and tests it by means of a carefully designed research strategy (Saunders et al., 2016). The deductive approach is also known as 'top down' (see Figure 4.2), as its reasoning works from the more general to the more specific (Trochim et al., 2016).

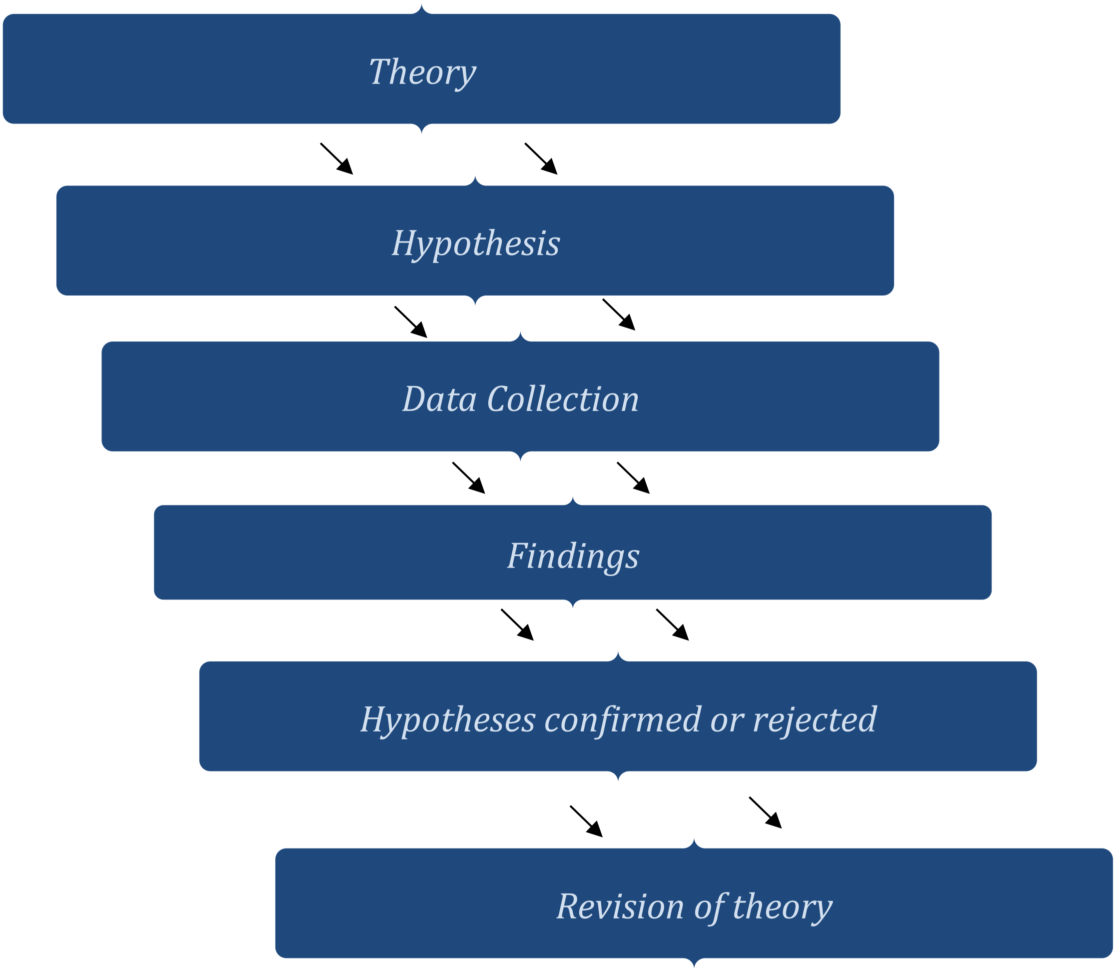


Figure 3.2: The deduction process (Bryman, 2006)

3.3.2 Induction

The inductive approach is associated with qualitative research and depends on empirical observation to draw general conclusions (Ghauri and Grønhaug, 2010). The researcher collects data and develops a theory as a result of analysing the data (Saunders et al., 2016). The inductive approach is considered to be 'bottom-up' (see Figure 4.3), because its reasoning works from specific observation to generalisation (Trochim et al, 2016).

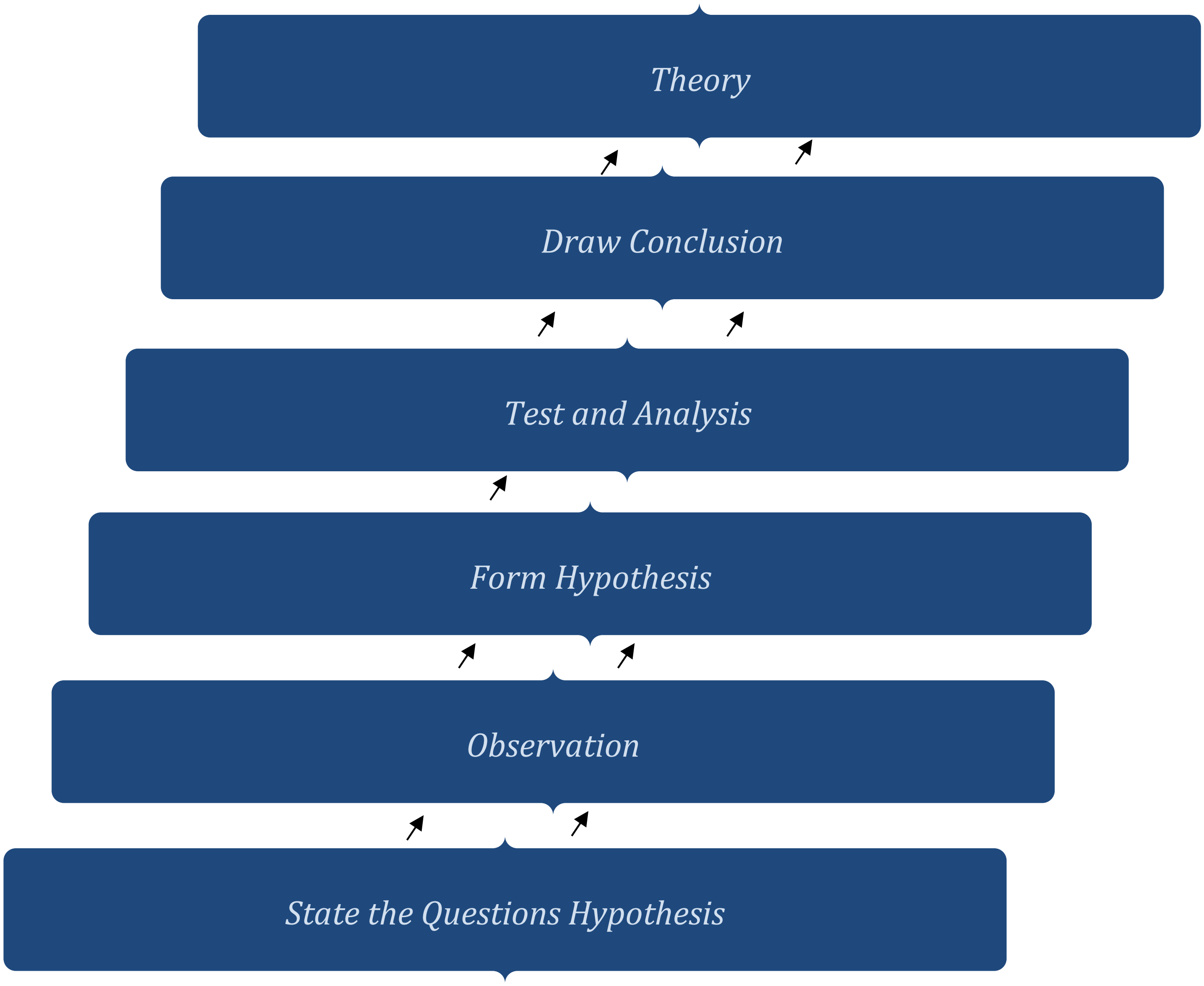


Figure 3.3: The induction process (Bryman, 2006)

In summary, based on the critical review of the deductive and inductive approaches, this research takes an inductive approach in the first stage of data collection. In this stage, the researcher gathered data relevant to the causes of change orders in the Jordanian construction industry, as well as to levels of awareness of BIM and barriers and drivers, in order to address hypothesis. The second stage of the research took a deductive approach by testing the hypothesis developed through a statistical analysis of the responses to the questionnaire. This research thus combines inductive and deductive approaches.

3.4 Methodological choice

The research choices available consist of the mono-method, the mixed method and the multi-method (Saunders et al., 2016). In the multi-method, two quantitative or qualitative techniques are used in a single piece of research, for example a survey and an experiment, or an interview and observations (Saunders et al., 2012; Pluye et al., 2009; Harrison, 2012). Some researchers believe that using the mono-method is a risk to the advancement of social science, and wonder how stakeholders can develop confidence in findings that depend on one method only (Onwuegbuzie and Leech, 2005; Sechrest and Sadani, 1995). Therefore, depending on mono method for adoption new technology in construction industry could be risky and couldn't be effectively gotten valid and reliable results. Furthermore, adoption new technology required much data that should be gathered from several resources which is not applicable in mono-method. In mixed method investigations, quantitative and qualitative techniques are used in the same piece of research. The combination of qualitative and quantitative research methods is a very powerful way of gaining insights and results, as well as assisting in making inferences and drawing conclusions.

The qualitative approach is deemed most suitable for understanding complex and specific social phenomena (McMurray, 2009; Frankfort-Nachmias et al, 2015). This research seeks to understand the critical success factors for reducing the cost of change orders through the adoption of BIM in the Jordanian construction industry. The qualitative research approach is suitable for providing new information on these factors. However, the researcher could not adopt a purely qualitative approach due to its subjective nature, with interpretations based on multiple realities which limit its credibility in the real world (Zikmund, 2003a).

In contrast, the quantitative approach provides objective, value-free findings which can be generalised and replicated (McMurray, 2009). However, a quantitative research approach alone would be unsuitable for this research for a number of reasons. Firstly, as discussed previously, there are few theories (or indeed no theories) on the impact of the adoption of BIM on reducing the cost of change orders in the construction industry in Jordan. Secondly, the quantitative approach is not suitable because positivism does not take into account the influence of human factors and social context upon individual action (Bryman, 2008). Any adoption of BIM relies upon people's motivations, prior experience, perceptions and knowledge (Eastman et al., 2011).

Finally, to achieve the aim and objectives of the research, as well as to fill a research gap, this study used a mixed method investigation, namely qualitative followed by quantitative, which has similar advantages to triangulation. This research adopted a mixed method approach which integrates thematic and statistical data and combines qualitative and quantitative methods. Moreover, it allows investigation from both the deductive and inductive perspectives (Johnson et al., 2007; Jogulu and Pansiri, 2011; Östlund et al., 2011). Consequently, in the first stage, the research used semi-structured interviews to collect data related to the research topic. The interviews were conducted with experts in the Jordanian construction industry. The data was then analysed through content analysis, and this gave a clear picture of the major causes of change orders that are responsible for cost overruns, as well as of the status of BIM in the Jordanian construction industry, and of levels of awareness, barriers, drivers and benefits. The qualitative results formed the basis of a questionnaire. This questionnaire (a quantitative method) was distributed across the Jordanian construction industry. Finally, descriptive and statistical analyses were undertaken in order to fulfil the research aim and objectives. Section (3.7.3) explains these methods of data collection, both qualitative and quantitative, in detail.

3.5 Research strategy

A research strategy is the way in which the research seeks answers to the questions it poses. It is influenced by the research philosophy and the research approach taken (Saunders et al., 2012). There are many research strategies which can be implemented to achieve the research aim and objectives. Research can use quantitative or qualitative approaches, or a mixed method utilising both approaches (Saunders et al., 2012). The following literature review focuses on some of these techniques.

3.5.1 The qualitative method

Qualitative researchers are interested in understanding how people make sense of their world and the experiences they have through understanding the meaning that they have constructed

(Merriam, 2009). To capture the reality of this world and describe people in natural situations, the researcher concentrates on what they say and on observation (Amaratunga et al., 2002). Qualitative data therefore includes a large quantity of words, pictures and images from a small number of people or organisations (Neuman, 2006). Moreover, the qualitative approach believes that multiple perspectives on reality produce multiple realities, while perception alone is not reality (Bryman, 2008; Denscombe, 2014; Tashakkori and Teddlie, 2010). Qualitative research methods include several techniques such as the case study, grounded theory, action research and ethnography (Myers, 2009). Table 3.3 illustrates the strengths and weaknesses of qualitative methods

Table 3.3: The strengths and weaknesses of qualitative methods. (Source: adapted from ACAPS, 2012)

	Strengths	Weaknesses
Qualitative Methods	provides rich and detailed information about change orders and BIM in the Jordanian construction industry	complexity of analysis
	inclusion of a diverse and representative cross-section of industry	data not objectively verifiable
	enables in-depth analysis of the major causes of change orders, as well as the current situation of BIM	
	limited numbers of participants for data collection	

3.5.1.1 Case study

The case study is a research strategy which focuses on understanding the dynamics present within a single setting (Amaratunga and Baldry, 2000). It is an ‘empirical inquiry’ which examines an event 'within its real life context' (Yin, 2003). This research uses the case study in the first stage of data collection for a number of reasons: in order to be close to a real-life situation which involves a good deal of detail (Flyvbjerg, 2006), and to derive theoretical outcomes from practical data, as the case study affords an opportunity to investigate things in their natural environment and provides good opportunities for a researcher to understand the complex processes taking place in certain environments and the reasons behind their occurrence (Cepeda and Martin, 2005). Finally, observation, focus groups, documents and interviews can be used in a case for deep investigation and validation of the research (Yin, 2003). The next section explains both interview and focus group techniques.

3.5.1.1.1 Interviews

The interview involves an exchange of information between people who have a common interest in a certain issue. According to Bogdan and Bikle (quoted in Bu Jawadah, 2013), the interview is "…a purposeful conversation usually between two people that is directed by one in order to get information from the other". Cohen et al. (2000) outline the purposes of interviews, which include appraising people in some way, choosing employees for positions or for promotion purposes, developing and testing hypotheses, gathering data for research purposes, and collecting people's opinions about specific topics. The interview used in this research is discussed in detail in section (3.7.3.1).

3.5.1.1.2 Focus group

A focus group is a case study method that depends on interaction between participants to form a detailed view of a specific topic. According to Stewart and Shamdasani (2014), the important dynamic aspect of a focus group is that participants may modify their answers after listening to other group members. A focus group is led by a moderator who carries out the interview and the key role of collecting and validating insights from group contributions (Stewart and Shamdasani, 2014). The focus group is particularly useful when researching collective learning, as it allows participants to interact in a stimulating atmosphere while a researcher elicits the opinions, mental models and attitudes of the interviewees (Pahl-Wostle and Hare, 2004). The focus group gathers data through verbal communication and narrative speech. The data it generates gives insights into participants' views because of the active verbal communication within the group (Ritchie et al., 2013). Many researchers offer views on the number of participants there should be in a focus group. Bloor et al. (2001) suggest six to ten participants, while Morgan (1998) suggests 10 to 12. However, Krueger and Casey

(2014) suggest that five to eight participants is appropriate as this makes it easier for the moderator to control the discussion, as well as allowing participants to present their views freely and make effective contributions to the group. In this research, the researcher invited seven experts to participate in the focus group used in the validation stage. This number of participants was based on Krueger and Casey (2014) suggestion in order to facilitate the discussion between participants, as well as gives participants enough time to provide their view freely. Also, let the moderator to control the discussion and collect key points and comments. According to Stewart and Shamdasani (2014), a focus group can be used to facilitate the interpretation of previously obtained quantitative results. The discussion which took place in the focus group in this research was valuable in clarifying the relationships between the causes of change orders in the Jordanian construction industry and the benefits of BIM by House of Quality technique. Also, rank barriers of BIM through ISM.

3.5.1.2 Grounded theory

Grounded theory was introduced by Glaser and Strauss in 1967, and was defined as “the discovery of theory from data, systematically obtained and analyzed in social research” (Cho and Lee, 2014). This means that the researcher can produce meaningful theory from observations and the observers’ consensus in certain contexts (Suddaby, 2006). Grounded theory is effective in producing theory from collected data. According to Khan (2014), grounded theory is commonly used in various disciplines across the world as a form of qualitative inquiry. Charmaz (2014) argues that grounded theory is used in research that focuses on conceptual thinking and theory building rather than the testing of theory, and that grounded theory is based on inductive strategies for data analysis. Grounded theory uses different methods for collecting data such as documents, observations, interviews, historical records and video recordings (Bryman, 2008).

Grounded theory has a number of advantages: it has intuitive appeal, fosters creativity, offers a framework for conceptualization, constitutes a systematic approach to data analysis, and provides depth and richness in the data it collects. However, the disadvantages are that it is an exhausting process, there are potentially methodological errors, the literature is reviewed without developing assumptions, there are multiple approaches, and there is limited generalizability (Cho and Lee, 2014). The current research draws on the literature reviewed to develop an initial perspective on how far the adoption of BIM may reduce the cost of change orders in the construction industry. It also draws on deductive reasoning in its focus on testing hypotheses through statistical analysis. These factors, together with other features of grounded theory such as the time required, led to the conclusion that this is not a suitable qualitative method for this research.

3.5.1.3 Ethnography

There are many definitions of ethnography. According to Myers (2009), ethnography is a qualitative research approach which reveals the worldview of people and the cultural meanings they assign to things in their daily lives, and brings researchers closer to where the action takes place. Watson (2011), defines ethnography as a method “which draws upon the writer’s’ close observation of and involvement with people in particular social settings and relates the words spoken and the practices observed or experienced to the overall cultural framework within which they occurred’’. Bryman (2008) suggests that the researcher should engage with a specific group over a long period and collect data by asking questions, conducting interviews, making observations, and understand and analyse discussion amongst employees. Ethnography has various characteristic features. According to Hammersley (2017), drawing on several definitions, these are:

- ✓ a relatively long-term data collection process,
- ✓ the use of naturally occurring settings,
- ✓ reliance on participant observation or personal engagement,
- ✓ the collection of a range of types of data,
- ✓ the aim of documenting what truly goes on,
- ✓ a critical emphasis on the meanings people give to objects, including themselves, in the course of their activities, or in other words on culture,
- ✓ a holistic focus.

Because the current research was to be conducted within a limited time and the fact that ethnography depends on the use of a focus group and requires an extended period for data collection, it was decided that this method was not suitable.

3.5.1.4 Action research

Action research has to do with how the researcher could develop systems to improve the quality of his/her work. According to Jarvinen (2007), action research is a “method which aims to contribute both to the practical concerns of people in an immediate problematic situation and to the goals of social science by collaboration within a mutually acceptable ethical framework”. Action research differs from other qualitative methods in that it involves the collaboration of the researcher with the participants (Linville et al., 2003). Its focus is on doing the research with, for and by the 'subjects' rather than on them, in order to produce practical, useful knowledge (Reason and Bradbury, 2007). Connaughton and Weller (2013), drawing on a number of studies, summarise the main features of action research as the fact that it:

- ✓ addresses a ‘real life’ problem, often of shared concern,
- ✓ is participant- (rather than researcher-) led and performed collaboratively, with collective judgment on the outcome,
- ✓ seeks to solve practical problems and expand knowledge through interpretation and intervention,
- ✓ pays attention to ethical and power considerations,
- ✓ has a focus on how learning and change processes become self-generating and self-maintaining,
- ✓ is often longitudinal and involves more than one discipline.

Action research is not suitable for the current research due to the limited time available. A further problem is that it requires support from organisations, which must offer full access to the required data, as well as encouraging participants to cooperate with the researcher over an extended period.

3.5.1.5 Content analysis

The purpose of content analysis is to organise the data gathered, elicit meaning from it, and to draw realistic conclusions (Bengtsson, 2016). Many researchers have offered definitions of content analysis. According to Billore et al. (2013), content analysis is a technique which identifies and conceptualises important features of a given concept through a systematic analysis of the text. Thia and Ross (2011) define content analysis as a technique for gathering information and then methodically codifying qualitative and quantitative information into predefined categories in order to derive patterns in the analysis and report information.

Content analysis may be qualitative or quantitative. Qualitative content analysis provides rich descriptions of phenomena (Abbott and McKinney, 2013), while quantitative content analysis classifies a lot of words in a text into far fewer content groups or categories. This depends on extracting content categories from the text and counting their occurrence in the sampled text

(Vitouladiti, 2014). Content analysis has several strengths and weaknesses. According to (Vitouladiti, 2014), the strengths and weaknesses of content analysis are as follows:

Strengths

- ✓ can be applied to examine any written document, as well as pictures, videos, and situations,
- ✓ widely used and understood,
- ✓ can help decipher trends in groups or individuals,
- ✓ is inexpensive, and can be easily repeated if problems arise,
- ✓ is in obtrusive and does not necessarily require contact with people,
- ✓ is useful for analysing archival material,
- ✓ allows reliability to be established in an easy and straightforward way,
- ✓ scores highest of all research methods with regard to ease of replication. Usually the materials can be made available for others to use.

Weaknesses

- ✓ is a purely descriptive method. It describes what is there, but may not reveal the underlying motives for the observed pattern (i.e. reveals the 'what' but not the 'why'),
- ✓ is limited to an analysis of the available material.

The process of content analysis includes many steps which must be followed to get credible results. Kulatunga et al. (2007) list five steps as follows:

1. becoming familiar with the data set,
2. initial coding,
3. searching for concepts/themes from the dataset,
4. assigning the codes,
5. reviewing concepts/themes and codes.

The current research used content analysis in the first stage of data collection for an in-depth analysis of interviewees' opinions. In that stage, using inductive reasoning, the researcher's aim was to develop conclusions or formulate hypotheses from the collected data. Content analysis thus helped the researcher to analyse the interview responses in order to identify the major causes of change orders in the Jordanian construction industry and clarify the current status of BIM.

3.5.2 The quantitative method

The quantitative method is based on objective data collection and analysis, and is concerned with quantitative measurements and the analysis of causal relationships between variables (Manning and McMurray, 2009; Morgan, 1998). This makes it suitable for testing theory (Zikmund, 2003a). The quantitative method is a positive approach, and its focus is on confirming an existing theory rather than discovering or building a new theory (Greene and Caracelli, 1997). From an epistemological perspective, the positivist paradigm requires the researcher to be independent, objective and remote from the research process. As with other positivist methods, the findings are value-free (Frankfort-Nachmias et al, 2015, Bryman, 2008). The quantitative method includes techniques such as surveys, simulations, laboratory experiments, statistical analysis, mathematical modelling, structured equation modelling and econometrics (Myers, 2009). In experimental techniques, a sample population is examined within a controlled environment to investigate causal relationships between variables (Fellow and Liu, 2008). It was decided that this technique was not suitable for the current research as a survey would achieve the research aim and objectives more effectively because of the features mentioned in section (3.4). Table 3.4 shows the strengths and weaknesses of quantitative methods.

Table 3.4: The strengths and weaknesses of quantitative methods, Adapted from ACAPS (2012)

	Strengths	Weaknesses
Quantitative Methods	numerical estimates	possible gaps in information due to omissions in questionnaire
	allows relatively uncomplicated data analysis	participation may be limited
	data is verifiable	
	allows comparisons between different stakeholders	

3.5.2.1 Surveys

A survey is a commonly used way of gathering data in quantitative form. Cohen et al. (2000) argue that the survey is a suitable method for collecting data to establish relationships between events at a specific point of time. It is also used when it is not possible to observe or experiment with human behaviour, and in order to gather data about people and their thoughts, beliefs, actions, and so on (Martin and Guerin, 2006). The questionnaire is considered to be the main method of conducting a survey. A questionnaire is a relatively quick and cheap method of collecting data on a specific topic from a large number of individuals, and elicits answers to the same questions from all the individuals surveyed (Charities Evaluation Services, 2016). A questionnaire was used in the second stage of the current research, and it was designed on the basis of the literature review and the interview results. The responses to a questionnaire analysed to get the final results and conclusion. The questionnaire used in this study is discussed in detail in section (3.7.3.2) below.

This section has discussed both qualitative and quantitative methods, and the research used both of them to answer the research questions. Table 4.5 shows the differences between these two methods.

Table 3.5: Differences between qualitative and quantitative methods, adapted from ACAPS (2012)

	Qualitative Methods	Quantitative Methods
When to use it	to gain an in-depth understanding of the research topic	to get a broad, comprehensive understanding of the research subject
	when a holistic approach to the research topic (process and outcomes) is required	to clarify the relationships between different issues
	to understand the perceptions, behavior and priorities of the	when accurate and precise data are required

	research subjects	
Objectives and main features	to explore and understand phenomena	to seek precise measurements, to quantify, to confirm hypotheses
	provides an in-depth understanding of specific issues	provides a general overview
	detailed and complete information allows contextualization, interpretation and description	objective and reliable
	elicits the perspectives, opinions and explanations of affected populations in relation to events, beliefs or practices	objectively verifiable
		causal explanation
Data format	mainly textual (words, pictures, audio, video), but also categorical	mainly numerical and categorical values
		data which can be counted or measured; involves amount, measurement of quantity
Perspective	looks at the whole context from within	looks at specific aspects
	searches for patterns	
Methods	individual interviews	quick counting estimates
	key informant interviews	sampling surveys
	semi-structured interviews	population movement tracking
	focus group discussions	structured interviews
	observation	

Sampling	non-random (purposive)	random
Analysis	involves a systematic and iterative process of searching, categorizing and integrating data	descriptive statistics
	describes the meaning of research findings from the perspective of the research participants	inferential statistics
	analysis is descriptive	uses deductive methods
	uses inductive reasoning	

3.6 Time horizon

The time horizon for any research can be cross-sectional or longitudinal (Saunders et al., 2016). Because of the limited time allowed for PhD degree research, this is a cross-sectional study.

3.7 Data collection

3.7.1 Types of data

Collecting research data is related to the research questions, and the aim and objectives of the research. The data should be sufficient to answer the research questions. Two main types of data were collected in this research: the first type is secondary data, and the second primary data.

Secondary data is defined as qualitative or quantitative data that has been gathered by other researcher(s) for purposes other than its intended use in the current research (Ellram and Tate, 2016). There are various types of secondary data available, the most commonly used being the existing literature, census data, government information, financial data, organisational reports and records (Lind et al., 2012). Secondary data forms a base that helps the researcher to develop a full understanding of the subject. This data could be freely accessible, available by permission of the party who collected the data, or available only on payment of a fee (Ellram and Tate, 2016). Using secondary data can reduce the bias that is sometimes introduced in case studies and the intrusiveness of data collection that is inherent in more experiential methods such as action research, experiments or interviews (Rabinovich and Cheon, 2011). In this research, the secondary data served the essential function of highlighting the research problem, as the various sources indicated a weakness in the failure to utilize BIM to reduce the cost of change orders in the Jordanian construction industry, and at the same time showed that other techniques have not been significantly successful in reducing these costs. Moreover, the secondary data also increases the researcher's understanding and awareness of the issue which is the focus of the research. The research used various sources of secondary data including books, journals, official websites, theses, government reports and reports from organisations. This data is used in all the chapters of this dissertation, but it is mainly the literature review chapter that draws directly on it to define and categorise change orders and explore their causes and effects, as well as defining BIM and specifying levels of awareness of BIM and benefits, barriers, drivers and its adoption globally.

Primary data, on the other hand, is data collected by the researcher through different methods such as interviews, surveys, and so on (Sindhu, 2012). This data is used to address the problem in question, and may be gathered by qualitative, quantitative or mixed methods (Currie, 2005). In this research, primary data was collected through semi-structured interviews and a questionnaire in order to answer the research questions.

3.7.2 Types of variable

Various types of variable may be measured in research. According to Field (2013), variables are categorized as dependent and independent. Additionally, two types of test can be used, namely parametric and non-parametric. According to Field (2013), variables are further sub-divided as follows:

1. **Categorical variables:** categorical variables include three types: binary, nominal and ordinal. Binary variables have two options only, for example true or false, or dead or alive. Nominal variables have more than two options, in no natural order. The final type of categorical variable is ordinal, which indicates that there is a logical categorical order, as

for example scores on a scale of one to five, and where one is the lowest and five the highest score.

2. **Continuous variable**s: continuous variables include two types: interval and ratio. Interval variables could be equal intervals or an equal difference between options. Ratio variables are similar to interval variables, but based on a ratio, and must be expressed logically when they are compared with each other.

The current research uses categorical variables. The questionnaire asked participants to state their disciplines and their years of experience. In the second and third parts of the questionnaire, a five-point Likert scale was used to elicit views about the major causes of change orders, levels of awareness of BIM and barriers to BIM. These items are thus ordinal and non-parametric (Field, 2013).

3.7.3 Data collection and analysis procedures

Data collection techniques for carrying out research depend on the methodology selected. This research attempts to apply existing knowledge about the implementation of BIM to identify the major causes of change orders in the Jordanian construction industry and the adoption of BIM in Jordan as a means of reducing the costs arising from change orders in construction projects. The research was conducted in two stages. The first stage of data collection was interviews with experts working in the construction industry, which in itself enabled the researcher to develop further knowledge and understanding. In the second stage, the results obtained from the interviews also provided the basis for designing a questionnaire which was distributed to a large sample across the construction sector in order to confirm the findings from the first stage, as well as to test the outcomes descriptively and statistically. Finally the results were validated by using House of Quality and ISM through a focus group. A variety of research strategies was adopted in order to gain valid and reliable results. These strategies are described in detail below.

3.7.3.1 Semi-structured interviews

There are three main types of interview: structured, unstructured and semi-structured (Fellow and Liu, 2008). Structured interviews increase validity and reliability by using planned questions. The unstructured interview is based on unplanned questions, which could result in straying from the research topic and wasting time in irrelevant discussion. Semi-structured interviews were considered to be the best method for gathering data in this case in that they involve questions designed to explore the various research topics in depth, but also give participants the opportunity to raise issues which they themselves consider relevant. According to Gillham (2005), semi-structured interviews provide a balance between unstructured and structured interviews, and were appropriate for this research as it was felt that they would provide relevant and in-depth data.

A well-designed sampling process is important for strong and unbiased findings. Participants were therefore selected on the basis of their knowledge, experience, and their management positions - all of them are projects managers - in relation to get valuable information. The sample also included a variety of participants in order to enrich the data collected and lead to a deep understanding. Participants' opinions were elicited on change orders in the Jordanian construction industry and their causes and effects, and the research also sought their views on BIM. 17 interviews were conducted with participants, and the informants included business owners, civil engineers, mechanical engineers, architects, construction managers and academics. The number of interviews was not defined in advance - rather the researcher decided to continue to hold interviews and dig further to a point beyond which no further information of value was yielded. Each interviewee was able to withdraw at any point during the interview. Interviewees gave permission for the interviews to be recorded, and the interviews were then written up. All the interviews were tape-recorded, except for one on which notes were taken, and each interview lasted approximately 40 minutes. To ensure confidentiality, the interviewees remain anonymous and are identified only by symbols. The interviews focused on four main topics in the Jordanian construction industry: the major causes of change orders, awareness of BIM, barriers to BIM and drivers of BIM. The data collected was analysed through content analysis, and the results were used to design the questionnaire (the second stage of data collection).

3.7.3.2 Questionnaire

A questionnaire (quantitative method) was used in the second stage of data collection. A wide range of participants with a variety of experience from various organisations in the Jordanian construction industry contributed in this stage. This diversity ensured that the sample had a wide range of knowledge about the research topic in the Jordanian context, and made it possible to group and rank all the variables that have a bearing on the adoption of BIM in the Jordanian construction industry as a means of reducing the costs of change orders.

Questionnaires fall into two main types. Self-administered questionnaires are generally completed by the participants, while interviewer-administered questionnaires are recorded by the interviewer on the basis of each participant's responses (Saunders et al., 2009). The questionnaire used in this research was self-administrated, and participants were given a choice of whether or not to take part in the research and were allowed to answer the questions freely.

Questionnaire sampling can be grouped into two main categories: probability sampling and non-probability sampling. Probability sampling relates to the distribution and proportion of the sample in relation to the overall population, and participants are selected by means of a probabilistic mechanism so that the probability of every participant is known (Fricker, 2008). Probability sampling also allows the researcher to generalise the conclusions drawn from the sample to the population (Charities Evaluation Services, 2016). It can be based on four different methods, as outlined below (Charities Evaluation Services, 2016; Fricker, 2008; Proctor et al., 2005).

1. **Simple Random Sample:** in this type of sampling, all the participants have a known and identical likelihood of appearing within the sample, and are chosen randomly. Simple random sampling is unbiased sampling, but must use the whole population as the sampling frame from which the researcher takes the sample. For practical reasons, however, the whole population may not be available as a sampling frame.

2. **Systematic Sampling:** the researcher selects participants non-randomly, for example by taking every 10th name from a database.

3. **Stratified Sample:** this is a sophisticated technique which is useful when the population comprises a number of homogeneous groups, or when there may be a problem with ordinary random sampling. In this type of sampling the population is divided into subsets, which are selected systematically on the basis of known facts about the population, each individual is assigned to one group, and then random sampling is used within each subset.

4. **Cluster Sampling:** in this type of sampling the population is divided into mutually exclusive sub-populations called clusters, and then a sample of these clusters is chosen, often randomly, so that all the individuals in the selected cluster form the sample.

Non-probability sampling does not have any basis in the concept of probability (Baohua et al., 2000). It differs from probability sampling in that it does not include choices based on a probability, sometimes because it is not possible to determine the probability of individuals being included in the sample. However, this form of sampling is not dependent simply on conjecture. In general, social research cannot use probability sampling because it is not possible, practical or hypothetically reasonable, so in such cases a broad variety of non-probabilistic options may work better (Trochim et al, 2016). There are five forms of non-probability sampling (Arif, 2011; Baohua et al., 2000 (cited in Hashmi) 2015).

1. **Model Instance Sampling:** in this type of sampling the researcher takes the most frequent or most typical cases. This method is only logical for a causal sampling context.

2. **Expert Sampling:** in this type of sampling the researcher forms the sample by selecting individuals on the basis of their knowledge and proficiency in a particular area.

3. **Quota Sampling:** the sample is selected non-randomly, but the researcher specifies quotas for the desired number of respondents with certain characteristics. Quotas may be:
   - proportional (to the population)
   - non-proportional (sufficient for statistical tests to be carried out).

4. **Heterogeneity Sampling:** this type of non-probability sampling is designed to include all opinions and attitudes, and is not concerned with distributing these opinion impartially.

5. **Snowball Sampling:** this depends on referrals from initial respondents to suggest others they might know who satisfy the requirements of the research. Snowball sampling is useful when part of the population may not be directly contactable by the researcher, when it is difficult to find them, or when the research involves studying relationships among population members. According to Oppenheim (2000), the snowball technique is applied in the social sciences (quantitative data) because it ensures accurate sampling, avoids interview bias, and is low cost.

The current research used the non-probability snowball sampling technique to select individuals who represent the target population in the Jordanian construction industry. This method of sampling requires participants' support in that they are asked to approach other potential participants on behalf of the researcher. 155 participants completed online questionnaire forms. The sample involves the Jordanian Ministry of Public Works and Housing, the Jordanian Engineering Association, the Jordanian Construction Contractors Association and The Engineer; designers and consultants in civil, architectural, mechanical and electrical engineering, project managers and first-class contractors.

The questionnaire was designed to address the research aim and objectives, and drew on all the findings of the literature review and the interviews which had helped the researcher develop an in-depth understanding of the issues related to the research topic. According to Kim (2013), a customised questionnaire is developed on the basis of the parameters revealed by context immersion in a specific sector or topic. The questionnaire was formulated in clear and simple language, including both English and Arabic. It was divided into three parts:

- In the first part, the questions focus on the participant's profile. This part of the questionnaire includes general questions about the participant's discipline and years of work experience. Responses to these questions provide an understanding of the sample and link it to the research findings. However, the recovered forms from participants they don't work as engineers in the Jordanian Ministry of Public Works and Housing, the Jordanian Engineering Association, the Jordanian Construction Contractors Association and The Engineer; designers and consultants in civil, architectural, mechanical and electrical engineering, project managers and first-class contractors were terminated.

- The second part seeks to identify the major causes of change orders in the Jordanian construction industry. Each question uses a five-point Likert scale, from 'strongly disagree' to 'strongly agree'.

- The third part includes three subsections, relating to awareness of BIM, barriers to and drivers of BIM, in the Jordanian construction industry. Each question uses a five-point Likert scale, from 'strongly disagree' to 'strongly agree'.

Participant's opinions were ordered on the basis of a Likert scale ('strongly disagree', 'disagree', 'neither agree nor disagree', 'agree' and 'strongly agree'). According to Hair et al., (2009) a Likert scale presents a statement accompanied by pre-coded categories, and respondents select one of the categories to indicate their level of agreement or disagreement. This allowed the researcher to determine the major causes of change orders in the Jordanian construction industry that are responsible for cost overruns, as well as identifying the current level of awareness of BIM and identifying barriers and drivers. It also helped to identify the relationship between the adoption of BIM and reducing the cost of change orders. The questionnaire yielded descriptive data for all sections, and then factor analysis and correlation were used to identify the causes of change orders and barriers to BIM in the Jordanian construction industry.

3.7.3.3 Pilot study

The questionnaire was designed on the basis of the literature review and the findings of the interviews. A pilot study was used for the final draft of the questionnaire before it was distributed across the Jordanian construction industry. According to Charities Evaluation Services (2016), piloting is the live test of the questionnaire and is the last step before finalising the questions and designing the form. In this exercise, the researcher asks the pilot test respondents to complete the questionnaire and provide feedback on specific questions. The pilot will show whether the questionnaire is producing information that is related to the research subject, as well as providing feedback on the questionnaire design and content. The items in the questionnaire were thus pilot-tested for clarity and appropriateness in a self-administered pre-test with five experts in the Jordanian construction sector. They were asked to complete the questionnaire and identify any complexities, unclarities or ambiguities they had experienced in responding to the questions. Each participant stated views in relation to several criteria mentioned by Bryman and Bell (2007), including the clarity of the instructions, the simplicity of the questions, unnecessary questions, possible changes of questions, and the time needed to complete the questionnaire. The pilot tests were returned with comments, and some items were eliminated and others modified in the light of this feedback.

3.7.3.4 House of Quality

House of Quality is the most common Quality Function Deployment (QFD) tool that employs a matrix to list implementation priorities by degree of importance, as well as undertake quality conversion (Dror and Sukenik, 2011). It can be used for evaluating the effectiveness of new products by clarifying the relationship between product characteristics and customers' needs. House of Quality was therefore used to evaluate and validate the outcomes of the data collection stages to determine the relationship between the causes of change orders in the Jordanian construction industry and the effects of adopting BIM. A focus group helps to develop a critical understanding of the research topic through the discussion between the participants (Ritchie et al., 2013). The focus group used in this research comprised seven experts who worked in the Jordanian construction industry. This number was based on the suggestion of Krueger and Casey (2014). The focus group applied House of Quality to clarify how far utilising BIM minimised the cost of change orders. It also critically compared the effectiveness of current practices with the use of BIM for reducing change orders.

3.7.3.5 Interpretive structural modelling (ISM)

Interpretive structural modelling (ISM) is a well-established method of identifying the relationships between specific items (Attri et al., 2013). This approach has been used by various researchers to ascertain the interrelationships among the elements which make up an issue. The same group of experts who participated in the House of Quality exercise also contributed in the ISM activity. The focus group applied ISM to organise and rank the barriers to the adoption of BIM in the Jordanian construction industry. The ISM approach starts with the identification of variables which are relevant to an issue – in this case the barriers to the adoption of BIM in the Jordanian construction industry. Then a contextually relevant subordinate relation is chosen. Once the contextual relationships have been decided, a structural self-interaction matrix (SSIM) is developed based on a pairwise comparison of variables. After this, the SSIM is converted into a reachability matrix (RM) and its transitivity is checked. Once transitivity embedding is complete, a matrix model is obtained. Then the partitioning of the elements and the structural model - ISM - is derived. The ISM model is used to validate and evaluate the outcomes of data collection stages.

3.7.4 Ethical issues

Ethical issues are an essential consideration in data collection, especially insofar as they relate to the rights of those participating in the research. According to Saunders et al. (2009), it is very important in the data gathering stage to avoid potential ethical issues, namely privacy, confidentiality, anonymity and possible misuse of the findings. This research took these issues into consideration during both stages of data collection, i.e. the interviews and the questionnaire. The research topic was explained to the participants in a brief presentation. The research questions are related to the research topic, and there were no personal or particular questions. The participants were given a choice of whether to take part in the data collection exercise or not, all were told that they would be able to withdraw at any time, and there was no pressure on any of them to contribute during data collection. Then, in the interview stage of data collection, the researcher assured them that their privacy and anonymity would be respected by keeping their personal details and answers confidential. In addition, they were told that they would be able to review the research outcomes to avoid any possible future risk. Furthermore, when they filled in the questionnaire, the participants' identities were not known even to the researcher. Prior to the data collection, an ethical approval form covering the issues described above was submitted for authorisation by a governance and ethics committee of the University of Salford (see appendix A).

3.7.5 Reliability and validity

Reliability and validity are important aspects of research, and critical to the quality of any research activity. Reliability has to do with how well the way in which data is collected and analysed produces dependable findings. According to Saunders et al. (2009), the reliability of research refers to whether consistent findings would be obtained if the data collection procedures were repeated. However, the concept of reliability cannot be measured, but only estimated (Trochim et al, 2016).

Validity relates to the accuracy and truthfulness of the research results (Bryman and Bell, 2007). Reliability and validity were taken into consideration during the data collection stages, i.e. in the semi-structured interviews and the questionnaire, in order to improve the quality of the research. Meeting the criteria of reliability and validity is important as it helps to ensure that the finding generated are correlated at an acceptable level and therefore develop a better measurement scale (Rossiter, 2002; Suddaby, 2010). In addition, it minimises the likelihood of getting answers wrong (Saunders et al., 2012).

3.7.5.1 Reliability

A method is reliable when other researchers use it or the same researcher uses it again, and the results obtained are the same. In other words, the test is considered to be reliable if re-testing would lead to the same results (McNeill and Chapman, 2005). This research therefore followed Robson's (2002) suggestion for ensuring a high level of construct reliability by reducing four threats to reliability, namely:

- **Participant errors:** this refers to errors in participants' answers arising from the timing of data collection. In this research, a suitable time was selected to conduct the interviews with the experts to give them enough time to participate in the research. These times were the end of the working day or the end of the week. For the questionnaire, the participants had enough time to answer the questions and return them.

- **Participant bias:** this refers to the possibility that the participants may be influenced by their managers' views in their answers. They were therefore assured that their responses would be kept completely confidential so that they would feel free to state their own opinions.

- **Observer error:** this has to do with the fact that a questionnaire should be developed in a highly structured way to minimise threats to its reliability.

- **Observer bias:** this depends on how the responses are interpreted. However, this threat should not exist since the researcher is the only one to see and analyse the answers.

In order to ensure quantitative reliability, a number of procedures were applied, including the use of a suitable sample size (155 participants for the questionnaire). The rationale for this number was that it is similar to the number of participants used in similar research (Sukati et al., 2011; Ondiek and Kisombe, 2013; Devaki and Jayanthi, 2014). Also, statistical analyses usually require a minimum sample size of 30 (Saunders et al., 2012). Cronbach's alpha test was used to ensure the internal consistency and reliability of the questionnaire. According to

Field (2013), in science research the value of Cronbach's alpha must be over 0.7 to be acceptable and for a research instrument to be considered consistent. In this research, the value of Cronbach's alpha was higher than 0.7 for all questions (see Chapter 5), which means that it is reliable.

3.7.5.2 Validity

Validation is essential for both qualitative and quantitative research. In qualitative research, validation depends on factors such as honesty, the richness of the data, the depth of the research, triangulation and objectivity. In quantitative research, on the other hand, validation can be determined through measures of error, statistics, sampling and proper instrumentation (Cohen et al., 2000). Validity can be divided into internal and external validity. According to Bryman and Bell (2015), internal validity (credibility) is related to how believable the findings are, while external validity (transferability) relates to how far the research findings are generalisable. Sampling is an essential factor in improving external validity; for example, the use of random selection will increase validity (Arif, 2011). In this research the internal validity of the quantitative method was achieved by designing the questionnaire so that it was able to quantify what it was planned to quantify, which means that the findings represent the reality of the Jordanian construction industry in relation to change orders and BIM. External validity was achieved by using a suitable number of participants representing different stakeholders in the Jordanian construction industry. In order to validate the qualitative results, the researcher used the four evaluation criteria proposed by Hammarberg et al. (2016), namely trustworthiness, credibility, applicability and consistency. Triangulation is another strategy that can improve the validity of research. Saunders et al. (2009) define triangulation as a process of collecting data from multiple source to ensure that the data is consistent. Shenton (2004) also suggests that triangulation addresses both credibility and confirmability (trustworthiness), while using background data to establish context will address transferability (applicability). Finally, presenting a full description of the methodology used will address dependability (consistency).

1. **Trustworthiness:** qualitative research should use consistent and robust methods for collecting data as well as describing those methods to ensure that it is free of bias (Hammarberg et al., 2016). A reviewer should be able to follow the progression of events and decisions, as well as understanding their logic, from an adequate description, explanation and justification of the methods used (Kitto et al., 2008). In this research,

various methods were used to improve the trustworthiness of the findings. Qualitative data was collected from critical interviews conducted with experts who represented various disciplines in the Jordanian construction sector. The interview questions were derived from the literature review, and the responses were compared with the findings of the literature review to confirm the results.

2. **Credibility:** credibility is the criterion for evaluating the truth value (internal validity) of a qualitative study (Hammarberg et al., 2016). In the first stage of data collection, a sufficient number of professionals participated. Furthermore, the questionnaire was distributed to a large number of participants in the construction industry, which significantly enhanced the outcomes and confirmed the results of the interviews.

3. **Applicability:** the applicability or transferability of the research outcomes is the criterion for evaluating external validity. Research is considered transferable when its results fit a context outside the study situation (Hammarberg et al., 2016). In the current research, a diverse range of respondents participated in the interviews, including clients, contractors, engineers and academics, and this supported transferability. The participants had different experiences, and worked in different disciplines in the Jordanian construction industry. Furthermore, the results of the interviews were compared to the findings of the literature review as well as with each other. All of these factors improved the applicability and quality of the research.

4. **Consistency:** the consistency or dependability of the results is the criterion for assessing reliability. This means that other researchers using the same data will get the same results (Hammarberg et al., 2016). The results are thus based on research methods that could be followed by other researchers. In this research, many methods, as illustrated in Figure (1.4), were used to get valid results, starting with a comprehensive literature review and followed by semi-structured interviews and a questionnaire.

3.8 Conclusion

This chapter has discussed in depth the methodology used to answer the research questions and to achieve the research aim and objectives. The approach is based on Saunders et al.'s (2016)'s 'onion model', and a rationale has been presented for the research philosophy, approaches, strategies, choices and time horizon, and for the data collection and analysis methods. The ontological, epistemological and axiological underpinnings of this research lean towards objectivism and positivism, and it is value-free. A review of research approaches led to the use of both of deductive and inductive approaches, with the inductive approach being used in first stage of data collection (the interviews) and the deductive approach in second stage (the questionnaire). The critical discussion of research strategies (i.e. the qualitative and quantitative methods) focused on their respective strengths and weaknesses, and provided a rationale for adopting a mixed method in order to improve the quality of the research and provide reliable and valid outcomes.

With regard to data collection, the research draws in the first instance on secondary data, namely literature including for example journals and government reports. In particular, the information gained from the literature on change orders and BIM gave a clear picture of the research subject, and provides a justification for the research. Data was then collected in two stages. In first stage, data was collected through a semi-structured interview with experts in the Jordanian construction industry. These interviews were then analysed by using a systematic content analysis technique, and the results supported the research justification and provided a clear picture of change orders and BIM in Jordan. The findings from this first stage were then used to design a questionnaire which was distributed across a suitable sample in the Jordanian construction sector. In second stage a self-administered questionnaire was distributed in order to get more reliable and valid data for the research topic. The questionnaire used a Likert scale to investigate the major causes of change orders, levels of BIM awareness, and barriers to and drivers of BIM in the Jordanian construction industry. The data thus gathered was analysed descriptively and statistically through the Severity Index, factor analysis and correlation tests. Ethical issues and the question of reliability and validity were taken into consideration in collecting the data in order to produce high quality research. The next chapter (Chapter 4) discusses the data collected in the first stage (from the semi-structured interview), and Chapter 5 examines the data collected by the questionnaire.

CHAPTRE FOUR: INITIAL DATA COLLECTION

4.1 Introduction

This chapter covers the first phase of data collection, which was described in the previous chapter. The findings provide an intriguing insight into the current situation of change orders, as well the current status of BIM in the Jordanian construction industry. It is believed that BIM can be demonstrated to be an effective information management tool that will lead to a reduction in the cost of change orders in the Jordanian construction industry by minimizing the causes of change orders. The aim of the interviews was to explore the causes of change orders in Jordan, the current level of awareness of BIM, and barriers and drivers in relation to the adoption of BIM. Participants were therefore selected on the basis of their knowledge, experience, and their management positions - all of them are projects managers - in relation to get valuable information. Construction experts from different engineering firms (design and consultancy firms), construction management firms, contractors, the Ministry of Public Works and Housing, universities, Jordanian Engineering Association (JEA) and Jordanian Construction Contractors Association (JCCA) were therefore invited to be interviewed. A diverse range of experts was invited so as to enrich the data collected and gain a deep understanding with regard to the subject. Table 4.1 presents profiles of the interviewees and their details, including their position and experience. 17 interviews were conducted with these professionals to collect data which would facilitate a deep understanding of the issues. This phase also supports the justification of the research by increasing the reasoning, rationale, and the significance of the adoption of BIM to reduce the cost of change orders in Jordan, as there are not many studies on this topic. Furthermore, the second tool used for data collection, i.e. the questionnaire, was designed on the basis of the outcomes of the literature review and the interviews.

Interviews are a qualitative method, and these interviews were semi-structured. Most of the interviews were recorded on tape, and notes were taken on some of them, and each interview lasted approximately 40 minutes. The researcher used a list of core questions that all participants were asked, but also digressed from these to follow up any issues of interest raised by participants.

Table 4.1: Interviewee profiles

Participant	Job Title	Experience (Years)
A	Senior Design Project Manager	19
B	Head of QC and Mechanical Engineering Department	35
C	Planning and Contract Engineer	7
D	Project Manager	30
E	Executive Manager in the Jordanian Ministry of Public Works and Housing	25
F	Civil Engineer	30
G	CEO of Architectural Design Company	28
H	Civil Engineer	28
I	Property Developer	32
J	Project Manager - Consultant	10
K	Project Manager – Civil Engineer	7
L	Production Manager - Mechanical Engineer	8
M	Architectural Engineer	4
N	Lecturer and Member of JEA	24
O	Construction Manager – Civil Engineer	28
P	Production Manager - Architectural Engineer	17
Q	Manager of the Change Orders Department in the Jordanian Ministry of Public Works and Housing	25

The interview questions were divided into five main parts, as shown in Appendix B: the first included general questions about the participants, and the second related to the current situation of change orders in the Jordanian construction industry, including their causes. The third and fourth sections were about the current level of awareness of BIM and barriers to the adoption of BIM in the Jordanian construction industry respectively. The fifth section, finally, investigated the drivers of BIM in the Jordanian construction industry. The data collected was transcribed and analyzed using the five steps of content analysis (Kulatunga et al., 2007) to identify the main themes, and once these had been identified, they were put into a coding system which was used for in-depth analysis. The coding scheme used for the data analysis was developed on the basis of the dominant themes identified within the first content analysis, as well as on the literature review.

4.2 The current situation of change orders in the Jordanian construction industry

Changes in construction projects become inevitable and occur frequently - most projects have many changes in their life cycle. Change orders are used in construction projects because of the benefits they offer such as improvements in quality, and time and cost savings, while they are not preferable in other projects because of their negative impact on the projects such as delayed completion and cost overruns.

In Jordan, change orders are a complicated issue: some stakeholders consider them a problem, while others see them as an essential feature of the construction sector. Participant E was of the opinion that *"change orders are very contextual issues that vary from one project to another."* Thirteen of the 17 participants believed that change orders are not preferred by clients and engineers because of their effects, while contractors did favour them as a way of increasing their profits. Participant A clarified this: *"at the end of the day, change orders are not liked by clients because of the costs, and engineers do not like change orders because they create many problems for them, but on the other hand contractors prefer change orders to increase their income."* At the same time, Participant E felt that change orders in Jordan do not improve the quality of the project or enhance its characteristics: *"change orders are problems in the Jordanian construction industry, as they are related to a weakness in design or unclear project scope. Some change orders do have many advantages for the project and lead to cost savings, but in general change orders in the Jordanian construction industry are seen as something negative. It is like saying there are many advantages to cancer. The* *advantages of change orders are that they allow errors in the project to be rectified. From the contractor's point of view, change orders are disruptive and hinder the construction process, as well as having a negative impact on quality and decreasing the contractor's motivation.*"

On the other hand, only one participant believed that change orders in the Jordanian construction industry were positive as they could rectify errors in the project documents and improve the project's aim and objectives; however, clients did not like them, and considered them to be problems in the project. Between these two extreme positions, three interviewees took a neutral view about change orders, such as interviewee I, who commented *"I think both are right. If the project is very well designed, there will be fewer change orders. On other hand, change orders can also be issued to improve the quality of a project."*

Hence, it can clearly be concluded that change orders are not welcomed in the Jordanian construction industry if they have negative effects on the project such as overruns. In order to determine whether change orders are a major problem in the Jordanian construction industry, a specific question was asked. The answers show that there were disagreements among the experts: 12 of the 17 participants see change orders as a major problem in the Jordanian construction industry which have a negative effect on the project, as well as leading to disputes between the project parties. According to participant Q, *"even when change orders are mainly to deal with an error in the project, they are still considered a major problem in the Jordanian construction industry as a result of the extra costs and time. Moreover, they lead to litigation between the projects parties in most cases."* However, three participants took a neutral position. According to participant L, *"it depends on the volume of change orders, but generally the cost of change orders is a major problem in the Jordanian construction industry.*" Only two experts believed that change orders and their costs were not major problems in the Jordanian construction industry.

Overall, the experts' views confirm that change orders are common in the Jordanian construction industry, but they are not desirable and so both clients and engineers try to eliminate them. The interview results thus show that change orders are major problems in the Jordanian construction sector, which should be solved in order to minimize their negative impact on construction projects.

4.3 Causes of change orders in the Jordanian construction industry

It can be considered that change orders are inevitable in the Jordanian construction industry – this has been confirmed by many studies, and is one motivation for this research. During the research process, and to achieve the first objective of the research, the researcher asked experts to identify the main causes of change orders in the Jordanian construction industry that are responsible for the high number of cost overruns. The main causes of change orders in the Jordanian construction industry were identified as below.

4.3.1 Design errors

Design errors were seen as one of the main causes of change orders in the Jordanian construction industry by 13 of the 17 participants. A critical analysis of interviewees' answers indicated that many factors could lead to design errors in construction projects, including limited time for the design of the project. According to participant P, *"limited time for the design because of pressures from the client means that there are many design errors, incomplete designs and other problems in the design work, which results in many change orders."* Design errors may also occur as a result of not taking regulations or requirements into consideration during the design process, according to participant L: *"the process does not comply with national requirements during the design phase. For example, the design of the cooling system in a commercial building can lead to change orders later on*."

Three participants also saw design errors as arising from the use of unqualified staff either for the design or its implementation. According to participant P, *"using unqualified staff for design and implementation in the construction industry is responsible for many change orders in Jordan*." Figure 4.1 shows the main causes of design errors in the Jordanian construction industry as identified by the participants, namely pressure from the client to finish the project, not following Jordanian regulations and requirements, limited time for design and construction, and the use of unqualified staff.

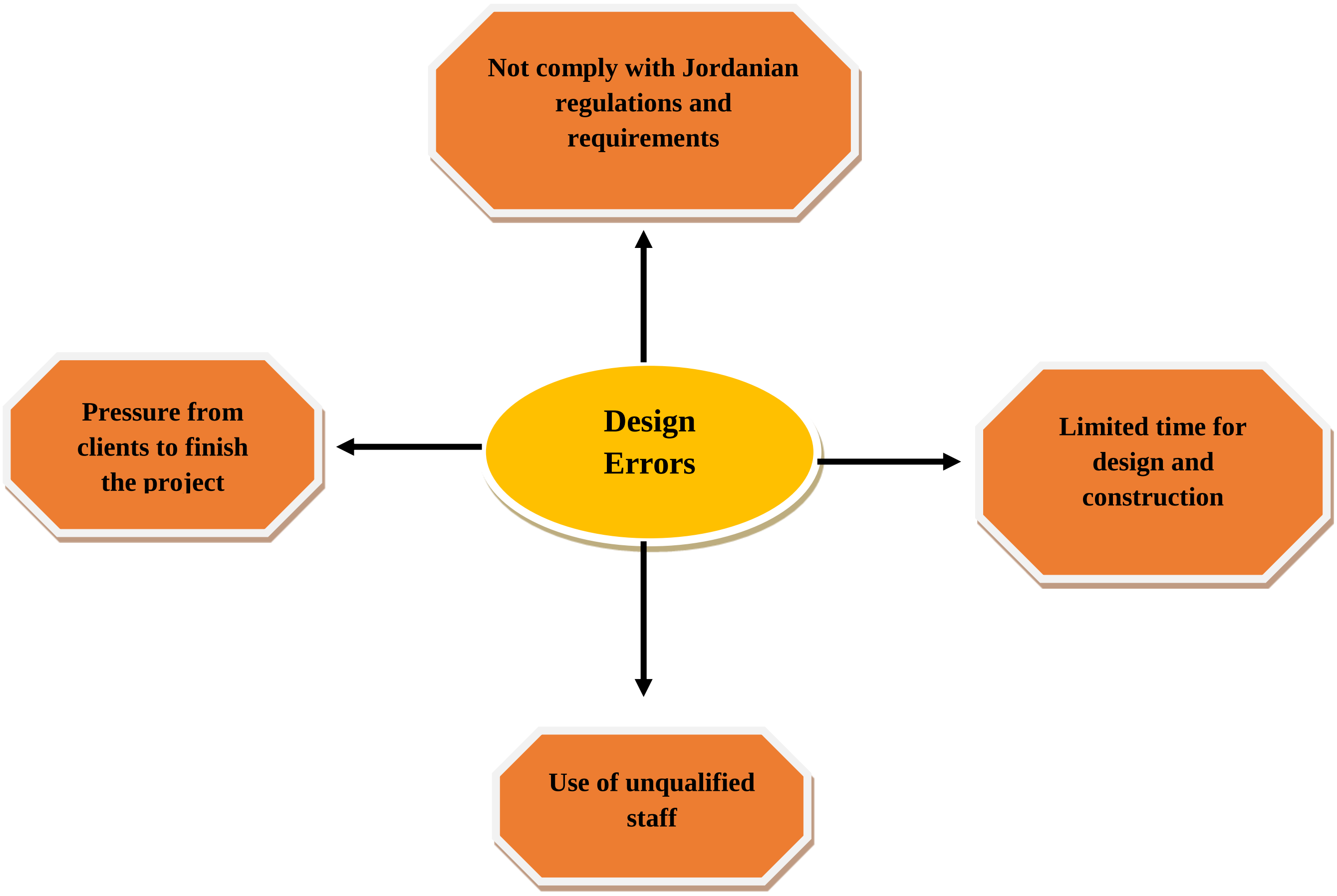


Figure 4.1: Causes of design errors

It can be concluded that participants see design errors as a major cause of change orders in the Jordanian construction industry, and believe that they could occur for many reasons, including limited time for design and the use of unqualified staff. This suggests the following hypothesis:

H1: Design errors cause change orders in the Jordanian construction industry.

4.3.2 Changes initiated by clients

The second key cause of change orders in the Jordanian construction industry is changes made by clients, and many interviewees agreed that clients made changes for many reasons. Firstly, the client may ask for changes as a result of changing requirements or needs. In this context, participant Q said that *"changes are made by clients as a result of changes in their* *needs and requirements."* A further eight interviewees felt that changes requested by clients were a result of changing requirements or needs.

Nine of the 17 participants felt that changes instigated by clients arose from their inadequate awareness or lack of knowledge and understanding of the project, or from a lack of vision. These factors are responsible for many change orders. According to participant J, *"a client may not understand the project very well. For example, a client has certain ideas about the project during the design phase, but during the construction process he is usually surprised at what has been done and says, 'This is not the kind of work needed - I meant something else!' So he issues change orders to make it match his ideas."* Participant O also felt that *"clients' lack of awareness about their requirements leads to many changes during construction. For example, in one project, the area planned was 55,000 m^2, which was based on the client's requirements and for which the budget had been approved. However, after the design was completed, the client's requirements meant that the total area had to be increased to 98,000 m^2, which shows the client did not really understand his own requirements."*

Sometimes changes may also occur in a construction project due to the client's financial situation, which is the third cause of changes initiated by a client. A client asks for changes to adapt to new financial circumstances, as confirmed by participant I, who said that *"change orders may happen due to changes in design because of the financial situation of the owners."* Moreover, some changes initiated by the client arise from a change in senior management or the mindset of decision makers, which was seen as the fourth cause of client's change orders in this category. Respondent I pointed out that *"a change in the senior management team might result in requests for changes in the scope and design of the project. In addition, the mindset of decision makers is responsible for many change orders in construction projects in Jordan."* These findings indicate that changes demanded by clients are a major cause of change orders in Jordanian construction projects, and these could arise for a variety of reasons, such as changing client requirements and needs.

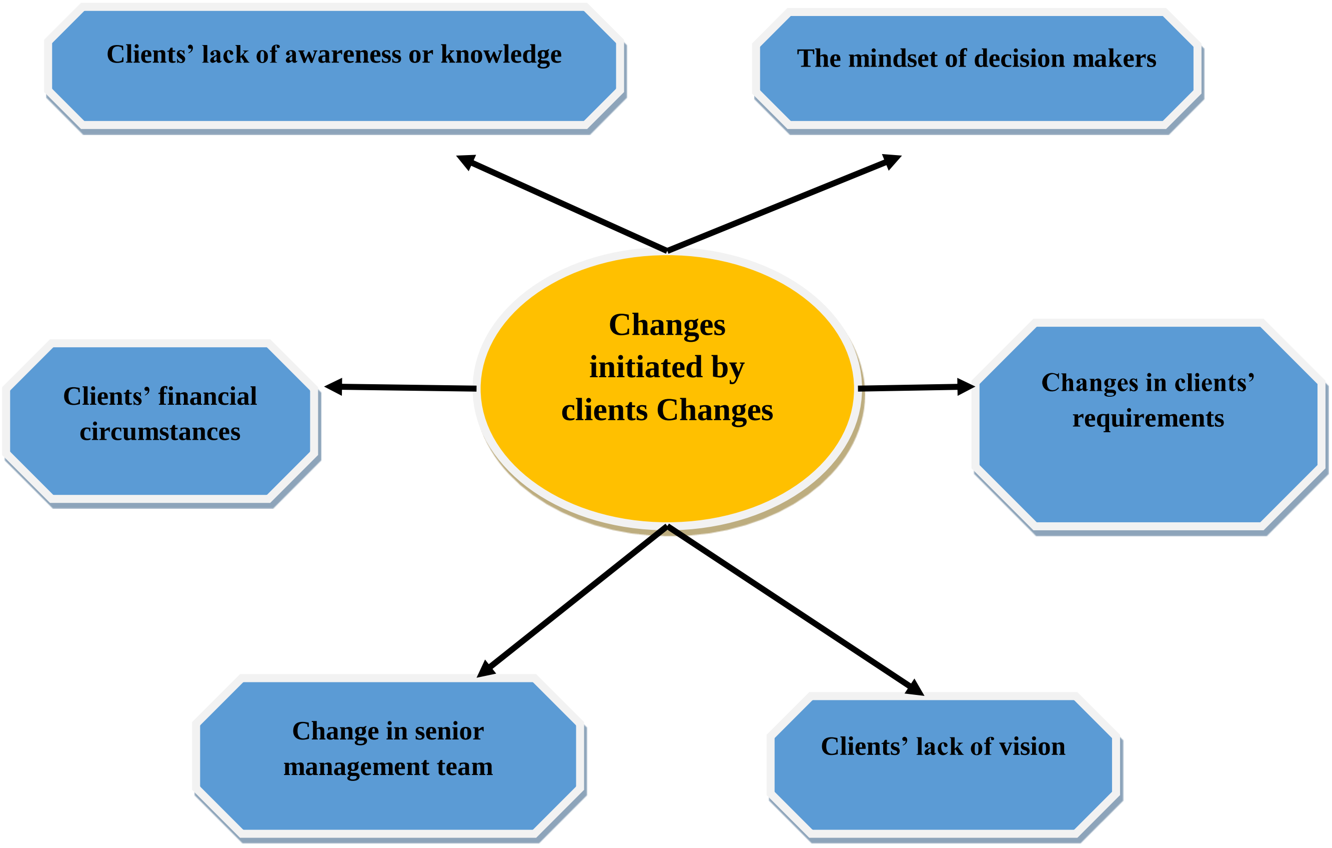


Figure 4.2: Causes of changes instigated by clients

Figure 4.2 summarizes the factors that lead to changes instigated by clients in the Jordanian construction sector, namely the client's lack of awareness or knowledge, the mindset of decision makers, the client's financial circumstances, changes in the client's requirements, a change in the senior management team or a client's lack of vision. These findings lead to the following hypothesis:

H2: Clients cause change orders in the Jordanian construction industry.

4.3.3 Incomplete design

Incomplete design was identified as a major cause of change orders in the Jordanian construction industry by eight participants. As in the case of design errors, incomplete design arises because there has been insufficient time for the design phase or unqualified designers have been used. Participant F commented on *"unprofessional designers who have not fully* *completed the design."* The interviews thus indicate that incomplete design is a major cause of change orders in Jordanian construction projects, which suggests the following hypothesis:

H3: Design errors cause change orders in the Jordanian construction industry.

4.3.4 Estimation errors

An analysis of the responses in the interviews indicates that errors in estimating the quantities of materials required for a project are also responsible for many change orders in construction projects, so this can be considered one of the main causes of change orders in the Jordanian construction industry. Five participants supported this conclusion, including participant J, who said that *"mistakes in the estimation of quantities and materials budgeting lead to many change orders."* In other words, it can be concluded that change orders could be issued as a result of estimation errors in Jordanian construction projects. This is the basis for the following hypothesis:

H4: Estimation errors cause change orders in the Jordanian construction industry.

4.3.5 Inconsistency between contract documents

Inconsistency between contract documents, i.e. between drawings and specifications, drawings and Bill of Quantity (BOQ), and between different drawings, are another major cause of change orders in the Jordanian construction industry. The findings indicate that inconsistency between contract documents accounts for a high proportion of cost overruns. Six of the 17 participants supported this conclusion. According participant A, the causes of change orders are *"design errors and omissions, incomplete designs, clashes (discrepancies) between construction documents such as discrepancies between BOQ and specifications with drawings, as well between different drawings."* Participant M gave the example of *"clashes between MEP and structure design."* An analysis of these findings shows that inconsistency between contract documents is a major cause of change orders in Jordan which results in a significant increase in project costs, which leads to the following hypothesis:

H5: Inconsistency between contract documents causes change orders in the Jordanian construction industry.

4.3.6 Lack of communication between project parties

Construction projects are fragmented in nature, and this requires high levels of communication between all the project parties if the project is to be completed in full and in accordance with its objectives. In the context of Jordan, the interview results suggested that a lack of communication between the project parties is a major cause of change orders. Five of the 17 participants felt that the project parties do not cooperate properly in sharing information with each other or with the different disciplines represented by each stakeholder, which causes ambiguity, lack of clarity and gaps in the information shared. This then increases the probability of errors either in the design or construction phase. Interviewee C confirmed this conclusion when he said that *"the lack of communication among project parties is one of the main causes of change orders"*, and this was supported by interviewees K and O: interviewee K felt that *"change orders occur as a result of a lack of communication between the client and the designer (engineer)"*, while interviewee O noted that *"the weakness during the design process is the transfer of information between designer and client, which leads to misunderstandings by the client and to changes during the construction process. This is a cause of change orders in Jordan."* Participant P was more emphatic: *"there is a huge gap in knowledge and experience of the construction work carried out at the site and the design process due to a lack of communication, so the design is one thing while the construction is something else. This leads to further problems and increases the number of change orders."* The lack of communication between the project parties is thus a major cause of change orders in Jordanian construction projects, and this could be between different project parties or between the different disciplines represented by the same stakeholder. This conclusion suggests the following hypothesis:

H6: Lack of communication between project parties causes change orders in the Jordanian construction industry.

4.3.7 Time lag between project design and construction

The period between completion of the project design and the commencement of construction work could be responsible for some change orders. The gap between the design and construction phases, whether it is long or short, could cause changes later on. For example, a short period may be imposed by pressure from a client who aims to start construction work as soon as possible, which may cause many errors that lead to change orders later on to resolve them. This is the point made by participant P: *"due to limited time for the design because of pressure from the client, the design may not be complete and there may be many other problems arising from this which lead to many change orders."* On the other hand, a long period could mean that a client's requirements may change, which could also lead to many changes in the project. Change orders in the Jordanian construction industry could be a result of the lag between the design and the construction phases, although only one interviewee made this point. This leads to the following hypothesis:

H7: A time lag between the completion of the design and the commencement of construction causes change orders in the Jordanian construction industry.

4.3.8 Different site conditions

Change orders for a construction project could be issued in order to adapt to a new situation at a construction site, for example specific site conditions, new ground conditions, and so on, which are not related to the project parties. In the context of Jordan, two experts mentioned different site conditions as one of the main causes of change orders in construction projects. The interview findings confirmed that change orders in the Jordanian construction industry might be due to changes in site conditions. This suggests the following hypothesis:

H8: Different site conditions cause change orders in the Jordanian construction industry.

4.3.9 Shortage of materials

During the project life cycle there could be changes in the availability of different resources which impact on the construction process. Materials are the main item in construction projects, and their availability fluctuates over the project life cycle. The analysis of the interview results shows that shortages of materials could cause change orders in the Jordanian construction sector. This is the reason for proposing the following hypothesis:

H9: Shortages in materials cause change orders in the Jordanian construction industry.

4.3.10 Summary

In conclusion, the interviews make it clear that change orders in the Jordanian construction industry can be caused by any of the project parties. Design errors, incomplete designs and errors in estimating quantities of materials are three main causes of change orders in the

Jordanian construction sector. These arise from using unqualified staff for design or quantity surveying work, short design periods or a failure to adhere to institutional and national regulations in the design. Changes initiated by the client are also considered to be one of the main causes of change orders in the Jordanian construction industry. A client requests changes in a construction project because of changes in the scope of the project, changes in their requirements and needs, a lack of awareness or knowledge about the project, their financial circumstances, or a change in the senior management team. Critical analysis of the interviews also found that change orders in the Jordanian construction industry are frequently a result of inconsistencies between contract documents, as well as a lack of communication between the project parties. Finally, participants mentioned other causes of change orders in the Jordanian construction industry such as shortages of materials, different site conditions, or a lag between the completion of the project design and the start of construction. Table 4.2 below shows the causes of change orders in Jordan grouped according to the themes identified in the interviews, and Figure 4.3 presents a cognitive map of these causes.

Table 4.2: Themes in the causes of change orders in the Jordanian construction industry

Causes of Change Orders In the Jordanian Construction Industry (Code)	
Themes	design errors
	changes initiated by the client
	incomplete design
	estimation errors
	inconsistency between contract documents
	lack of communication between project parties
	shortages of materials
	different site conditions
	lag between design and construction

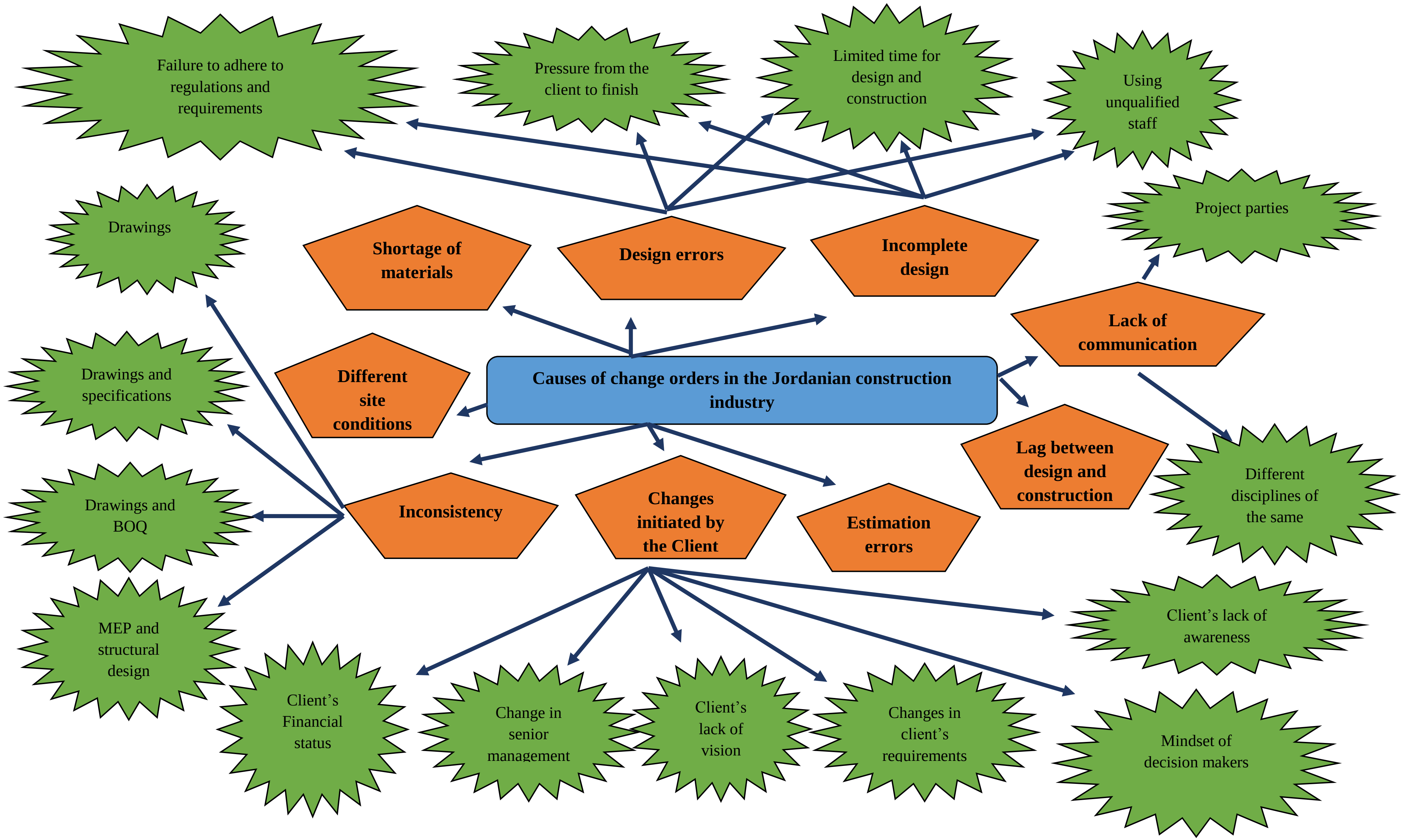


Figure 4.3: Cognitive map of the causes of change orders in the Jordanian construction industry

4.4 The current level of awareness of BIM in the Jordanian construction industry

In order to achieve the second research objective, which focuses on clarifying the current level of awareness of BIM in the Jordanian construction industry, the researcher asked many questions on this topic. The questions focused on the level of awareness of BIM both individually and over the whole construction sector. They also sought to ascertain the current take-up of BIM in construction firms, and whether there are adequate guides to implementing BIM. The first step was to investigate participants' level of understanding of BIM, how they are able to articulate their knowledge of BIM, and what BIM means to them. The answers show that participants' knowledge of BIM can be categorized at three levels. The first level, in which there is no or very little awareness of BIM, is the one which describes most participants (eight out of the group of 17). Participants in this category cannot define BIM clearly; for example, participant J claimed *"I have very little knowledge about BIM, which is insufficient."* Similarly, participant F said *"I don't have enough information about BIM - my knowledge is so poor."*

The second category includes those who have a little knowledge of BIM. Six of the 17 participants were classified as belonging to this category. These participants were able to say more about BIM than those in the first category. For example, participant O admitted *"I don't have a lot of information about it. BIM analyses the project items and elements before the start of the construction process, and creates a database for the project which includes project cost, time, clash detection, incomplete design detection and the requirements for completing the project."*

The third category includes participants who have a good knowledge of BIM. This category has only three participants. According to participant A, *"BIM is a tool that can be useful for dealing with several issues; it can be used in different ways, depending on your discipline as a consultant, designer, contractor or client. For example, consultants and designers can improve the quality of drawings, and minimize discrepancies in construction documents by producing more accurate drawings, specifications and BOQ. It could be said that implementing BIM primarily improves communication between engineers' disciplines and consequently achieves the benefits already mentioned. For contractors, BIM has great benefits because it can be used as a control tool during the life cycle of the project right from the start. The contractor builds a model of the project to investigate its constructability, and* *can develop more constructible methods for problems which may occur in the project, as well as identifying significant solutions which need to be accepted by all the project parties, and which save cost and time. In addition, BIM can be used as a control tool for cost and time, for example if the client asks for a change to the design (e.g. adding doors), the model makes the change automatically on all the drawings, lists of quantities and other documents. Therefore, the contractor can measure the impact of the changes on the work process, cost and time, and then take a decision about it and go back to the client with full details. For clients, BIM is considered to be a good tool for controlling the budget and immediately giving a very good picture of what impact changes will have on the cost of the project, so that he can make decisions about them – whether finances mean the changes are viable or not, or whether there are other solutions which are within budget. Moreover, BIM warns the client if he has overrun in his project, so he can take appropriate action. Finally, it is also a tool which enables all the project parties to communicate with each other in a timely way - not like what is going on at the moment."*

Participant G defined BIM as an integrated model that makes connections between construction processes, as well between project parties through different software: *"it is a piece of software for design and drawings that links various activities with design components including structural, mechanical, architectural and electrical features. So when a change occurs in one item, the BIM system reflects this change everywhere else, and calculates its impact. BIM is an integrated model, which shares the information input between all project parties and disciplines."* Participant L also showed a good understanding of BIM processes: *"BIM takes all the building information and makes a model, which is presented in 3D and has full details of costs, the site, size, volume and quantities. So it builds the project virtually, just as it would be in real life. In addition, BIM improves communication between disciplines, which minimizes clashes and errors, and also estimates the quantities of material required with high accuracy."*

On the other hand, the interview results showed that there was zero implementation of BIM in construction firms, with 10 participants saying that their firms still depended on 2D CAD, and a further seven reporting that only 2D CAD and 3D CAD were used in their firms. In order to investigate successful examples of the implementation of BIM in the Jordanian construction industry, the researcher asked participants about construction projects which were implementing or had implemented BIM and could therefore be a guide for the adoption of

BIM in other projects in Jordan. All the participants agreed that there were no projects which had implemented BIM, which means that there is no successful project which had implemented BIM and could serve as a guide for its adoption in other projects.

In conclusion, awareness of BIM in Jordan can be classified into three levels: very little, little and good. Most of the participants have very little knowledge and awareness of BIM, while only three participants have an adequate understanding. Between these groups is an intermediate category for participants who have a basic understating only of BIM. The interview results also indicated that there is a lack of knowledge and awareness of what is involved in implementing BIM, with the majority of construction firms still depending on 2D CAD for design or construction. All the participants indicated that the Jordanian construction industry is very poor at implementing BIM successfully, which supports the conclusion that the level of awareness of BIM is still low.

4.5 Barriers to the adoption of BIM in the Jordanian construction industry

Despite the many benefits of BIM for construction projects, the implementation of BIM to control the cost of change orders is facing difficulties. With this in mind, and to achieve the third research objective, the researcher asked participants to identify the barriers to the adoption of BIM to control the cost of change orders. These barriers related to products, individuals and processes.

4.5.1 Barriers related to products

The first category of challenges that hinder the adoption of BIM is related to BIM products. The interview results indicate that there is only one barrier in this category.

4.5.1.1 Financial considerations

The interview findings indicate that the main financial barriers to adopting BIM in the Jordanian construction industry are the cost of BIM software and upgrading hardware, and training costs. Sixteen of the 17 participants believed that the cost of software is the main barrier to the adoption of BIM in the Jordanian construction industry. Upgrading hardware is also essential to meet the requirements of the BIM software and to enable it to work effectively, but 14 participants believe that the cost of upgrading hardware is preventing the adoption of BIM. This forces construction firms to think about alternatives to BIM. This was the opinion expressed by participant H: *"in general, there is a problem with using BIM, as the majority of Jordanian construction firms are concerned about the costs of software or of upgrading hardware."* The cost of training is the third financial barrier, and this was raised by nine participants. Participant J's answer to the question about financial barriers was *"the cost of training."* It can clearly be concluded from these expert views that financial matters are a major barrier to the adoption of BIM in the Jordanian construction industry. Financial considerations include the cost of software, the cost of upgrading hardware and the cost of training. The following hypotheses were therefore formulated:

H10: Software costs are obstructing the adoption of BIM in the Jordanian construction industry.

H11: Hardware costs are obstructing the adoption of BIM in the Jordanian construction industry.

H12: Training costs are obstructing the adoption of BIM in the Jordanian construction industry.

4.5.2 Barriers related to individuals

The second category of challenges facing the adoption of BIM in the Jordanian construction industry is related to individuals. The interview results indicated that there is only one barrier in this category.

4.5.2.1 Staff training

An in-depth analysis of participants' responses indicated that a shortage of skilled and trained staff who could implement BIM is a major barrier to the adoption of BIM, with ten supporting this conclusion. According to participant E, *"there is a shortage of staff who have the abilities to implement BIM professionally."*

In the interviews, 12 of the 17 participants said they believed that the Jordanian construction industry as a whole does not have the qualified staff for the adoption of BIM at present. According to participant D, *"at the moment, most construction firms have only staff who do not have the skills or training to implement BIM."* Similarly, participant B felt that at present there are only a few staff who are in the early stage of using Revit, but they need more training and courses to be able work with BIM. He stated that *"only a few staff in certain* *companies are in the early stages of implementing Revit, but for BIM they still need training and courses."* On the other hand, five of the 17 participants believe that Jordanian construction firms do have the qualified staff they need for implementing BIM, but these staff are few and work only in certain first-class firms. According to participant N, *"there is a limited number of professional workers in some first-class firms in the construction industry."* This was also the view of participant F: *"there are only a few skilled and trained staff, in first-class firms*." It can thus be concluded that there is a shortage of qualified staff in the Jordanian construction sector who could implement BIM effectively, which is a major barrier to the adoption of BIM. This supports the following hypothesis:

H13: A shortage of skilled and trained staff is obstructing the adoption of BIM in the Jordanian construction industry.

4.5.3 Barriers related to process

The interview results show that BIM has not been implemented to control change orders as part of current practices and procedures in the Jordanian construction industry. Indeed, it is not using BIM in construction projects at all. The researcher therefore elicited participants' opinions on barriers to the adoption of BIM related to processes in Jordan. The responses indicate that there are many obstructions to the adoption of BIM, as outlined below.

4.5.3.1 Traditional processes

Current communication processes between project parties are hindering the adoption of BIM. Eight participants believed that current practices depend on traditional processes, which are fragmented in nature, with each stakeholder doing his job in a way that suits him and being reluctant to change. According to three participants, there is a gap between current practices and what is required for the implementation of BIM, with the current situation relying on traditional processes which work separately for each project party, and without any effective integration or collaboration. According to participant A, *"current practices and procedures are hindering the adoption of BIM. Contractors stick with certain practices in the way they carry out and manage construction work, and they don't want to change this. Engineers also use traditional processes in the design and supervision of projects, and they don't want to use BIM. So both contractors and consultants find excuses for not going for BIM."*

The results also indicated that the project parties do not communicate effectively with each other in the Jordanian construction sector. Participant E felt that *"the processes of the construction industry are still traditional, while BIM requires the collaboration and integration of all project parties. The current communication system does not result in integration between project parties. For example, the architects design the project without consulting the structural engineers, which leads to errors in the design and change orders during construction."* Overall, participants' opinions support the conclusion that traditional processes lead to fragmentation and lack of coordination between project parties, and that the current communication system does not support the adoption of BIM in Jordan. All of this suggests the following hypotheses:

H14: The current communication process between project parties is obstructing the adoption of BIM in the Jordanian construction industry.

H15: Dependence on traditional processes in the Jordanian construction industry is hindering the adoption of BIM.

4.5.3.2 The current culture of the Jordanian construction industry

The second barrier to the adoption of BIM in the Jordanian construction industry related to process is its culture. Ten of the 17 participants were of the opinion that the current culture of the Jordanian construction industry is reluctant to adopt BIM. The attitude in Jordanian construction firms means that they are reluctant to try anything new, so the adoption of BIM faces a major obstacle in construction firms. Participant A supported this conclusion: *"in addition, people resist anything new."* Similarly, participant F felt that *"the mentality of construction firms is still hostile to the adoption of BIM or new technologies."* What is more, the adoption of BIM is opposed by top management in construction firms, and three participants emphasized this. For participant Q, *"current practices in the Jordanian construction industry are hindering the adoption of BIM due to the way of thinking of all stakeholders*." Participant I added that *"most project practices are hindering the adoption of BIM; for example the moodiest of senior management along with their way of thinking are hindering that*." It can thus be clearly seen that reluctance on the part of top management to adopting new technologies in general, and BIM in particular, is a major barrier related to culture in the Jordanian construction industry.

At the same time, recruiting specific staff for day-to-day work who are not able to implement BIM is another barrier related to the cultural factor. The interview results indicate that most Jordanian firms are using staff who are not able to work with BIM, although they are competent to do the other work expected of them. Participant L felt that the best way to accept BIM would be to change the culture of the construction sector, which relies completely on staff who cannot work with BIM: *"theoretically, they accept BIM, but the reality is that they don't, because for that to happen we need to change a culture of depending on staff who can only do things other than BIM."* This dependency on staff who do not have the skills required for BIM is another obstruction related to the culture of the construction industry. In conclusion, the culture of the Jordanian construction industry results in two major barriers to the adoption of BIM, firstly the reluctance of construction firms to adopt new technologies, and secondly their dependence on staff who cannot work with BIM. This leads to the following hypotheses:

H16: Top management in the Jordanian construction industry is reluctant to adopt BIM.

H17: Dependence on staff who are not skilled or trained in using BIM is obstructing the adoption of BIM in the Jordanian construction industry.

4.5.3.3 Lack of interest and demand

To adopt BIM in the construction sector, the approval of senior management is very important. In the Jordanian context, the analysis of the interviews found that organizations in the construction industry are not interested in BIM, and are reluctant to adopt it. Participant L confirmed this conclusion, commenting that *"there is a lack of interest on the part of senior management in implementing BIM."* Participant E also said that *"there is no enthusiasm for adopting BIM."* The adoption of BIM in the Jordanian construction industry thus faces many obstacles related to this lack of interest and demand, and most construction firms do not give much thought to BIM. This conclusion leads to the following hypothesis:

H18: Lack of interest and demand is hindering the adoption of BIM in the Jordanian construction industry.

4.5.3.4 Lack of awareness

The analysis of the interviews indicated a lack of awareness as one of main challenges facing the adoption of BIM in Jordan. Five of the 17 participants thought that the lack of awareness is hindering the adoption of BIM in the Jordanian construction industry. According to participant F, *"there is a lack of awareness in the Jordanian construction industry about BIM."* Participant D agreed, saying that *"nowadays the level of awareness of BIM and its benefits is still low, and has not spread sufficiently or reached the level where it would be supported by all stakeholders."* Furthermore, the lack of awareness will be enhanced in case there is a successfully BIM implementation in construction projects. However, the results show that there is no project which has implemented BIM which could be a guide for the adoption of BIM in the Jordanian construction industry. Participant C supported this conclusion: *"there has been no suitably successful implementation of BIM in the Jordanian construction industry which can be taken as a guide for implementation. So, firms will face a lot of challenges if they adopt BIM."* The result is that the Jordanian construction sector is suffering in terms of knowledge and awareness of BIM, the lack of which is considered a major barrier to the adoption of BIM. Projects which have successfully implemented BIM will increase the level of awareness of BIM throughout the construction industry, but the interviews bear out the fact that there has been no project in Jordan which has implemented BIM recently. This leads to the following hypothesis:

H19: Lack of awareness is obstructing the adoption of BIM in the Jordanian construction industry.

4.5.3.5 Lack of a legal framework

The lack of a legal framework in relation to BIM in Jordan is seen as a major obstruction to the adoption of BIM. The interview results show that the Jordanian construction industry does not have any legal or contractual set of standards or protocols for BIM, and all 17 participants commented on this. Participant A said *"we don't have any legal or contractual framework for BIM in Jordan"*. Participant D also noted that *"Jordan has no contractual standards in relation to BIM."* The Jordanian Ministry of Public Works and Housing and the Jordanian Engineering Association should take responsibility for managing BIM in Jordan, where the current system and regulations are both hindering adoption. According to participant M, *"the current systems and regulations of the Jordanian Ministry of Public Works and Housing and the Jordanian Engineering Association can be seen as challenges facing the adoption of BIM"*.

Discussions in the interviews concluded that the approval process for new projects involves requesting authorization from the Jordanian Ministry of Public Works and Housing, the JEA and other bodies. But these organizations do not have regulations for managing BIM, nor are they implementing BIM or are even able to use it. It can therefore be concluded that the current approval system for new projects is obstructing the adoption of BIM in Jordan. Participant N agreed: *"currently it is necessary to get approvals from the JEA, the Ministry of Public Works and Housing and other bodies, but these organizations are not able to use BIM, and do not have the skilled and trained staff for it, so the current approval procedures are hindering the adopting of BIM."* In conclusion, these interviews show that there is a lack of legal regulations and standards in the Jordanian construction industry which is delaying the adoption of BIM. What is more, the main organizations in the industry, i.e. those that are responsible for approving new construction projects, are not using BIM themselves and have no regulations regarding BIM. The current approval system for new projects is thus hindering the adoption of BIM, as the organizations responsible for giving approval are not competent to assess projects which use BIM. This leads to the following hypotheses:

H20: The lack of a legal framework in relation to BIM is obstructing the adoption of BIM in the Jordanian construction industry.

H21: The current approval system for new projects is obstructing the adoption of BIM in the Jordanian construction industry.

4.5.3.6 Low budgets for new projects and high competition

Competition in the construction industry is a major factor which can improve the quality of a project, but in the Jordanian context the interview results indicated that competition pushes against the use of BIM, as there is pressure to keep bids in line with those of competitors, and the cost of implementing BIM would make this impossible. According to participant Q, *"the fact that project tendering prices are so low nowadays is considered to be another reason why firms are not using BIM, because the revenue will not cover the costs of BIM, or even part of the costs."* Participant O explained further that *"there will be less chance to win contracts because firms which have implemented BIM will charge higher prices than other firms, so in this situation the client will go for the lowest price, so the likelihood of getting the project is nearly zero, and that will mean financial problems for firms which are using BIM."* This shows the link between the budget for new projects and competition between construction firms: there is high price competition between firms for new projects, which pushes them to reduce the costs of construction - and hence the bidding price - to a point at which it cannot cover the costs of BIM. The following hypotheses can thus be proposed:

H22: Low budgets for new projects are hindering the adoption of BIM in the Jordanian construction industry.

H23: High competition between construction firms is hindering the adoption of BIM in the Jordanian construction industry.

4.5.3.7 The time factor

The time factor is another major barrier to the adoption of BIM in the Jordanian construction industry. The findings show that the time required to train staff significantly obstructs the adoption of BIM, as confirmed by six participants. Construction firms avoid doing training courses related to BIM because of the time it will take. According to participant B, *"most companies do not want to spend a lot of time and money to adopt BIM because the training may be very lengthy."* Currently the Jordanian construction industry has no proper infrastructure of trained staff for BIM, and the time required to develop such an infrastructure is seen as another factor which hinders the adoption of BIM. According to participant L, *"I cannot implement BIM for projects overnight, by magic. The time factor is one of main barriers to the adoption of BIM in the current situation. Implementing BIM involves preparing an adequate environment of software families, library resources and training. In addition, it will take a lot of time to do all this and create a proper environment for the adoption and implementation of BIM, which is not available given prevailing practices in the construction industry."* It can thus be concluded that the time factor is a major challenge for the adoption of BIM in Jordan, as the construction sector is concerned about the amount of time and the high costs of training, as well as the time required to develop a suitable infrastructure for the adoption of BIM. These considerations lead to the following hypotheses:

H24: The duration of the training required is obstructing the adoption of BIM in the Jordanian construction industry.

H25: The time required to prepare a suitable environment for implementing BIM is hindering the adoption of BIM in the Jordanian construction industry.

4.5.4 Summary

In conclusion, a thorough analysis of participants' views has identified several barriers which are hindering the adoption of BIM in the Jordanian construction industry. These barriers are linked to the product, to individuals and to processes. The main barriers related to the product are the cost of software, the cost of upgrading hardware and the cost of training. Those related to individuals are the shortage of skilled and trained staff, i.e. a situation in which there is limited availability of professionals in construction firms for implementing BIM, meaning that most construction firms are dependent on staff who cannot use BIM. The barriers related to processes are the use of traditional processes, and the culture of the Jordanian construction sector, as well as the lack of interest and demand, the lack of awareness, the lack of a legal framework, low budgets for new projects, competition in the construction sector, and the time required for the adoption of BIM. Table 4.3 below shows the code, themes and sub-themes relating to the barriers to the adoption of BIM to control the cost of change orders in the Jordanian construction industry. Figure 4.4 presents a cognitive map of the barriers which hinder the adoption of BIM in the Jordanian construction industry.

Table 4.3: The code, themes and sub-themes of the barriers to the adoption of BIM to control the cost of change orders in the Jordanian construction industry

Barriers to the Adoption of BIM to Control the Cost of Change Orders in the Jordanian Construction Industry (Code)		
Themes	**Sub-Themes**	
Products	**Financial Considerations**	software costs
		costs of upgrading hardware
		training costs
Individuals	**Training**	shortage of skilled and trained staff
Processes	**Traditional Processes**	current communication processes
		traditional work processes
	Culture	reluctance of senior management
		dependence on unskilled staff
	Lack of Interest and Demand	lack of interest and demand
	Lack of Awareness	lack of awareness
	Legal Issues	lack of standards and regulations relating to BIM
		current approval system for new projects
	Low Budget for New Projects	low budget for new projects
		high competition
	Time Required	time required for training
		time required to prepare a suitable environment for the adoption of BIM

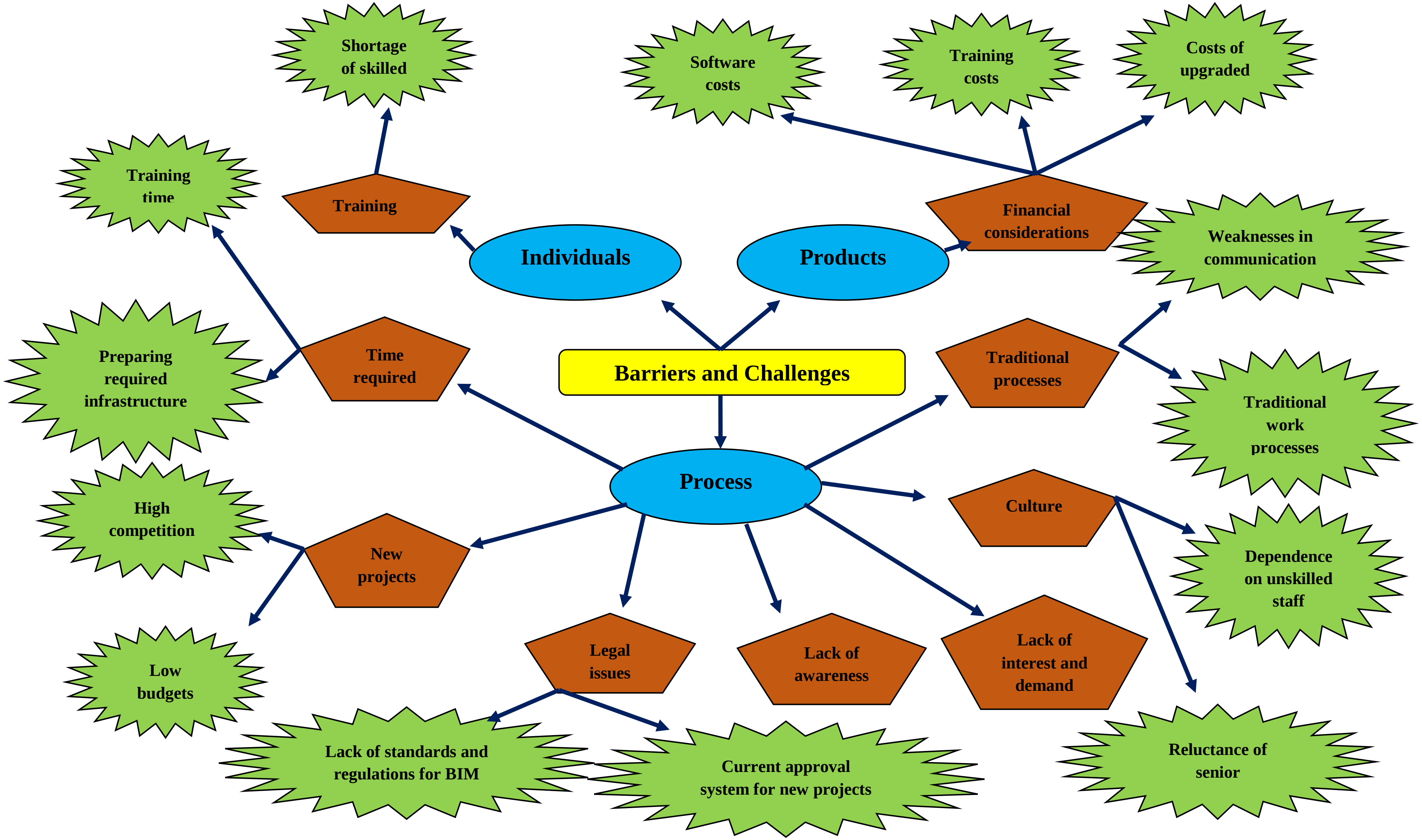


Figure 4.4: Cognitive map of the barriers to the adoption of BIM in the Jordanian construction industry

4.6 The perceived effects of implementing BIM on change orders

In order to investigate the effects of implementing BIM on change orders in the Jordanian construction industry, the researcher asked participants who have experience in the field about their perceptions of reducing the costs of change orders as a result of implementing BIM. There was significant agreement says that implementing BIM would assist in controlling the causes of change orders, as well as in decreasing the number of change orders, in the Jordanian construction sector. The consensus was that implementing BIM would lead to a reduction in the cost of change orders. According to participant D, *"the number of change orders will be dramatically decreased".* However, using BIM in construction projects impacts on change orders in a variety of ways, and participants mentioned some of the ways in which the adoption of BIM could reduce the cost of change orders by minimizing their causes, as described in the following sections.

4.6.1 Reducing design errors

In relation to how the adoption of BIM could minimize cost overruns resulting from change orders in Jordan, several experts said that implementing BIM would lead to a reduction in the number of design errors in a project, which would be reflected in a reduction in the number of change orders that may occur. Participant D believed that implementing BIM would identify errors at an early stage of the project life cycle, which would prevent change orders occurring later on: *"implementing BIM will identify design errors at an early stage of the project, so we can avoid them later on. For example, BIM identifies design errors and any incompleteness in the design, so there will be nothing to cause change orders later on."* The conclusion is clearly that the adoption of BIM in the Jordanian construction industry will have a positive influence on minimizing cost overruns through reducing change orders arising from design errors.

4.6.2 Improving communication and collaboration

Six of the 17 participants were of the opinion that implementing BIM in construction projects would improve communication and collaboration between stakeholders, as well as between the different stakeholder disciplines, and this would result in a decrease in the causes of change orders. According to participant K, *"implementing BIM in the construction industry would improve the communication between the project parties, and that would affect change orders and reduce their numbers by minimizing errors, omissions, and incomplete designs* *and clashes, as well as improving the understanding of the elements of the project."* Improved communication between project parties would provide more time for clarifying a client's requirements, as well as more time to develop more clarity about the design phase. This means that where lack of communication and collaboration between project parties is one of the main causes of change orders, the adoption of BIM will effectively decrease change orders which in turn will reduce cost overruns in construction projects.

4.6.3 Improving clients' knowledge

Analysis of the interview results showed that implementing BIM will give a client greater knowledge and awareness in relation to the project than traditional practices, so the client will be able to focus wisely on their needs and requirements, as well as being able to determine the project's objectives thoughtfully on the basis of the budget and time available. According to participant C, *"in the design phase, BIM clarifies the project by giving the client a virtual model, which helps them to specify the scope of the project, as well as its objectives. So the number of change orders will go down as a result of this increased level of awareness, especially in the later stages of the project life cycle, which is when they are considered costly."* Implementing BIM will thus help to decrease the number of change orders later on. It will give the client a greater involvement and improve their understanding of the costs of the project and its progress over the whole project life cycle. This, in turn, will reduce the number of change orders, as mentioned by participant L, who pointed out that *"the BIM system allows a client to be involved in 4D and 5D, which is a very important feature for the client. This will mean the client is informed throughout about costs and time at any stage of construction, as well as the shape of the project and what has been completed."*

Figure (4.5) shows what BIM enables the client to do, based on the building of a 3D model as a means of improving their awareness and understanding of the project. In the first stage, the client is able to determine and focus on their needs, and then has up-to-date details of the final shape of the project, and of time and costs. Overall, this will result in minimizing the number of change orders and their costs.

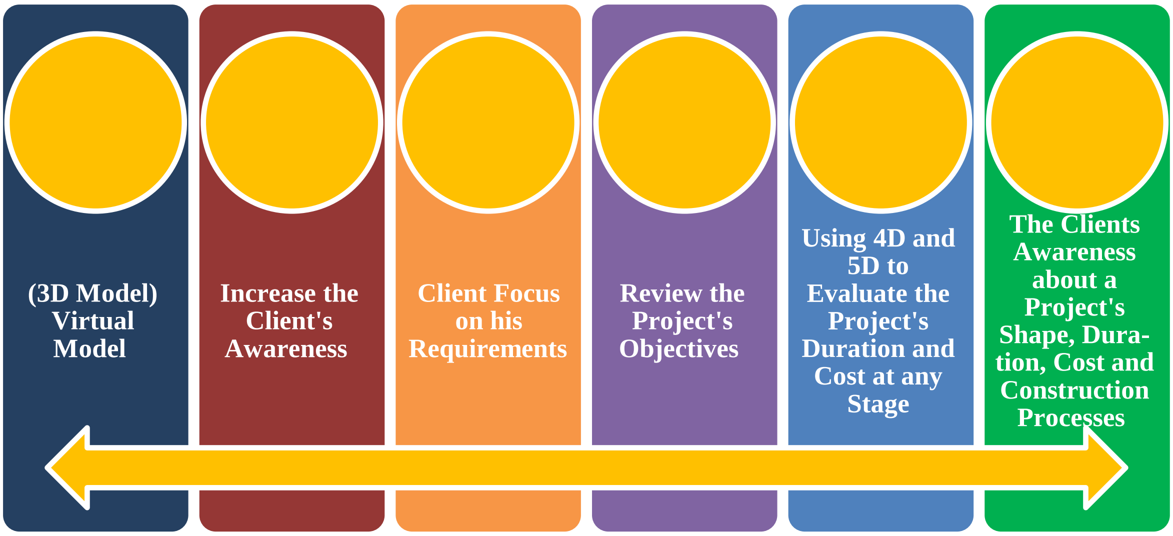


Figure 4.5: The effects of BIM on changes orders initiated by the client

To summarize, the interviews indicated that BIM can significantly improve clients' knowledge and understanding of their project, so they are able to assess their needs and requirements more critically. Moreover, they will be able to participate effectively throughout the project lifecycle. This will minimize the number of changes the client initiates in a construction project and reduce the cost overruns which arise from change orders.

4.6.4 Making appropriate decisions

An analysis of the data collected indicates that utilizing the BIM model will provide a good opportunity for all the project parties to evaluate the effects of change orders on a project's time and budget, so that they can make appropriate decisions with known results. Figure 4.6 is derived from participants' responses, and shows the impact of BIM on the decisions that are made. Five of the 17 experts believed that determining the impact of change orders on project costs and time before actually implementing a change order will lead to selecting only essential change orders, i.e. those that will improve the quality of the project and fulfill the client's requirements, and thus to a decrease in the number of change orders. According to participant N, *"the BIM model will significantly clarify the impact of changes on project costs and time, so decisions will be taken very carefully."* In other words, identifying the impact of change orders on the time and costs of a project encourages clients to choose only the essential changes that will improve the project's objectives and are in line with its budget.

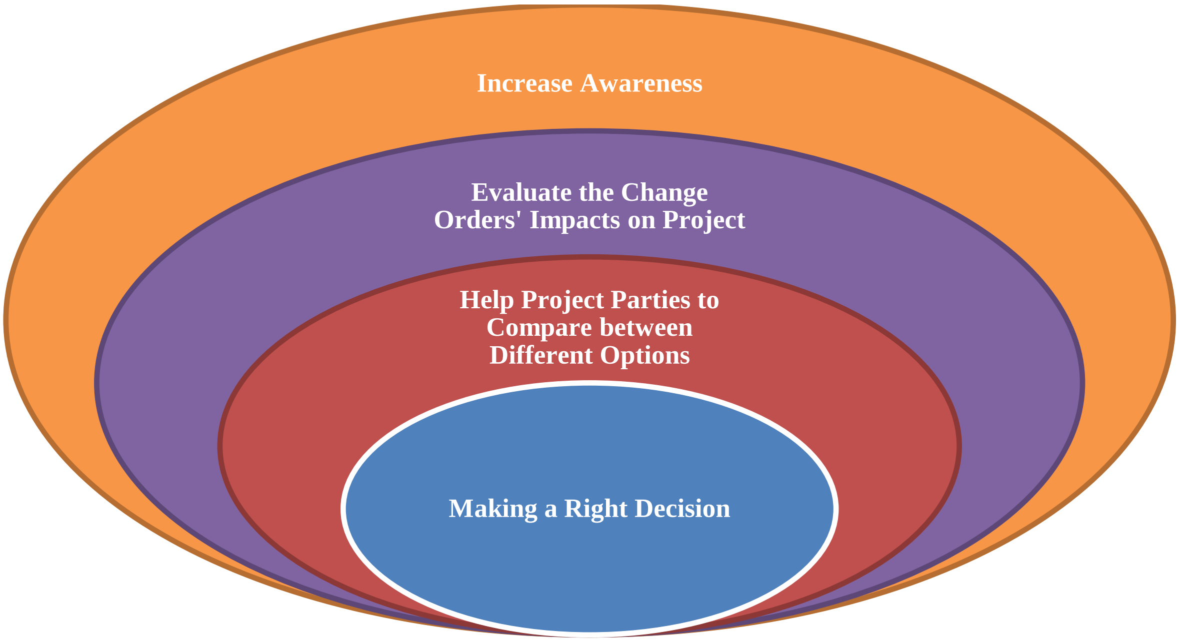


Figure 4.6: The impact of the BIM Model on decision-making

Overall, the adoption of BIM in the Jordanian construction industry will help to reduce the cost of change orders because the project parties will be able to assess the impact of changes on the project's time and costs. They are thus able to make appropriate decisions after comparing different options. Making appropriate decisions will result in minimizing the number of change orders, and thus their costs.

4.6.5 Clash detection

The analysis found that clash detection is one of the ways in which the number of change orders in the Jordanian construction industry can be reduced by the adoption of BIM, and that this can consequently reduce the project costs. Most of the experts believed that the implementation of BIM would be useful for detecting clashes as well as any inconsistencies between the contract documents, and that this in turn would decrease the number of change orders. In this regard, participant O felt that implementing BIM would eliminate change orders in the Jordanian construction industry which result from clashes and inconsistencies between drawings or between drawings and specifications. This would significantly decrease the cost of change orders in construction projects.

4.6.6 Supporting the construction process

The interview findings indicate that the BIM model will support performance by building the project virtually before the start of the construction process, which improves all parties' understanding of the methods and procedures of the construction work. According to expert D, *"the virtual BIM model provides an opportunity to select suitable methods for constructing the project."* Participant A pointed out that *"for a contractor, it helps him to determine the project's constructability and the construction methods that will be used, as well as improving control of costs and time."* BIM would thus significantly reduce the number of change orders in the Jordanian construction and their cost by providing the knowledge and information required to facilitate construction procedures and choose suitable methods for construction work.

4.6.7 Summary

In conclusion, a critical analysis of experts' responses indicated that several benefits can be gained by utilizing BIM in the Jordanian construction industry. Figure 4.7 illustrates the perceived benefits of BIM in relation to change orders in Jordan. BIM helps to eliminate the causes of change orders by reducing design errors, improving communication and collaboration between project parties and improving clients' awareness and knowledge in relation to the project by developing a virtual model of the project and providing full details of the final outcomes, which minimizes the number of change orders which may appear later on. In addition, it helps the project parties to make appropriate decisions in a series of steps, starting by increasing awareness, then enabling stakeholders to evaluate the impact of change orders on the project time, costs and shape, compare different options and finally select one which is within the client's budget and timescale and meets their needs. It also improves clash detection, and supports construction procedures. These benefits were all mentioned by the participants, and their effect will be to reduce the number of change orders and their costs.

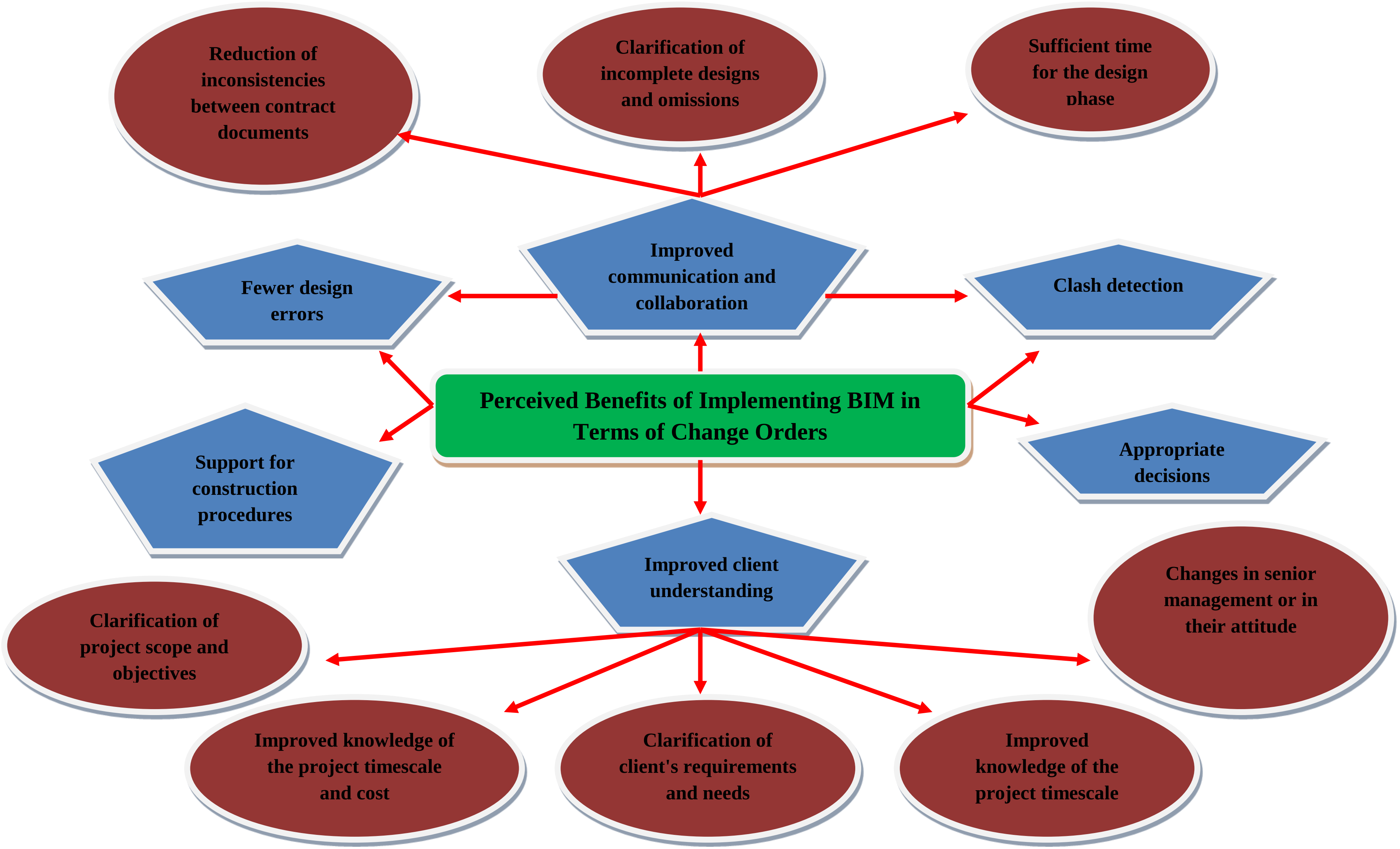


Figure 4.7: The benefits of implementing BIM in relation to the causes of change orders

4.7 Drivers of the adoption of BIM in the Jordanain construction industry

In order to investigate who should take responsibility for the adoption of BIM in the Jordanian construction industry, the researcher asked interviewees for their opinions on this question. The analysis of the data collected identified seven drivers could lead to the adoption of BIM in Jordan.

4.7.1 The Jordanian Ministry of Public Works and Housing (JMPWH)

The analysis of the interviews showed that the Jordanian Ministry of Public Works and Housing (JMPWH) is seen as the main driver for the adoption of BIM in the Jordanian construction industry. The Jordanian Ministry of Public Works and Housing (JMPWH) should manage the adoption of BIM by issuing regulations covering BIM, as well as increasing awareness of BIM across the whole construction sector. Participant M supports this idea: *“the Jordanian Ministry of Public Works and Housing must take the lead for the adoption of BIM in Jordan."* Other participants believe the responsibility for providing a legal framework for BIM lies with the Jordanian Ministry of Public Works and Housing: according to participant E, *"BIM must be part of the Ministry of Public Works and Housing and come within its remit.”* Similarly, participant Q felt that *"it is very important that the Ministry of Public Works and Housing should issue regulations and contractual guidance in this area.”* It can clearly be concluded that the Jordanian Ministry of Public Works and Housing is seen as a significant driver of BIM in the construction industry, and as such it should increase awareness levels, organize training courses and provide a legal and contractual framework for managing and organizing the adoption of BIM.

4.7.2 The Jordanian Engineering Association (JEA)

The second main driver of the adoption of BIM in Jordan should be the Jordanian Engineering Association (JEA). The interviews show that the adoption of BIM could be initiated by the JEA, according to participant E: *"the adoption of BIM must start with the JEA."* The JEA should improve levels of awareness of BIM across the construction sector to push and facilitate the adoption processes. Participant D felt that *“the processes of adopting BIM should start with the JEA offering sessions and training courses on BIM software.”* Participant K suggested that *“the JEA should produce a proposal covering proper awareness and the costs and requirements of using BIM in the Jordanian construction industry, as well* *as explaining the benefits which can be gained through its implementation.”* However, the JEA cannot lead the adoption of BIM in Jordan by itself, but should cooperate with other important drivers to ensure the adoption process is successful. Participant H said that *"the JEA is the main driver, and can work with the government to support the adoption of BIM.”* Participant K suggested that the Jordanian Ministry of Public Works and Housing and the JEA should cooperate to implement BIM, suggesting that *“the Jordanian Ministry of Public Works and Housing must collaborate with the JEA as one team to support the adoption of BIM."* Participant P agreed: *"the Jordanian Ministry of Public Works and Housing and the JEA must adopt BIM in their own work and train their staff to use it, and then ask construction firms to implement it."* Participant L suggested that the Ministry of Public Works and Housing and the JEA were responsible for preparing a legal framework for BIM in Jordan, saying *“it must be prepared by the Ministry of Public Works and Housing together with the JEA.”* The findings thus show that the JEA is seen as an important driver of the adoption of BIM in the Jordanian construction industry, and can take the lead in stimulating and facilitating adoption processes effectively through initiatives to increase awareness levels and by conducting training sessions. Furthermore, in order to reinforce the adoption process, the JEA should collaborate with the Ministry of Public Works and Housing so that they work together as one team to push BIM forward.

4.7.3 The Jordanian Construction Contractors’ Association (JCCA)

The interviews also suggested that the adoption of BIM in the Jordanian construction sector could be supported by the Jordanian Construction Contractors’ Association (JCCA). Participant D saw the JCCA as a driver of the implementation of BIM, saying *“in addition, the JCCA could do some training courses and sessions on BIM software that will support the adoption of BIM."* Participant A suggested *"improving the participation of public associations such as the JEA and JCCA in the adoption of BIM, and especially the JEA."* It is obviously seen that the Jordanian Construction Contractors’ Association is potentially a driver of BIM which could support the adoption process by conducting training sessions and cooperating with other drivers such as the JMPWH and the JEA to ensure the successful adoption of BIM.

4.7.4 Clients

Clients have a vital role in leading the adoption of BIM in the Jordanian construction industry. Two participants agreed that clients and developers should support the adoption of BIM in their projects as part of the adoption process over the whole construction industry. According to participant I, *"clients or their representatives (construction managers) are responsible for adopting BIM by putting it as a requirement in the project contract,"* and participant J added that *"owners and developers are responsible for implementing BIM. So if they are aware of its benefits, then definitely they will push for it to be used in their projects."* It is clearly felt that clients' support for the adoption of BIM in the Jordanian construction industry is important. Clients can drive the adoption of BIM by asking for it to be used in their projects and including BIM in contract documents.

4.7.5 Construction firms

Construction firms, i.e. both engineering firms and contractors, should support the adoption of BIM in the Jordanian construction sector. The content analysis of interviewees' views showed that four participants believed that large construction firms must play a part in the adoption of BIM in the Jordanian construction industry. According to participant A, *"large construction firms in the Jordanian construction industry* - *contractors and engineering firms (consultants)* - *should be aware of BIM and participate in the adoption of BIM."* Participant H also talked about *"implementing BIM through large construction firms, including contractors and engineering firms (consultants)."* It can be concluded that construction firms, and especially large firms, are an essential driver and can contribute effectively to the adoption of BIM in the Jordanian construction sector.

4.7.6 Jordanian universities

Jordanian universities play an important part in the construction industry by supplying the construction sector with qualified staff who can add value to the sector. This research found that universities in Jordan are not seen to be supporting the adoption of BIM in the Jordanian construction industry, but that they should do more in this regard. The responsibility of universities in relation to the adoption of BIM comes as a result of their participation in the Jordanian construction industry by supplying it with competent staff who have essential knowledge in different construction sectors.

Participant M claimed that *"universities are not supporting the adoption of BIM, and could do more in this regard."* This testifies to the importance of the support of universities for the adoption of BIM in the Jordanian construction industry, in view of the fact that universities are one of the pillars of the Jordanian construction sector.

4.7.7 Construction management firms

The final driver for the adoption of BIM in Jordan is construction management firms. The interview findings indicate that the support of construction management firms is not vital, as they have limited responsibility in the construction sector, and according to participant A, could provide only indirect support: *“construction management firms could advise clients to use BIM in their construction projects and include it in the contract documents.”* It is thus not seen that construction management firms are a major driver of the adoption of BIM in the Jordanian construction sector, as their participation is restricted to advising clients to use BIM in their projects, which cannot be regarded as a significant factor.

4.7.8 Summary

Overall, it can be concluded that there are seven factors which drive the adoption of BIM in the Jordanian construction industry. The Jordanian Ministry of Public Works and Housing (JMPWH) and the Jordanian Engineering Association (JEA) are the main drivers. They can take a lead role in facilitating the adoption of BIM by increasing levels of awareness of BIM across the construction sector, conducting training courses that will improve staff skills, and managing and organizing the adoption of BIM by issuing regulations, rules and standards related to BIM. Furthermore, cooperation between them is essential to improve the adoption and implementation process in the construction sector. The Jordanian Construction Contractors’ Association (JCCA) could also play an important role in supporting the adoption of BIM by providing training courses and raising awareness of BIM. Clients are the fourth driver, as they can support BIM in the construction sector by asking for it to be implemented in their projects in contract documents. The fifth driver of the adoption of BIM in Jordan is construction firms, both engineering and construction firms, which could adopt BIM in order to improve the quality of their work and gain maximum benefits from BIM. However, large construction firms have a greater influence on the adoption process in Jordan than other firms. Universities are also considered one of the major drivers, as they supply the construction sector with a competent workforce, so their support for the adoption of BIM in the Jordanian construction sector is very important and should lead to good results. Finally, construction management firms are also a driver of the adoption BIM in Jordan. However, the participation of construction management firms is not significant as they cannot go beyond advising other organizations of the benefits of BIM.

4.8 Conclusion

This chapter has covered the first stage of data collection. Furthermore, this stage of data collection has helped the researcher to fulfil three of the research objectives as shown in Figure 4.8. In addition, the outcomes of this stage provide the basis for designing the questionnaire which was distributed across the whole of the Jordanian construction industry as the second stage of data collection, and the responses to this are analysed descriptively and statistically in the next chapter. Seventeen interviews were conducted with experts in the Jordanian construction industry. These experts are working with different stakeholders. The diversity of the experts made it possible to develop a deep understanding of the current situation of change orders, and identified the main causes of change orders which lead to overruns. The interviews were also critically analysed to identify the current level of awareness of BIM in Jordan, as well as barriers and drivers of BIM. Table 4.1 presents detailed information about these experts. Content analysis was used to break down the data collected into meaningful categories. These findings provided the researcher with a basis for achieving the aim and objectives of the research by designing a questionnaire. Content analysis identified the following outcomes of the first stage of data collection:

- Change orders are common in the Jordanian construction industry, and may have a positive or a negative effect on construction projects. However, the main impact is to increase the cost of construction projects. Thus, change orders are not desirable in the Jordanian construction industry. Most of the experts who were interviewed believe that change orders are a major problem facing the Jordanian construction industry.

- Critical analysis identified nine main causes of change orders that are responsible for cost overruns. These are design errors, changes initiated by clients, incomplete designs, estimation errors, inconsistencies between contract documents, lack of communication between project parties, time lags between design and construction, different site conditions, and shortages of materials. Figure 4.3 presents a cognitive map of the causes of change orders and their sources in the Jordanian construction industry.

- The in-depth analysis of the data collected identified significant weaknesses in the level of awareness and knowledge of BIM in the Jordanian construction industry. More than half the experts, i.e. eight of the 17 interviewees, have no or very little knowledge and awareness of BIM. A further six do not have a sufficient level of awareness to support the adoption of BIM, while only three have adequate understanding which would enable them to implement BIM.

- Most construction firms still depend on 2D CAD for their projects, while others are using only 3D CAD. However, the interviewees did not identify any organization which is currently implementing BIM. Similarly, no project was identified which had implemented BIM and could serve as a guide to the adoption of BIM in Jordan.

- The analysis of participants' views identified 16 barriers to the adoption of BIM in the Jordanian construction industry. These barriers were categorized according to nine sub-themes and linked to three main themes, namely product, individual and process, as illustrated in Table 4.3.

- The barriers linked to products are software costs, the cost of upgrading hardware, and training costs.

- The barrier linked to individuals is the shortage of skilled and trained staff.

- The barriers linked to process are current communication processes, traditional work processes, reluctance on the part of senior management, dependence on unskilled staff, lack of interest and demand, lack of awareness, lack of BIM standards and regulations, the current approval system for new projects, low budgets for new projects, high competition, training time, and the needed period to prepare a suitable environment for the adoption of BIM.

- The interviews identified seven drivers which could facilitate the adoption of BIM in the Jordanian construction industry, namely the Jordanian Ministry of Public Works and Housing (JMPWH), the Jordanian Engineering Association (JEA), the Jordanian Construction Contractors' Association (JCCA), clients, construction firms (both engineering firms and contractors), Jordanian universities, and construction management firms.

- Critical analysis of the data collected shows that many benefits could be realized if BIM is utilized in the Jordanian construction industry. The perceived benefits of BIM in relation to change orders are that it will reduce design errors, improve communication and collaboration, improve clients' knowledge, facilitate appropriate decisions, detect clashes, and support the construction process.

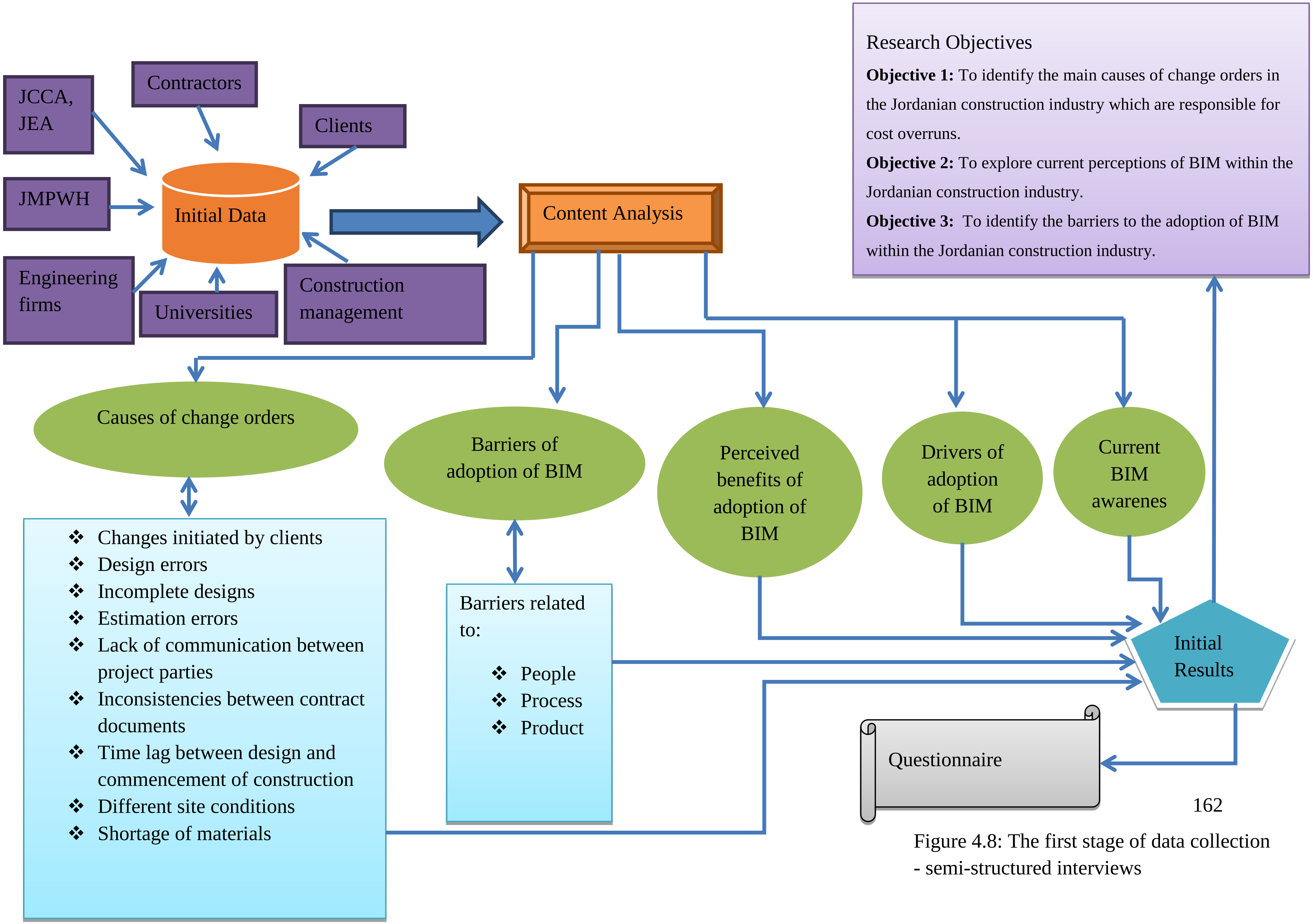


Figure 4.8: The first stage of data collection - semi-structured interviews

CHAPTRE FIVE: QUESTIONNIARE ANALYSIS AND RESULTS

5.1 Introduction

This chapter presents the second set of primary data, namely the responses to the questionnaire which was distributed across the Jordanian construction industry, and these are analyzed descriptively and statistically to achieve the aim and objectives of the research. This analysis will enable the researcher to draw reliable conclusions from the data (Ross, 2004). The questionnaire was designed on the basis of the findings from the interviews with experts in the Jordanian construction sector, and to explore the various causes of change orders, levels of awareness of BIM, barriers to the adoption of BIM and drivers of BIM in the Jordanian construction industry. Furthermore, the effects of BIM on the cost of change orders will be investigated by examining the relationship between the causes of change orders and barriers to the adoption of BIM.

The questionnaire was distributed online to people working and have experience in the Jordanian construction industry, and 155 questionnaires were completed and returned. The respondents should be involved in the construction industry as clients, engineers, first class contractors and construction managers, as well as working in regulatory bodies (the JEA and JCCA) and the government. The participants out of these categories can't participated in the questionnaire. The average time taken to complete the questionnaire was 15 minutes. The questionnaire sought respondents' opinions on the causes of change orders in the Jordanian construction industry, levels of awareness of BIM, barriers to the adoption of BIM and factors driving the adoption of BIM. The questions were derived from the analysis of the interview (see previous chapter). Respondents were asked to indicate their opinions on a Likert scale ('strongly disagree', 'disagree', 'neither agree or disagree', 'agree' and 'strongly agree') for each question. Firstly, the Severity Index (SI) was used to rank respondents' ratings of the importance of the nine causes of change orders in the Jordanian construction industry, as well as the 16 barriers to the adoption of BIM. The Severity Index is recommended by Shash (1993) for analyzing ordinal data where the mean and standard deviation are not suitable statistically for the overall ranking of variables. Many researchers have now adopted the Severity Index, including Olawale and Sun (2012), Ji et al. (2014) and Cheng (2014). The Severity Index is illustrated in the following formula:

Severity Index (SI) = $\left(\sum_{i=1}^{5} wi * fi\right) * \frac{100\%}{N}$

$$\mathbf{W}\boldsymbol{i} = \frac{\boldsymbol{i}}{\boldsymbol{N}}$$

Where

SI	=	Severity Index - this is computed as a summation of the importance rating
i	=	the rating from 1 to 5
w*i*	=	the weight of each rating
f*i*	=	the frequency of responses for a particular rating point
N	=	the total number of respondents rating a particular factor in the survey.

The Severity Index (SI) was used to analyze participants' descriptive responses. Then, factor analysis test and correlation tests were used respectively to analyze statistical data. These tests are considered effective for drawing reliable conclusions that can be used to validate or reject hypotheses, and support the development of a final model.

5.2 Questionnaire reliability

The reliability of research has to do with getting the same results if further data is collected by using the same procedure (Saunders et al., 2009). Field (2011) defined reliability as the consistency of respondents' answers on a given scale. Reliability can be estimated by Cronbach's alpha on a scale of 0% - 100%, with higher values representing more consistent answers and indicating greater reliability. The minimum acceptable value is 0.70, which means that the answers are reliable. In this research, SPSS was used to apply Cronbach's alpha analysis to estimate the reliability of the responses in all the sections of the questionnaire: the causes of change orders, levels of awareness of BIM and barriers to the adoption of BIM. This shows that all the reliability values are over 0.70, which means all the sections are reliable and consistent. Table 5.1 below shows the reliability values for each section of the questionnaire.

Table 5.1: Reliability values

Section	**Cronbach's alpha**
Causes of change orders	0.708
Awareness of BIM	0.714
Barriers to the adoption of BIM	0.764

5.3 Respondents' backgrounds

Three questions asked participants to provide information about their background, and the responses illustrate the diversity of the sample. The following sections discuss the respondents' fields of work, their years of experience and the sector (public or private) they work in.

5.3.1 Field of work

Figure 5.1 below shows that the highest proportion of the respondents (52) work in engineering firms. This is followed by 40 respondents who are contractors. Construction management accounts for the smallest proportion of the sample, with only nine respondents. Sixteen are working in government, 12 in regularity bodies (the JEA and JCCA), 11 in educational institutions, and 15 respondents are clients or developers.

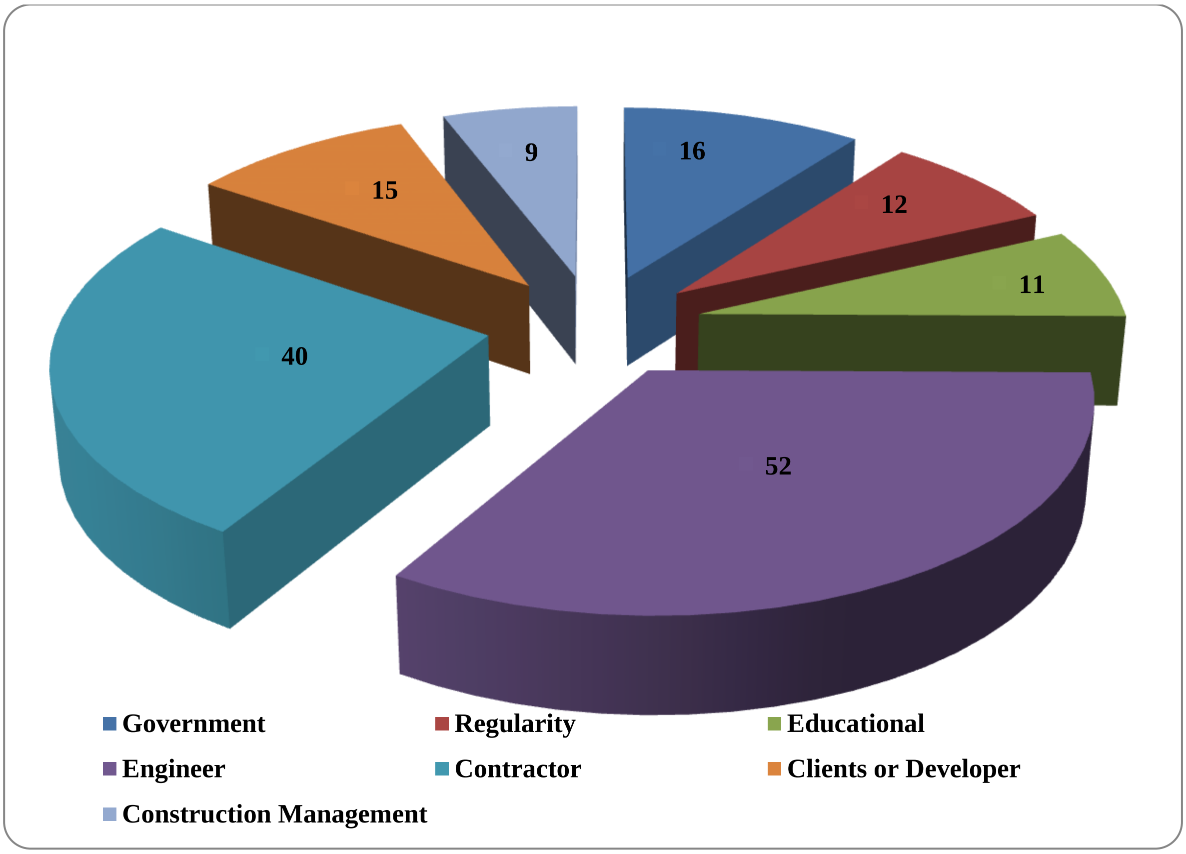


Figure 5.1: Distribution of respondents by field of work

5.3.2 Years of experience

The questionnaire also investigated respondents' work experience. Figure 5.2 shows that the highest proportion of respondents (29.7%) have worked in the construction industry for between 11and 15 years, while only 8.4% have five years of experience or less in the sector. 27.7 % have from 16 to 20 years' experience, followed by 20% who have more than 20 years. Finally, 14.2% of the total has from 6 to 10 years' experience.

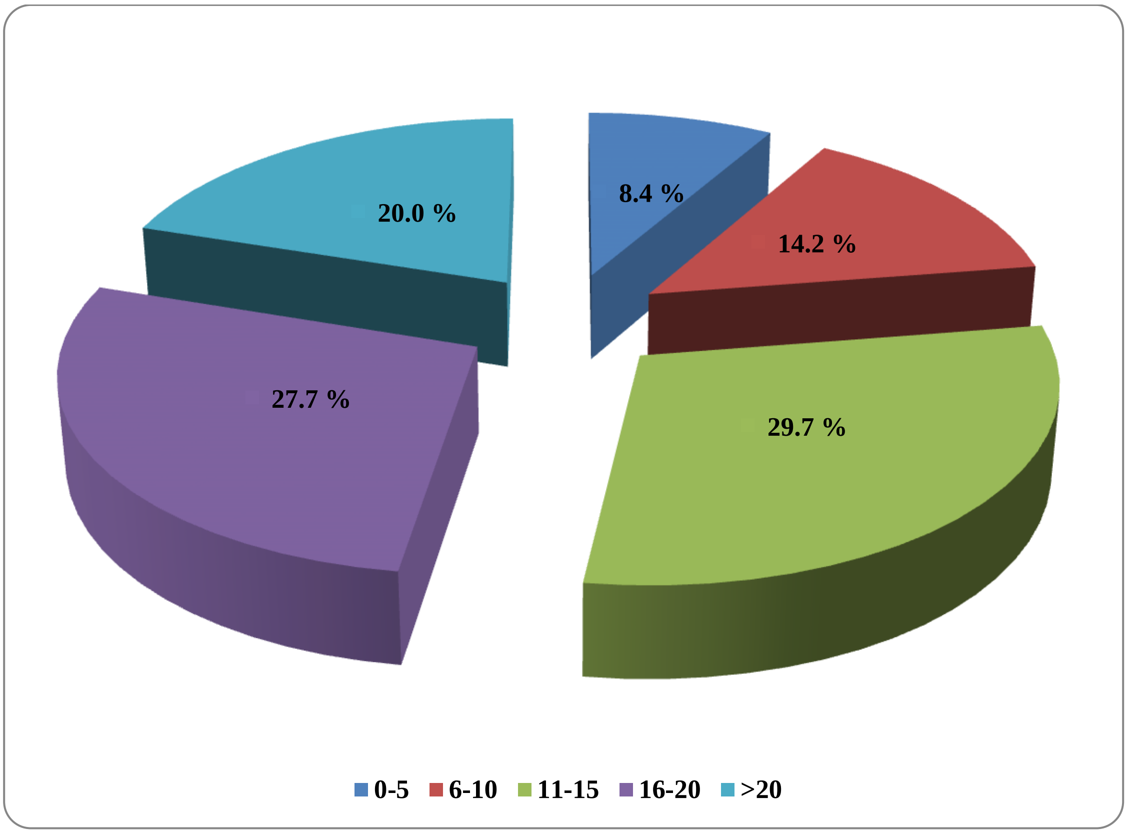


Figure 5.2: Respondents' years of experience

5.3.3 Sector

The respondents were asked to indicate the sector they are currently working in - public or private. It was found that the majority (82.6%) work in the private sector, while only 17.4% work in the public sector, as shown in Figure 5.3. This is in line with the focus of the research, which is on the adoption of BIM to control the cost of change orders in the private sector in Jordan.

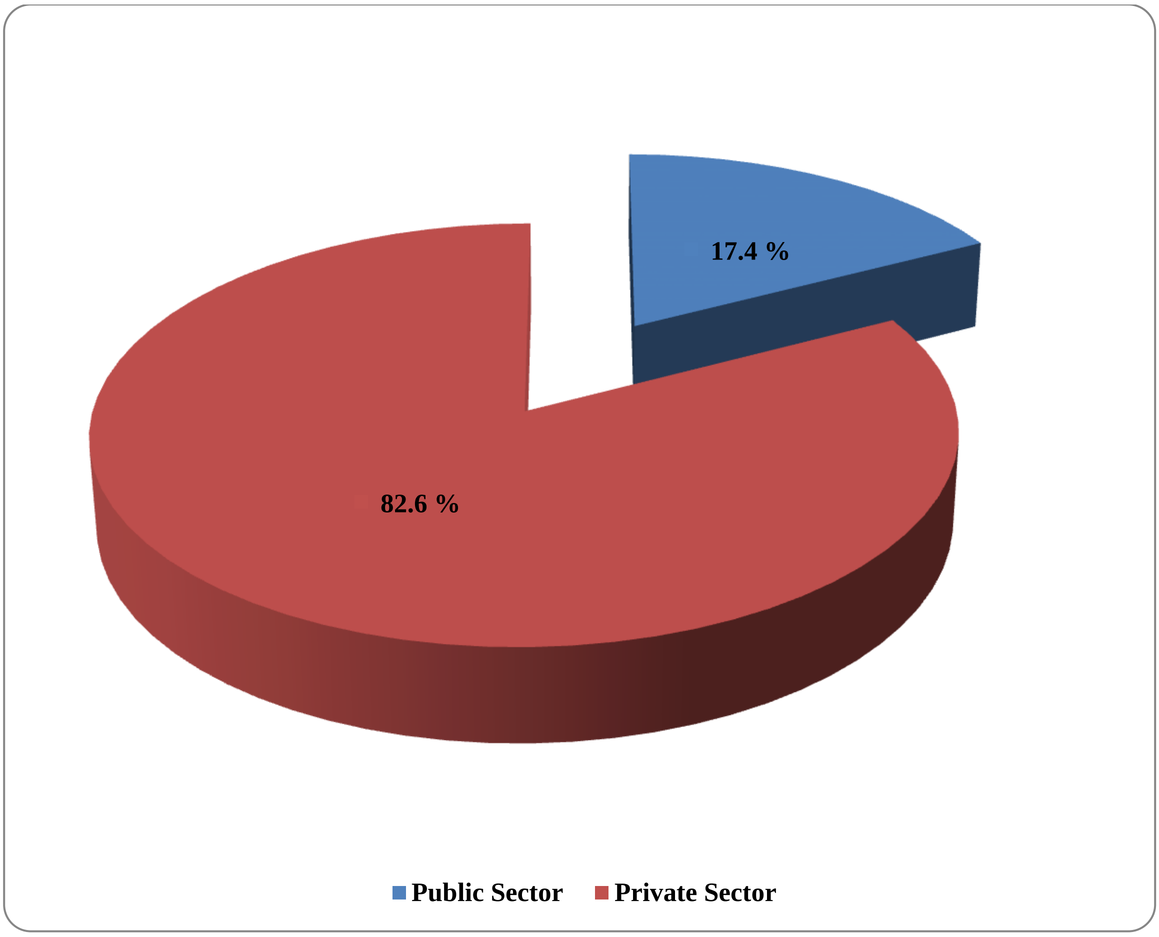


Figure 5.3: Distribution of respondents by sector

5.4 Causes of change orders in the Jordanian construction industry

The Severity Index was used to rank the nine causes of change orders in the Jordanian construction sector. It was found that changes requested by clients are the major cause of change orders in Jordanian construction projects, and have the highest Severity Index (SI), 93.42%, while shortages of materials has the lowest Severity Index (47.53%), which means this does not have a major impact on the number of change orders in the Jordanian construction industry. Table 5.2 below shows the Severity Index values for all the causes of change orders and their ranking, as well as the median, mode, and percentage of participants' responses to the relevant statements. Figure 5.4 presents a radar chart for the Severity Index values of the causes of change orders.

Table 5.2: Percentage of respondents, Severity Index (SI), median and mode for the causes of change orders in the Jordanian construction industry

No.	Causes of Change Orders	Percentage of Respondents						Median	Mode
		Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree	Severity Index		
1	Changes initiated by clients	0.7	0.7	6.6	15.1	77.0	93.42	5.00	5
2	Design errors	1.3	1.3	0.6	33.5	63.2	91.23	5.00	5
3	Inconsistency between contract documents	0.6	0.6	3.9	47.7	47.1	88.00	4.00	4
4	Lack of communication between project parties	0	1.9	6.5	63.9	27.7	83.48	4.00	4
5	Incomplete design	0.6	1.9	27.1	59.4	11.0	75.61	4.00	4
6	Estimation errors	0.6	5.2	31.6	55.5	7.1	72.65	4.00	4
7	Time lag between design and construction phases	0	7.1	38.1	51.6	3.2	70.19	4.00	4
8	Different site conditions	0.6	16.9	55.2	26.0	1.3	62.08	3.00	3

9	Shortages of materials	13.0	43.5	36.4	7.1	0	47.53	2.00	2

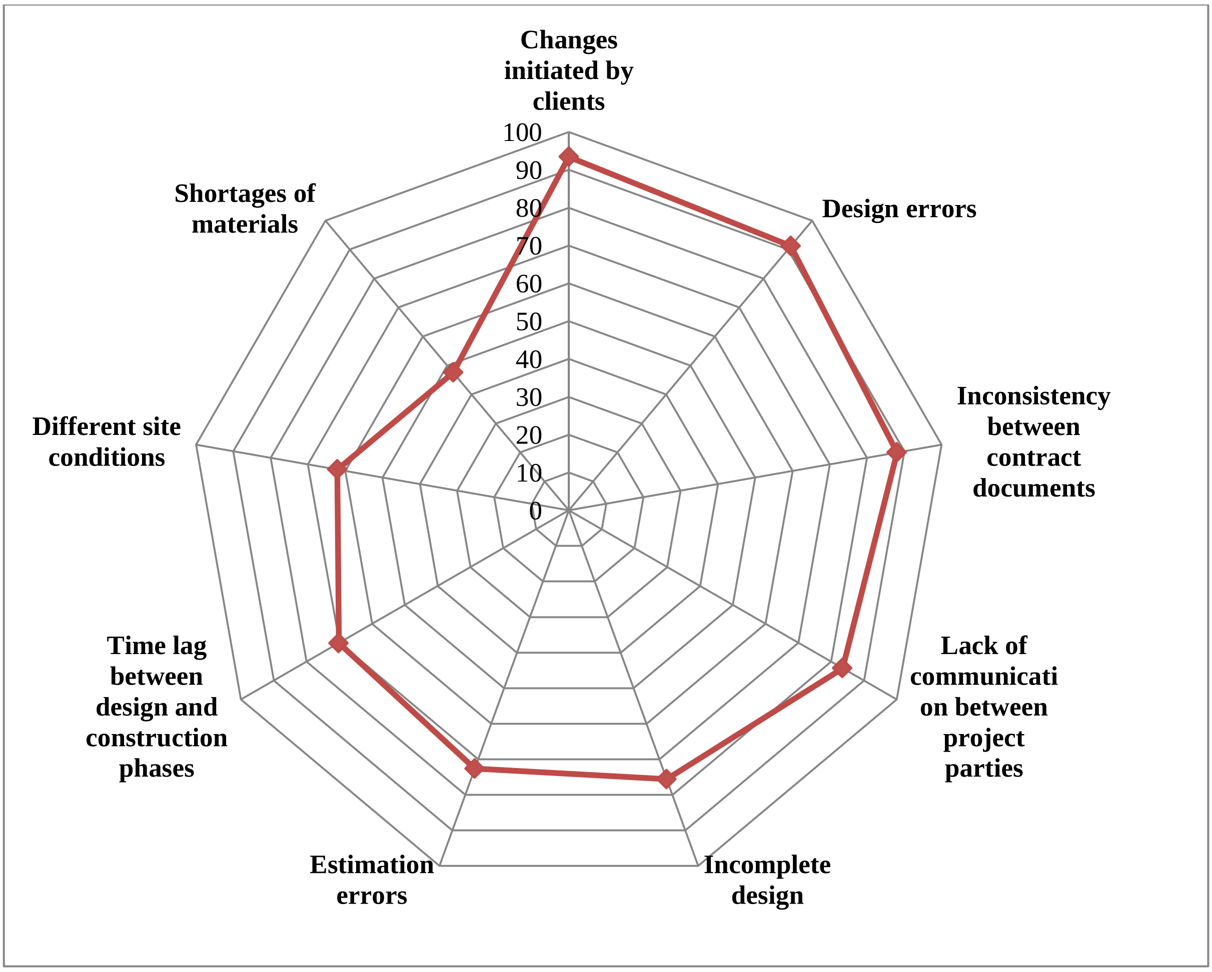


Figure 5.4: Severity Index for the causes of change orders in the Jordanian construction industry

The analysis of respondents' answers ranked the causes of change orders in the Jordanian construction industry that are responsible for cost overruns in construction projects as set out in the following sections.

5.4.1 Changes initiated by clients

The findings show that changes initiated by clients are the main causes of change orders in the Jordanian construction industry. The Severity Index (SI) for such changes is significantly high (93.42%), and both the median and mode are 5, as shown in Table 5.2. In addition, 92.1% of respondents agreed that changes initiated by clients are the main cause of change orders, while only 1.4% disagreed and 6.6% chose the middle option.

5.4.2 Design errors

Design errors ranked as the second main cause of change orders in the Jordanian construction industry. The Severity Index (SI) is relatively high, at 91.23%, and 96.7% of respondents agreed that they were an important cause, whereas only 2.6% disagreed.

5.4.3 Inconsistency between contract documents

Inconsistency between contract documents such as conflicts between drawings and specifications, or within drawings, was considered to be the third main cause of change orders in the Jordanian construction sector: 94.8% of respondents agreed with this statement, and the Severity Index (SI) is 88.0%. Only 1.2% did not think inconsistency between contract documents is a cause of change orders, and 3.9% neither agreed nor disagreed.

5.4.4 Lack of communication between project parties

The research results indicate that lack of communication between project parties or between different disciplines within the same stakeholder group is the fourth most important cause of change orders in Jordan. The Severity Index (SI) is high (more than 80.0%), and 91.6% of the respondents agreed that lack of communication is a cause of change orders in Jordan.

5.4.5 Incomplete design

Change orders in Jordanian construction projects may be the result of incomplete designs. This was investigated in the questionnaire (see Table 5.2), and it was found that 70.4% of the respondents believed that design errors are responsible for many change in construction projects, while 2.5% disagreed that change orders may occur due to incomplete design. 27.1% took a neutral position, neither agreeing nor disagreeing. The Severity Index (SI) is 75.61%, meaning that incomplete design ranked fifth.

5.4.6 Estimation errors

Estimation errors were ranked as the sixth cause of change orders in construction projects, with a Severity Index (SI) of 72.65%. 62.6% of the respondents believed that estimation errors lead to change orders, while 31.6 % neither agreed nor disagreed. The median and mode for responses to this statement are both 4.

5.4.7 Time lag between the design and construction phases

The time lag between finishing the design of a project and commencement of construction can result in change orders, as many changes may occur during this period. 54.8% of respondents felt that the time lag between the design and construction phases is one of the main causes of change orders in Jordan, while 38.1% neither agreed nor disagreed. The Severity Index (SI) is 70.19%, ranking this factor as the seventh most important cause. The median and mode of responses to this statement are 4.

5.4.8 Different site conditions

The Severity Index (SI) of different site conditions is below 70%, which means it is not seen as a significant cause of change. Only 27.3% of the participants agreed that different site conditions are a cause of change orders in the Jordanian construction industry, while 17.5% disagreed and 55.2% of the respondents chose the middle option. The median and mode here are 3.

5.4.9 Shortages of materials

At 47.53%, shortages of materials has the lowest Severity Index (SI) of all the causes of change orders in Jordan. The median and mode for the participants' answers are both 2. The low Severity Index (SI) implies that shortages of materials is not a significant cause of change orders in Jordan. The majority of participants, 56.5%, did not feel that shortages of materials in construction projects can lead to change orders. 36.4% of respondents neither agreed nor disagreed, while only 7.1% do believe that shortages of materials can result in a change order.

It can be clearly concluded from the Severity Index figures that changes requested by clients, design errors, inconsistencies between contract documents and lack of communication between project parties are the most significant causes of change orders in the Jordanian construction industry. These are crucial reasons for cost overruns in construction projects. At the same time, while different site conditions and shortages of materials can lead to change orders, they are not major causes in the Jordanian construction industry. Finally, the Severity

Index figures showed that incomplete design, estimation errors and the time lag between the design and construction phases could cause changes in construction projects, but are neither significant nor insignificant causes.

5.5 Levels of awareness of BIM in the Jordanian construction industry

In order to achieve the second research objective of assessing the current level of awareness of BIM in the Jordanian construction sector, the researcher asked participants to indicate their own level of awareness of BIM, their opinions about general levels of knowledge about BIM in Jordan, and whether there were any cases in which BIM had been implemented in construction projects in Jordan or in construction firms. Table 5.3 shows the responses, Severity Index (SI) values, and the median and mode for this section of the questionnaire. The radar chart (Figure 5.5) shows the Severity Index for each statement related to awareness levels of BIM in Jordan, followed by a critical analysis of the responses in each of these areas.

Table 5.3: Percentage of respondents, Severity Index (SI), median and mode for the level of awareness of BIM in the Jordanian construction industry

No.	Levels of awareness of BIM	Percentage of Respondents						Median	Mode
		Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree	Severity Index		
1	There is currently a project that is implementing BIM	50.7	25.0	24.3	0	0	34.74	1	1
2	BIM is being used in construction firms	52.6	21.7	25.7	0	0	34.61	1	1
3	Personally, I have a good awareness and knowledge of BIM	54.6	25.0	18.4	2.0	0	33.55	1	1
4	The construction industry has	55.3	23.7	21	0	0	33.16	1	1

	a good awareness and knowledge of BIM								

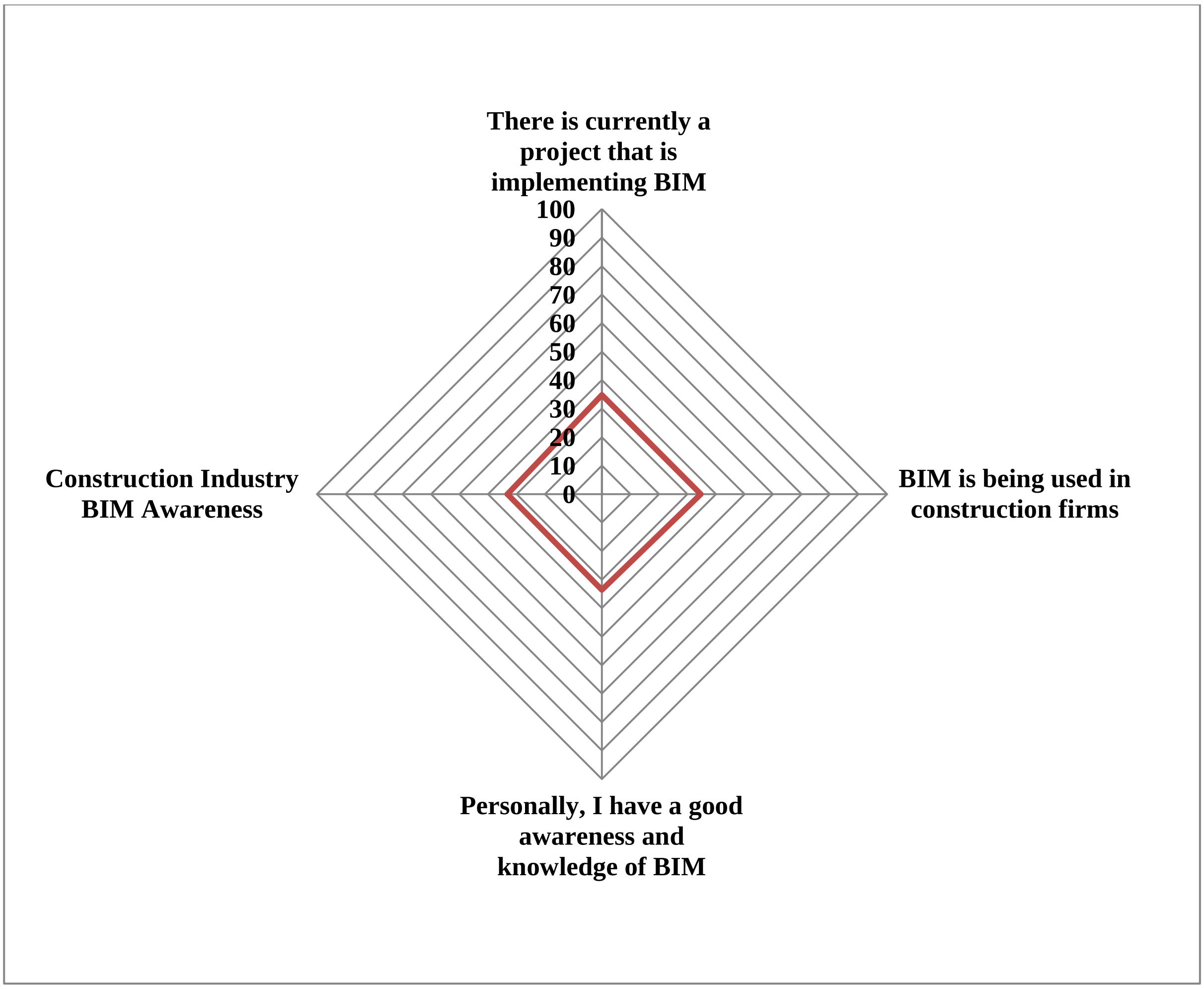


Figure 5.5: Severity Index for levels of awareness of BIM in the Jordanian construction industry

5.5.1 Personal awareness

The Severity Index (SI) for respondents' personal awareness of BIM is 33.55%, which is relatively low. This result indicate that awareness and knowledge of BIM on the individual level in Jordan is significantly low. Only 2% of the respondents believed their knowledge of BIM was good and that it was sufficient to implement BIM. On the other hand, 79.6% of the respondents said they did not have a good knowledge of BIM and that they would not be able to implement it. Both the median and the mode for responses here is 1, which reinforces this finding.

5.5.2 Construction industry awareness and knowledge of BIM

The results show that knowledge of BIM in the Jordanian construction sector overall can be considered relatively low, with a Severity Index (SI) of 33.16%, and 79% of the respondents did not believe that it is currently enough to implement BIM. None of the respondents believed that the current level of knowledge and awareness was sufficient to adopt BIM in the construction industry, and the median and mode of respondents' answers are both 1. It can thus be concluded that the current level of knowledge and awareness of BIM across the Jordanian construction industry is significantly weak, and that it would not be possible to implement BIM.

5.5.3 The implementation of BIM in Jordan

To further assess levels of awareness of BIM in the construction sector, the researcher asked participants about any cases where BIM had been successfully implemented in Jordan by firms or in any construction project. The results show that 74.3% of respondents did not believe that are currently any firms implementing BIM, and the severity index for this item is 34.61%, which is very low and thus supports the conclusion that there are no such cases. What is more, 75.7% of respondents thought there was no project which was using BIM at the moment in Jordan which could provide a model for the construction industry. The Severity Index for this statement is 34.74%, which supports these conclusions.

It can clearly be concluded that the current level of awareness and knowledge of BIM in the Jordanian construction industry is significantly low, and could not support the implementation of BIM. The Severity Index for BIM awareness on both the individual level and the level of the construction industry overall is less than 35%, which is considered relatively low and which supports the research results. It is also clear that there are no construction firms or projects which are currently implementing BIM, and this is backed up by a Severity Index figure of less than 35%.

5.6 Barriers to the adoption of BIM

To achieve the third objective of the research, the researcher asked respondents to give their views on 16 barriers to the adoption of BIM in the Jordanian construction industry on a Likert scale. These barriers were identified from the results of the initial data (i.e. the interviews). The findings showed that the cost of training was the main barrier to the adoption of BIM in

Jordan, for which the Severity Index is 94.74%. In contrast, high competition in the construction industry has the lowest Severity Index of 62.24%, as shown in Table 5.4 below. Figure 5.6 shows the radar chart for the Severity Index for the barriers to the adoption of BIM, and these figures are followed by a discussion of each barrier.

Table 5.4: Percentage of respondents, Severity Index (SI), median and mode for barriers to the adoption of BIM in the Jordanian construction industry

No.	Barriers to the adoption of BIM in Jordan	Percentage of Participants						Median	Mode
		Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree	Severity Index		
1	Costs of training	0	1.3	2.0	18.4	78.3	94.74	5.00	5
2	Time required for training	0	0.7	1.3	30.3	67.8	93.03	5.00	5
3	Costs of BIM software	0	1.3	5.9	21.1	71.7	92.63	5.00	5
4	Dependence on unskilled staff	0	0	2.0	72.0	26.0	84.80	4.00	4
5	Costs of hardware	0	2.6	10.5	52.6	34.3	83.68	4.00	4
6	Shortage of skilled and trained staff	0	2.0	7.9	60.5	29.6	83.55	4.00	4
7	Reluctance on the part of senior management	0	3.9	7.9	58.6	29.6	82.76	4.00	4
8	Lack of awareness	0	3.3	15.1	72.4	9.2	77.50	4.00	4
9	Traditional processes	0.6	3.3	18.4	67.8	9.9	76.58	4.00	4
10	Lack of interest and demand	0	3.9	42.2	37.5	16.4	73.29	4.00	3
11	Lack of a legal framework for BIM	0.7	9.2	32.2	52.6	5.3	70.53	4.00	4

12	Approval system for new projects	0	8.6	33.5	55.9	2.0	70.26	4.00	4
13	Low budget for new projects	1.3	11.2	44.7	40.2	2.6	66.32	3.00	3
14	Weakness in communication between project parties	0.7	16.4	39.5	42.1	1.3	65.39	3.00	4
15	Time required for preparation of BIM infrastructure	0	6.6	66.4	26.3	0.7	64.21	3.00	3
16	High competition in construction industry	2.0	19.7	45.4	30.9	2.0	62.24	3.00	3

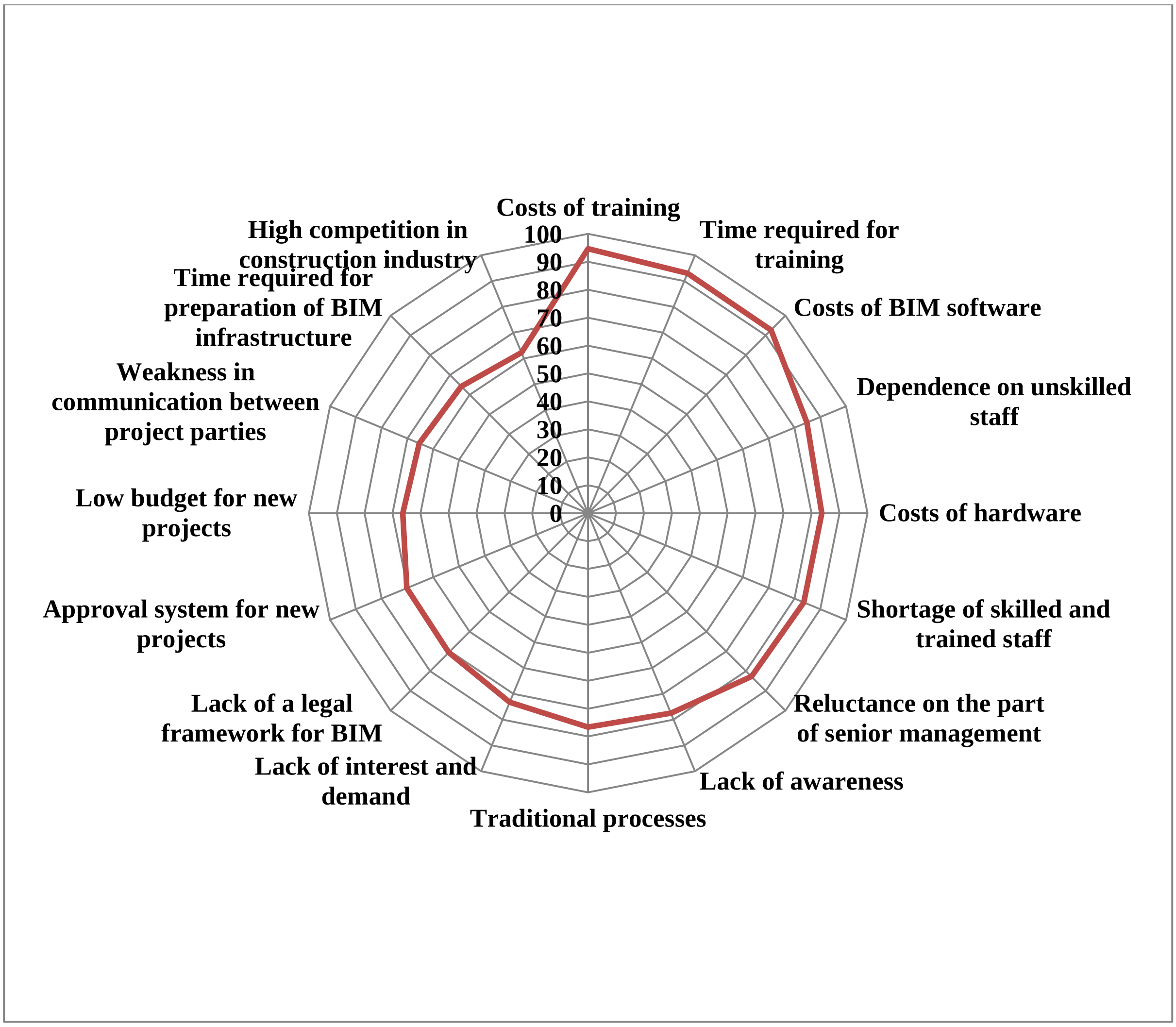


Figure 5.6: Severity Index for barriers to the implementation of BIM in the Jordanian construction industry

5.6.1 Training costs

The findings show that training costs are a significant barrier to the adoption of BIM in the Jordanian construction: this has a Severity Index (SI) of 94.74%, making it the top barrier to the adoption of BIM in Jordan. In addition, 96.7% of respondents supported this conclusion. The median and the mode of responses are 5. It can thus clearly be concluded that the costs of training are a crucial barrier which hinders the adoption of BIM in the Jordanian construction industry.

5.6.2 Time required for training

The duration of the training required is the second barrier in the Jordanian construction industry, with a Severity Index of 93.03%, and 98.1% of the respondents felt the adoption of BIM is hindered because of the period of training needed. This means that the time required for training is a major obstacle to the adoption of BIM in Jordan.

5.6.3 The costs of BIM software

The findings show that 92.8% of the respondents also considered the costs of software to be one of the main barriers. The Severity Index for this item is 92.63%, and the median and mode of participants' responses are 5. This is strong evidence to suggest that the costs of BIM present a barrier to the adoption of BIM in the Jordanian construction industry.

5.6.4 Dependence on unskilled staff

The Severity Index for dependence on staff who do not have the professional knowledge or experience to use BIM is 84.80%, which makes it the fourth barrier delaying the adoption of BIM. This figure also means that the construction sector is currently dependent on available manpower for design and construction, yet these employees do have not sufficient knowledge or awareness of BIM, nor are they able to use it, which constitutes a further barrier. 98% of the respondents agreed that is the case.

5.6.5 Hardware costs

The adoption of BIM may require upgrading available hardware, which means extra costs will be incurred. The Severity Index for hardware costs is 83.68%, ranking it as the fifth barrier to the adoption of BIM in Jordan. 86.9% of the respondents agree that hardware costs obstruct adoption. The median and the mode are both 4. It is therefore clear that hardware costs are a significant barrier to the adoption of BIM in the Jordanian construction industry.

5.6.6 Shortage of skilled and trained staff

The analysis of the responses showed that a shortage of skilled and trained staff who can use BIM is the sixth barrier to the adoption of BIM in Jordan. The Severity Index for this barrier is 83.55%. As well as that, 90.1% of respondents concur that a shortage of skilled and trained staff is impeding the adoption of BIM. The median and mode for this barrier are again 4. This confirms that a shortage of skilled and trained staff who are able to use BIM is a significant barrier to the adoption of BIM.

5.6.7 Reluctance on the part of senior management

The Severity Index for reluctance on the part of senior management is 82.76%, and 88.2 % of respondents believe that the attitude of top management in organizations is delaying the adoption of BIM in Jordan. It can thus be concluded that the decision makers in the Jordanian construction sector are hindering the adoption of BIM, and this factor ranks seventh of the barriers.

5.6.8 Lack of awareness

The research also found that a lack of awareness was a key barrier to the adoption of BIM, and this is indicated by 81.6% of the respondents. The Severity Index for lack of awareness is 77.5%, indicating that it is a strong barrier to the adoption of BIM. Again, both the median and mode of the responses are 4.

5.6.9 Traditional processes

A majority of the respondents believe that the current traditional work process, also obstruct the adoption of BIM. The Severity Index for this factor is relatively high, at 76.58%. More than three-quarters (77.7%) of the respondents are of this opinion.

5.6.10 Lack of interest and demand

The questionnaire responses show that more than half (53.9%) of the participants believe that the adoption of BIM in Jordan is also being obstructed by a lack of interest and demand, and this ranked tenth among the barriers, with a Severity Index of 73.29%. The research thus shows that stakeholders in the Jordanian construction industry are not interested in using BIM as they are able to achieve their aims by doing things the way they have always done them, i.e. without using BIM.

5.6.11 Lack of a legal framework for BIM

The Severity Index (SI) for the lack of a legal framework for BIM is 70.53%, which ranks it in eleventh position among the barriers to the implementation of BIM. 57.9% of the respondents agree that the Jordanian construction industry is hindered by the lack of a framework which regulates the way BIM is managed or organized. The median and mode of this barrier are 4. This supports the hypothesis that the lack of a legal framework for BIM is in important barrier to its implementation in Jordan.

5.6.12 Approval system for new projects

The current approval system for new projects has a Severity Index (SI) of 70.26%, which is in keeping with the fact that 57.9% of the respondents agree that it is hindering the adoption of BIM in Jordan. Applications are dealt with by staff from different disciplines which are not using BIM, or by people who have no experience of BIM for a variety of reasons, so the adoption of BIM will not run smoothly. The conclusion is therefore that the current approval system for new projects is obstructing the adoption BIM in Jordan.

5.6.13 Low budget for new projects

The budget for a new project might be too low to cover the costs of using BIM, or even part of those costs. The questionnaire responses identifies low project budgets as one of the barriers to the adoption of BIM, and this has a Severity Index of 66.32%. However, less than half the respondents agreed that the low budget is something which presents a barrier, and the median and mode of the responses are 3. This suggests that although the low budget for new projects can be seen as hindering the adoption of BIM, it is not a major barrier.

5.6.14 Current weaknesses in communication between project parties

Weaknesses in communication between stakeholders, as well as between different groups within in the same discipline, were considered to constitute a barrier to the adoption of BIM in the Jordanian construction industry. The Severity Index for this barrier is 65.39%. However, only 43.4% of the respondents agree that the current communication system in the construction sector hinders the adoption of BIM. The median and mode of the responses on this issue are 3 and 4 respectively.

5.6.15 Time required for the preparation of BIM infrastructure

The Severity Index of this issue is 64.21%, which ranks the amount of time required for preparing infrastructure for BIM in fifteenth position among the barriers, which means it is not a significant barrier to the adoption of BIM in comparison to others. Correspondingly, only 27% of the respondents agree that the amount of time needed to ensure there is a suitable environment is impeding the adoption of BIM. The median and mode of the responses in this case are 3. This clearly suggests that although the time involved in preparing infrastructure could delay the adoption of BIM, it is not a major barrier, as it has a low Severity Index and is felt to be an issue by only around a quarter of the respondents.

5.6.16 High competition in the construction industry

The Severity Index for high competition is 62.24%, which is the lowest of all the barriers, and this is not surprising given the fact that just 32.9% of the respondents believed that competition for new construction projects hinders the adoption of BIM in Jordan. The median and mode for this barrier are 3. What this indicates is that while the great competition between construction firms for new construction projects could obstruct the adoption of BIM, it is of limited significance.

5.7 Drivers of adoption BIM

The interview results identified seven drivers of the adoption of BIM in the Jordanian construction industry. In the questionnaire, the researcher asked participants for their opinions on who should take the main responsibility for the adoption of BIM in Jordan. These seven drivers become eight in the questionnaire, as construction firms were divided into engineering firms and contractors.

The responses confirmed that the Jordanian Ministry of Public Works and Housing (JMPWH) is the main driver, and should take responsibility for the adoption BIM, and this was the view of 147 participants (see Table 5.5), and the Ministry was followed by the Jordanian Engineering Association (JEA), as attested by 140 respondents. The Jordanian Construction Contractors' Association (JCCA) and clients were the third and fourth drivers, chosen by 126 and 123 participants respectively. Engineering firms and contractors ranked fifth and sixth, with 105 and 104 responses respectively, then universities (95 responses) and finally construction management firms (only 22 responses). The Jordanian Ministry of Public Works and Housing (JMPWH) and the Jordanian Engineering Association (JEA) are therefore seen as the main drivers in Jordanian construction industry, and should lead the adoption of BIM in Jordan. It can also be concluded that the JCCA, clients, engineering firms, contractors and universities are also effective drivers in the construction sector and could contribute effectively by supporting the adoption of BIM in Jordan. Construction management firms had the lowest rank, being selected by only 22 of the 155 respondents. They are therefore not seen as significant drivers of the adoption of BIM in Jordan and could not take a lead role.

Table 5.5: Frequency of the drivers of the adoption of BIM in Jordan.

Driver	No. of Respondents
Jordanian Ministry of Public Works and Housing (JMPWH)	147
Jordanian Engineering Association (JEA)	140
Jordanian Construction Contractors' Association (JCCA)	126
Clients/developers	123
Engineering firms	105
Contractors	104
Universities	95
Construction Management (CM) organizations	22

5.8 Inferential data

Statistical analysis is the second stage of questionnaire analysis. However, before proceeding with statistical tests, it is very important to identify the nature of the data. As mentioned in the Methodology chapter, data can be parametric, i.e. it has a normal distribution and an interval scale, or non-parametric, with an ordinal scale but not a normal distribution. This survey was based on the Likert scale, with five points as shown in Appendix (C), which means the collected data is assumed to be ordinal and non-parametric. Therefore, non-parametric tests have been used for analysis. Inferential statistics are used to improve the descriptive results, as well as to provide a basis for solid conclusions. A factor analysis test was therefore applied to the causes of change orders in the Jordanian construction industry (i.e. the nine causes), and to the barriers to the adoption of BIM (the 16 barriers) in order to group them and exclude non-significant causes or barriers. A correlation test was also employed to identify the relationship between the causes of change orders in the same group, as well as to clarify relationships between the barriers to the adoption of BIM. The correlation test also clarified relationships between the causes of change orders, the barriers to the adoption of BIM and levels of awareness of BIM. These relationships will be used to examine the influence of BIM on minimizing cost of change orders.

5.8.1 Factor analysis

Factor analysis is used to measure the effects of latent variables that are reflected in the observed variables, and can be considered a data reduction method (Field, 2013). The data analysis used a factor analysis test for all the nine main causes of change orders in the Jordanian construction industry, as well as for the 16 barriers to the adoption of BIM. The SPSS software package was used to group the nine causes of change orders, and dimension reduction (factor analysis) was run several times using absolute values of 0.50 and varimax rotation to the best reasonable causes correlated with the data. This placed the causes of change orders in the Jordanian construction industry into three main groups, as shown in Table 5.6. The factor analysis test was also applied using SPSS software to group the barriers to the adoption of BIM in the Jordanian construction industry. As in the process applied for grouping the causes of change orders, dimension reduction was run many times using absolute values of 0.50 and varimax rotation. During the process some barriers were eliminated while the others were grouped. This grouped the barriers to the adoption of BIM into four main groups, as well as eliminating some barriers, as shown in Table 5.7. The results of these factor analysis tests will be discussed in detail together with descriptive findings in the chapter 6 to draw appropriate conclusions about both the causes of change orders and the barriers to the adoption of BIM in Jordan.

Table 5.6: Factor analysis test results for the causes of change orders in Jordan

Latent Causes	Causes of Change Orders	Load		
Engineering causes	Design errors	.823		
	Incomplete design	.748		
	Estimation errors	.807		
	Inconsistencies between contract documents	.805		
Circumstances of the project	Different site conditions		.804	
	Shortages of materials		.904	
Causes related to the client	Lack of communication between project parties			.593
	Time lag between design and construction phases			.605
	Changes initiated by the client			.869

The factor analysis test for the causes of change orders in the Jordanian construction industry placed the nine causes in three main groups: engineering causes, causes related to the circumstances of the project and those related to the client. Engineering causes include design errors, incomplete designs, estimation errors and inconsistencies between contract documents. Design errors are found to be the main cause could be explain this category with the highest load (0.823). The second group is causes related to the circumstances of the project and includes only two causes, namely different site condition and shortages of materials. Both of these have a load of over 0.80, which means that each of them is a significant factor in relation to the circumstances of the project. The final category is causes related to the client, which contains three causes: changes initiated by the client, time lags between the design and construction phases, and lack of communication between project parties. Changes initiated by the client, with a load of 0.869, are the most important cause in this group. Table 5.7 presents the factor analysis test results for the barriers to the adoption of BIM.

Table 5.7: Factor analysis test results for the barriers to the adoption of BIM in Jordan

Latent Barriers	Barriers to the adoption of BIM	Load			
Financial	Costs of BIM software	.850			
	Costs of hardware	.848			
	Costs of training	.781			
Communication	Weakness in communication between project parties		.785		
	Approval system for new projects		.730		
	Traditional processes		.572		
	Lack of legal framework for BIM		.763		
Human	Shortage of skilled and trained staff			.696	
	Lack of awareness			.569	
	Dependence on unskilled staff			.627	
	Lack of interest and demand			.673	
Project Procurement	Low budgets for new projects				.816
	High competition in the construction industry				.775

The factor analysis test for barriers to the adoption of BIM, as shown in Table 5.7, eliminates three barriers: training duration, reluctance on the part of senior management and the time required to prepare the infrastructure for BIM. However, the analysis grouped the 13 barriers to the adoption of BIM in the Jordanian construction industry into four groups, namely financial, communication, human, and project procurement. There are three barriers in the finance category: software costs, hardware costs and training costs. The results show that all these barriers are significant financial factors. Software costs is the barrier with the highest load (0.85). The communication category includes four barriers: current weaknesses in communication between project parties, the approval system for new projects, traditional work process and the lack of a legal framework for BIM. Weaknesses in communication between project parties has the highest load, and is therefore a more significant barrier than the others. Human factors is the third category of barriers, and includes shortages of skilled and trained staff, lack of awareness, dependence on unskilled staff, and lack of interest and demand. The results show that shortages of skilled and trained staff, with a factor analysis load of 0.696, is the main barrier in this group. The final category, project procurement, has two barriers, the low budgets for new projects and high competition in the construction industry. The factor analysis load for both of these is more than 0.75, which means that both could explain the project procurement factor effectively.

5.8.2 Hypothesis testing

A total of 25 hypotheses was presented in the last chapter, all of which were derived from the analysis of the interview findings. These include nine hypotheses related to the causes of change orders in the Jordanian construction industry, and 16 related to barriers to the adoption of BIM in the Jordanian construction industry. Testing these hypotheses is based on the analysis of item loadings, and the results of factor analysis will then be used to accept or reject the hypotheses, i.e. by identifying the significant factors that determine the causes of change orders in the Jordanian construction industry and the barriers to the adoption of BIM. According to Schmitt and Sass (2011), item rotation for exploratory factor analysis has long been used in the social sciences to test hypotheses. Since it measures the correlation between the observed causes or barriers and the latent factor, the general rule is that the higher the figure, the more acceptable the hypothesis. Varimax rotation was used in this research, as it provided the lowest cross-loadings in comparison with other types of factor matrix rotation. A factor loading for an item above 0.5 – i.e. over the recommended minimum reliability figure of 50% - is further evidence that the hypothesized construct can be accepted.

In relation to the causes of change orders, the factor analysis concluded that design errors, changes initiated by the client, incomplete designs, estimation errors, inconsistencies between contract documents, a lack of communication between project parties, time lags between the design and construction phases, different site conditions and shortages of materials could all cause change orders in the Jordanian construction industry. Therefore hypotheses H1, H2, H3, H4, H5, H6, H7, H8 and H9 are accepted.

The factor analysis for barriers to the adoption of BIM in the Jordanian construction industry concluded that software costs, hardware costs, training costs, shortages of skilled and trained staff, the current communication process between project parties, traditional work processes, dependence on staff who do not have the skills and training to use BIM, lack of interest and demand, lack of awareness of BIM, the lack of a legal framework for BIM, the current approval system for new projects, low budgets for new projects and high competition between construction firms all hinder the adoption of BIM in the Jordanian construction industry. Therefore hypotheses H10, H11, H12, H13, H14, H15, H17, H18, H19, H20, H21, H22 and H23 are accepted. At the same time, the analysis showed that reluctance on the part of senior management, the time required for training and the time required to prepare a suitable environment for BIM do not hinder the adoption of BIM in the Jordanian construction industry, so hypotheses H16, H24 and H25 are rejected.

5.8.3 Correlation

Correlation is the relationship between two variables expressed in a single number called the correlation coefficient. This has a range from +1 to -1, and indicates the strength of the relationship and whether it is positive or negative. According to Mann (1995), a correlation test quantifies the strength of the linear relationship between two variables. A correlation test was used to determine the relationship between the causes of change orders, the barriers to the adoption of BIM and levels of awareness of BIM in the construction sector, and between the causes of change orders and both the levels of awareness of BIM and the barriers to the adoption of BIM in Jordan. The test used was Spearman's rho correlation test, which is a two-tailed test of statistical significance at two different levels - highly significant where $\rho < 0.01$ and significant where $\rho < 0.05$. The results are presented in Tables 5.8, 5.9, 5.10 and 5.11 below.

Table 5.8: Analysis of the correlation between the causes of change orders in Jordan

Causes of change orders in the Jordanian construction industry	Design errors	Incomplete design	Lack of Communication between project parties	Time lag between design and construction phases	Estimation errors	Changes initiated by clients	Inconsistency between contract documents	Different site conditions	Shortages of materials
Design errors	1.000	.554**	0.121	-0.031	.499**	-0.045	.576**	0.080	.194*
Incomplete design		1.000	.167*	-0.109	.561**	-.239**	.492**	0.065	.283**
Lack of communication between project parties			1.000	.219**	0.066	.177*	.355**	.278**	.199*
Time lag between design and construction phases				1.000	-0.063	.490**	-0.080	.420**	.373**
Estimation errors					1.000	-.270**	.458**	0.050	.354**
Changes initiated by clients						1.000	-0.129	.288**	0.118
Inconsistency between contract documents							1.000	0.114	0.111
Different site conditions								1.000	.620**
Shortages of materials									1.000

** Correlation is significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)

These results will be discussed in detail for each group of causes of change orders in the next chapter.

Table 5.9: Analysis of the correlation between factors related to the awareness of BIM in Jordan

Factors related to the Awareness of BIM in Jordan	Personal awareness	Awareness of the construction industry as a whole	Using BIM in construction firms	Availability of adequate guides
Personal awareness	1.000	.341**	.401**	.361**
Awareness of the construction industry as a whole		1.000	.383**	.206*
Use of BIM in construction firms			1.000	.523**
Availability of adequate guides				1.000

** Correlation is significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)

Table 5.9 shows the relationships between the individual's level of awareness of BIM, levels of awareness of BIM across the construction sector, the use of BIM in construction firms, and the existence of projects on which BIM has been implemented and which could therefore serve as a guide for the adoption BIM in Jordan. All the relationships are significant at the 0.01 level except for that between the awareness of the construction industry as a whole and the availability of adequate guides, which is significant at the 0.05 level.   .

Table 5.10: Analysis of the correlation between the barriers to the adoption of BIM in Jordan

Barriers to the Adoption of BIM in Jordan	Software costs	Hardware costs	Shortage of skilled and trained staff	Training costs	Time required for raining	Weaknesses in communication between project parties	Approval system for new projects	Traditional processes	Dependence on unskilled staff	Reluctance on the part of senior management	Lack of interest and demand	Lack of Awareness	Lack legal framework for of BIM	Low budgets for new projects	High competition in construction industry	Time required for preparation of BIM infrastructure
Software costs	1.000	.567**	.287**	.378**	.367**	.258**	.223**	.269**	0.091	0.135	.249**	.319**	0.159	0.152	0.129	0.094
Hardware costs		1.000	0.035	.531**	0.106	.162*	0.039	0.101	0.119	0.102	.416**	.240**	0.022	.170*	.385**	0.011
Shortage of skilled and trained staff			1.000	.251**	0.152	.169*	.188*	0.032	.491**	.354**	.219**	.545**	0.123	.207*	0.151	0.119
Training costs				1.000	0.159	.291**	.207*	0.000	0.061	0.068	.259**	.267**	0.105	0.031	.237**	0.131
Time required for training					1.000	.279**	.316**	.214**	.271**	.212**	0.095	.205*	.230**	.220**	0.111	0.093
Weaknesses in communication between						1.000	.639**	.295**	0.155	.211**	-185*	.284**	.538**	.190*	0.112	0.070

project parties																
Approval system for new projects							1.000	.279**	.177*	.281**	.176*	.330**	.501**	.225**	0.006	0.106
Traditional processes								1.000	.196*	.238**	0.002	0.085	.287**	.224**	0.098	.166*
Dependence on unskilled staff									1.000	.431**	.271**	.242**	.165*	.280**	.309**	.191*
Reluctance on the part of senior management										1.000	.223**	.196*	.459**	.242**	.297**	0.090
Lack of interest and demand											1.000	0.106	0.030	0.124	.359**	.272**
Lack of awareness												1.000	.162*	0.080	0.142	.254**
Lack of legal framework for BIM													1.000	.280**	0.015	0.052
Low budgets for new projects														1.000	.515**	.238**
High competition in the															1.000	.180*

construction industry																
Time required for preparation of BIM infrastructure																1.00

** Correlation is significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)

Table 5.10 shows the relationships between the 16 barriers to the implementation of BIM in the Jordanian construction industry, which include both positive and negative correlations. There are both positive and negative correlations between these barriers. The next chapter will discuss these results in detail for each main group of barriers.

Table 5.11: Analysis of the correlation between sum of the causes of change orders, the level of awareness of BIM and barriers to the implementation of BIM in Jordan

		Csum	Asum	Bsum
Csum	Correlation Coefficient	1.000	-.058	.512**
Asum	Correlation Coefficient		1.000	-.296**
Bsum	Correlation Coefficient			1.000

** Correlation is significant at the 0.01 level (2-tailed)

The results of the correlation test shown in Table 5.11 shows significant correlations between the barriers to BIM in the Jordanian construction industry and the causes of change orders. The relationship is significantly positive at the 0.01 level, which means that minimizing the barriers to BIM will lead to a reduction in the causes of change orders in construction projects. It can therefore be concluded that there is a significantly negative relationship between the benefits of BIM and the causes of change orders. Consequently, reducing the barriers so that BIM can be adopted will reduce the causes of change orders and therefore minimize cost overruns in construction projects. At the same time, the results do not indicate any significant relationship between the causes of change orders and the level of awareness of BIM in Jordan. Yet they do show a significant negative correlation between the barriers to BIM and the level of awareness of BIM. This indicates that until awareness of BIM reaches the level of acceptance, the barriers to BIM will remain solid and continue to significantly hinder the adoption of BIM in the Jordanian construction industry. These results will be discussed in detail in the next chapter.

5.9 Conclusion

This chapter has critically examined the causes of change orders, current levels of awareness of BIM, barriers to the adoption of BIM, drivers of BIM and the influence of BIM on cost overruns resulting from change orders in the Jordanian construction industry. The questionnaire was designed on the basis of the results of a content analysis of the 17 interviews which were conducted with experts in the Jordanian construction industry. The questionnaire was distributed online across the Jordanian construction industry to explore participants' opinions and to collect reliable data which is truly representative of the construction industry, and 155 responses were received.

The responses were analyzed descriptively and statistically by the Severity Index, factor analysis and correlation tests. These tests were used to ensure valid and reliable results which would achieve the research aim and objectives. The findings identify nine causes of change orders in the Jordanian construction industry, and these causes were ranked by their Severity Index. Changes relating to the client were the found to be the main cause of change orders in the Jordanian construction sector, followed by design errors, while shortages in materials was ranked bottom. The factor analysis test categorized these causes into three groups, namely engineering causes, causes related to the client and the circumstances of the project. Each of these groups includes a number of causes, as follows:

- ❖ Engineering causes: design errors, incomplete designs, estimation errors and inconsistency between contract documents;
- ❖ Causes related to the client: changes initiated by the client, lack of communication between project parties, and time lags between the design and construction phases;
- ❖ Circumstances of the project: different site conditions and shortages of materials.

Finally, the correlation test identified the relationship between the causes of change orders in each group to determine how far they influenced each other. These relationships are presented in Table 5.8.

The questionnaire results also investigated levels of awareness and knowledge of BIM in the Jordanian construction sector, and the severity index for the awareness of individuals and across the construction sector as a whole is less than 35%, meaning that it is significantly weak. Similarly, it was found that construction firms are currently not using BIM, and there are no projects which have used BIM and which could serve as a guide for its adoption in the Jordanian construction sector. These results clearly show a significant weakness in the level of awareness of BIM in the Jordanian construction industry on both a personal and industry-wide level. The correlation test showed how these factors affect each other, as presented in table 5.9.

The descriptive analysis also found training costs to be the main barrier to the adoption of BIM in the Jordanian construction industry, while the high level of competition was shown to be the weakest barrier. The factor analysis test identified three barriers which did not significantly hinder the adoption of BIM in the Jordanian construction industry, namely the time required for training, reluctance on the part of senior top management and the time required to prepare a suitable environment for BIM. Although these barriers individually might have a significant influence on the adoption of BIM, as a group they are not a major factor. The other 13 barriers were categorized into four groups, relating to finance, communication, human factors and project procurement. Each of these groups include a number of sub-barriers as follows:

- ❖ Financial factors: software costs, hardware costs and training costs;
- ❖ Communication factors: current weakness in communication between project parties, the approval system for new projects, lack a legal framework and traditional work processes;
- ❖ Human factors: shortage of skilled and trained staff, dependence on unskilled staff in construction firms, lack of awareness and lack of interest and demand;
- ❖ Project procurement: low budgets for new projects and high competition between construction firms.

The correlation test was conducted to determine the relationship between the barriers in each group in order to investigate their influence on each other. Table 5.10 presents the correlation of these barriers in full.

The questionnaire findings show that the Jordanian Ministry of Public Works and Housing and the Jordanian Engineering Association are significant drivers of the adoption of BIM in the Jordanian construction industry, and that they should lead the adoption of BIM. Other significant drivers are the Jordanian Construction Contractors' Association, clients, engineering firms, contractors and universities. However, construction management firms are not one of the main drivers.

Finally, the correlation test indicated a significant positive relationship between the causes of change orders in the Jordanian construction industry and barriers to the adoption of BIM. This means that there is a significant negative relationship between the causes of change orders and the benefits of BIM, which suggests that using BIM in construction projects will reduce the causes of change orders and thus minimize the cost of change orders. The next chapter will present a critical discussion of the literature review and the interview and questionnaire findings in order to draw conclusions for this research and review how it has achieved the research aim and objectives.

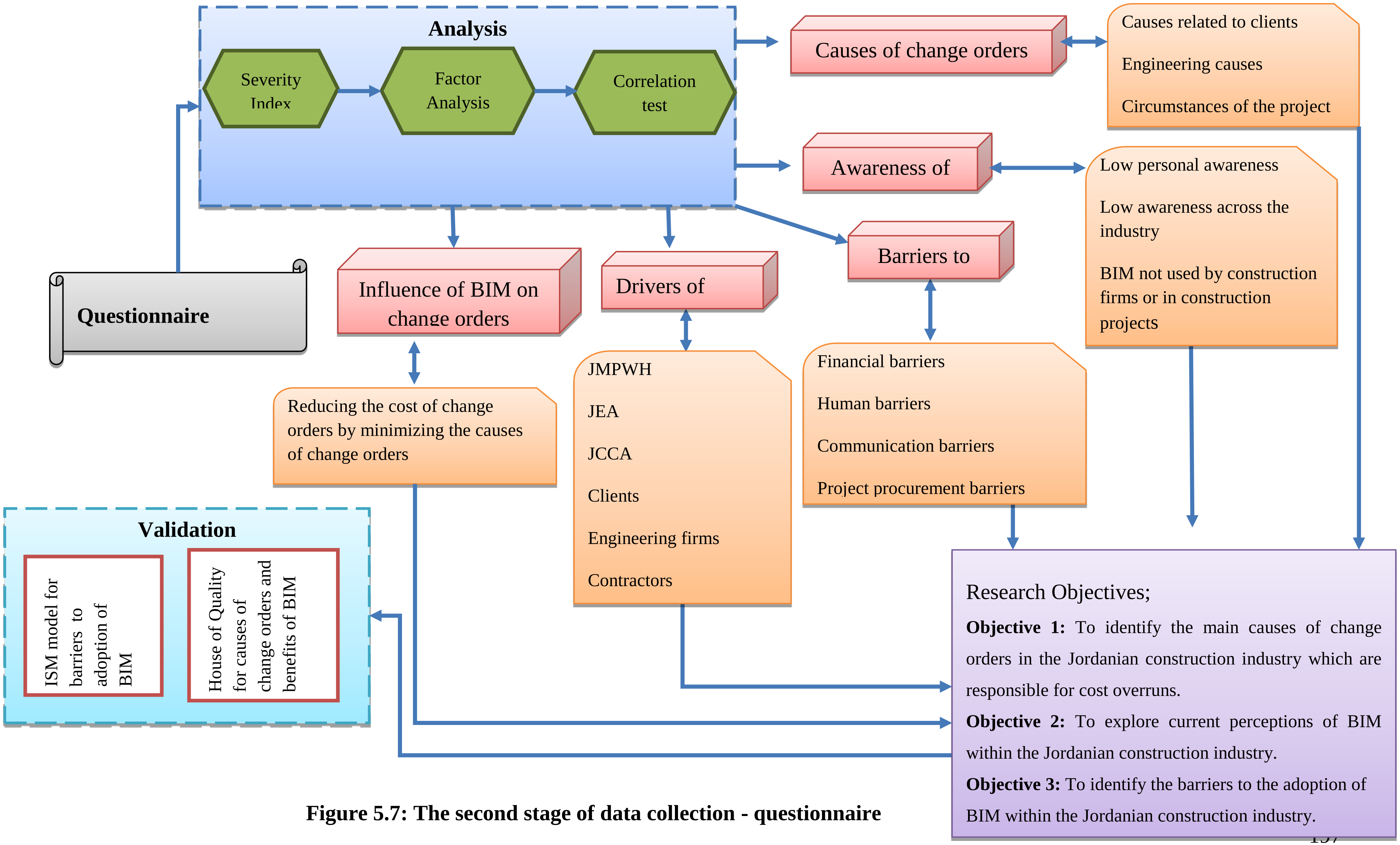


Figure 5.7: The second stage of data collection - questionnaire

CHAPTRE SIX: DISCUSSION

6.1 Introduction

In previous chapters, the researcher critically reviewed the literature on change orders and BIM in the construction industry, and this was followed by an analysis of 17 interviews with experts in the Jordanian construction industry in order to examine the current status of change orders, as well as current levels of awareness of BIM, barriers to the implementation of BIM and drivers and benefits. The interviews were analyzed through content analysis, and the outcomes provided a clear picture of the status of change orders and BIM in the Jordanian construction industry. These outcomes formed the basis of a questionnaire which was distributed across the construction industry in order to get more in-depth information. 155 participants responded to the questionnaire, and in Chapter 5 they were categorized according to their experience, field of work and sector (public or private). The majority of the participants (over 80%) are working in the private sector. This matches the focus of the research, which is on the adoption of BIM to reduce the cost of change orders in the private sector. Several tests were applied to analyze the questionnaire responses. The Severity Index test ranked the causes of change orders, factors related to levels of awareness of BIM and barriers to the implementation of BIM. The factor analysis test grouped the causes of change orders into three main groups, and the barriers to implementation into four groups. Correlation analysis identified the relationships between the causes of change orders, barriers to the adoption of BIM, and factors related to levels of awareness of BIM, as well as clarifying the relationship between the adoption of BIM and the causes of change orders. These tests helped the researcher to answer the research question and achieve the aim and objectives of the research.

This chapter discusses the findings of the interviews and the questionnaire, and compares them with the literature reviewed. The chapter draws things together in taking a holistic approach to the adoption of BIM, and assesses the effect of utilizing BIM to reduce the cost of change orders in the Jordanian construction industry. The following sections present a critical exploration of the research results on the causes of change orders in the Jordanian construction industry, levels of awareness of BIM, barriers to the adoption of BIM, the benefits of BIM in terms of reducing the cost of change orders, and drivers of the adoption of BIM.

6.2 Causes of change orders in the Jordanian construction industry

Changes in construction projects are common, and can arise for many reasons and at any stage in the project life cycle, but also have a considerable impact on a project's costs, timescale and quality. This research has investigated the main causes of change orders in Jordanian construction projects. The findings grouped the causes of change orders into three main groups: engineering factors, client factors and factors related to the circumstances of the project, and in each group there are a range of causes.

6.2.1 Engineering factors

Many studies have categorized the causes of change orders, and engineering work has been commonly identified as a category which includes numerous causes. In Oman, Alnuaimi et al. (2010) classified the causes of change orders into four categories, of which consultant-related was one. The first group of causes of change orders in the Jordanian construction industry is that related to engineering. This includes four causes: design errors, estimation errors, inconsistencies between contract documents and incomplete designs.

Design errors are considered to be one of the main causes of change orders in construction projects, and they increase the costs and completion time of a project. According to Arun and Rao (2007), changes, defects and corrections in design are the roots of cost and time overruns. In the context of Jordan, the descriptive results show that the Severity Index (SI) of design errors is 91.23%, which makes this the first main cause of change orders under engineering factors, and the second main cause of change orders overall in the Jordanian construction industry. Design errors also have a factor analysis load of 0.823, which is further evidence of their impact. In the interviews, 13 of the experts identified design errors as a major cause of change orders in the construction sector. It can therefore clearly be concluded that design errors are a significant cause of change orders in the private sector in Jordanian construction projects. This matches the findings of Al Jaloudi (2012) and Assbeihat and Sweis (2015). Al Jaloudi (2012) concludes that design errors are the second main cause of changes in water and wastewater projects in Jordan, and that ambiguities and mistakes in specifications and drawings are the third cause of change orders in Jordanian public projects (Assbeihat and

Sweis, 2015). What is more, this corresponds to findings in other countries, i.e. that change orders occur due to design errors (Gould and Joyce, 2003, Hanna et al., 2004).

Design errors and omissions can arise for several reasons, such as human error. Design errors may happen as a result of using incompetent and unqualified staff, as respondent P pointed out: *"using unqualified staff for design and implementation in the construction industry is responsible for many change orders in Jordan.*" Another reason might be failure to adhere to local regulations and requirements: according to respondent L, *"design processes do not follow the country's requirements during the design phase*". A client may also exert pressure to complete the design of a project as quickly as possible. Respondent P noted that *"due to limited time for the design because of pressure from the client, design errors, incomplete designs, and other problems related to the designer's work are very common, which leads to a lot of change orders."* In conclusion, it can be seen that design errors in the Jordanian construction industry are a major cause of change orders, as indicated by the high SI value and the factor analysis load. What is more, in the interviews a majority of the experts agreed that design errors are one of the main causes of change orders in Jordan.

Changes to construction projects can also arise from estimation errors. According to Halwatura and Ranasinghe (2013), poor estimation is the main cause of variation orders in the road construction industry in Sri Lanka. It can be shown that estimation errors could lead to changes later on, during the construction process. In the Jordanian context, the research found that estimation errors are the second main cause of change orders related to engineering factors. The factor analysis load of estimation errors is 0.807, which is significantly high, and which explains how sturdily it can represent the engineering factor. However, estimation errors are ranked as the sixth cause of change orders overall in the Jordanian construction sector, with a Severity Index (SI) of 72.65%. Although this indicates that estimation errors may lead to change orders, they are not a major cause, and are less influencing in this regard than causes such as design errors. This conclusion is similar to the findings of studies by Al Jaloudi (2012), Assbeihat and Sweis (2015) and Msallam et al. (2015) which did not consider estimation errors to be a significant cause of change orders. In the interviews, five experts said estimation errors are responsible for many changes in construction projects. Respondent J, for example, said that *"mistakes in estimating quantities and materials budgeting will be lead to many change orders."* To conclude, both the interview analysis and the questionnaire results pointed to estimation errors as a main cause of change orders in the Jordanian construction industry, and this conclusion is supported by the high value of the Severity Index and the results of the factor analysis.

The third issue to be addressed here is inconsistencies in contract documents or between drawings and specifications, which may also result in change orders in construction projects (Saunders, 1996). The research found that inconsistencies between contract documents were the third cause of change orders in the Jordanian construction sector related to engineering factors. The factor analysis load of inconsistencies (0.805) is very close to that of estimation errors (0.807) and is significantly explain and representing the engineering factor. The Severity Index (SI) of inconsistency between contract documents is 88%, meaning that it is the third main cause of change orders in the Jordanian construction sector, and thus a significant cause. This conclusion was also supported by the interview findings. Respondent A answered the question on the causes of change orders in Jordan by highlighting *"clashes between construction documents and discrepancies between BOQ and specifications with drawings, as well between drawings themselves."* Respondent M gave a briefer answer: "*clashes between MEP and structure design.*" In conclusion, the high factor analysis load and the Severity Index confirm that inconsistencies in contract documents are a significant cause of change orders in the Jordanian construction industry. This is supported by Al Jaloudi's (2012) findings that conflicts between contract documents are the first cause of change orders in water and waste water projects in Jordan. Msallam et al. (2015) also found conflicts between contract documents to be a significant cause of change orders related to the consultant (engineer). Furthermore, in the United States, Perkins (2009) concluded that discrepancies between designs and specifications are one of the main causes of change orders, giving further support to the research findings. It can thus clearly be seen that inconsistencies in contract documents is a significant cause of change orders in the Jordanian construction industry that is related to the engineering factor.

The fourth factor, incomplete designs in construction projects, causes many mistakes in execution, and change orders are necessary to correct these mistakes, so they have a negative impact on the costs and duration of the project. According to Atout (2016), incomplete designs are the main cause of delays in construction projects in the Gulf region, and this is similar to the results of the current research which has identified incomplete designs as the final cause of change orders in the engineering factors category. Factor analysis shows that incomplete design has the lowest load factor (0.748) in this category. This is considered moderately high and explain main factor (Engineering) in high degree. The Severity Index (SI) is 75.61%, meaning that incomplete design ranks fifth of all the causes of change orders. In their interviews, eight experts identified incomplete design as a cause of change orders in Jordan, saying that is arose from things like the use of unqualified staff, pressure from clients to complete the design as quickly as possible or failure to follow local regulations during the design process. Participant F talked about an *"unprofessional designer who made an incomplete design.*" Incomplete design can therefore be considered a significant cause of change orders in the Jordanian construction industry.

The analysis found significant correlations between design errors and estimation errors, inconsistencies between contract documents and incomplete designs ($r = .499^{**}$, $\rho < 0.01$), ($r = .576^{**}$, $\rho < 0.01$) and ($r = .554^{**}$, $\rho < 0.01$) respectively. This result may be because any error in the design of a project is reflected in the estimations, so then a change will be needed, and this may also be a result of inconsistencies between drawings or incomplete designs. Similarly, there is a significant correlation between estimation errors and inconsistencies between contract documents and incomplete design ($r = .458^{**}$, $\rho < 0.01$) and ($r = .561^{**}$, $\rho < 0.01$), and inconsistencies between contract documents is also significantly correlated with incomplete design ($r = .492^{**}$, $\rho < 0.01$). Finally, the correlation analysis indicated a significant relationship between all these causes, which means that if one of them is found, another may appear.

It can be concluded from the research findings that change orders in the Jordanian construction sector could be a result of engineering work. The engineering-related group of factors includes four main causes: design errors, estimation errors, inconsistency between contract documents and incomplete designs. The most significant cause of change orders is design errors, which has a high factor analysis load and SI, and is the second main cause of change orders in Jordan. Design errors occur in construction projects for several reasons, such as using unqualified staff, failure to take local requirements into consideration, and being put under time pressure by the client. The factor analysis shows that estimation errors have a significant load, which makes them one of the main causes of change orders in the construction sector, although they are not as significant as design errors, and they are ranked as the sixth cause of change orders. Inconsistencies between contract documents have almost the same load as estimation errors, as well as a significant SI. Inconsistencies between contract documents are therefore a significant cause of change orders in the Jordanian construction Industry. Incomplete designs might be found for the same reasons as design errors. They have the lowest load, but the Severity Index is higher than that of estimation errors. They have both a moderately high SI and factor analysis load. This discussion has shown that incomplete designs are one of the main causes of change orders in the Jordanian construction industry. Moreover, the research findings are mirrored in many studies conducted in different sectors in the Jordanian construction industry, which also adds credence to the research conclusions. Finally, the correlation test showed significant correlations between all the causes discussed here, which means there is a high probability that to issue new change follow change occurred to any of them.

6.2.2 Client factors

Changes by clients are common in construction for reasons such as changes in their needs. According to Mohammed et al. (2010) and Isaac and Navon (2008), clients are the main source of change orders. In Jordan, Swies (2008) found that the many changes required by clients are one of the five major factors causing delays in the construction industry. The results of the current research show that changes initiated by the client are the second main causes of change orders in the Jordanian construction industry. Change orders many be initiated by clients for three reasons: changes in their requirements, the time lag between the design and construction phases, and lack of communication between project parties.

Change orders initiated by clients in construction projects are normal, and are to be found in most projects because the law allows clients to demand changes in construction projects. Clients have a right to make changes in their projects according to standard contract provisions (Gunhan et al., 2007). In the Jordanian context, the analysis of the data shows that changes demanded by a client are a significant cause of change orders, and this has the highest load (0.869), which means that it accounts for a significant proportion of the client factors category. Moreover, changes demanded by the client were ranked as the main cause of change orders, with a Severity Index (SI) of 93.42%, which is considered significantly high. The interview results also supported this conclusion, as the majority of experts felt that such changes are responsible for most change orders in construction projects.

The analysis of the data identified many reasons why clients demand change. Eight of the experts saw changes in requirements as a factor, such as respondent Q, who mentioned *“change as a result of changes in the needs and requirements of the client.”* This echoes the conclusion of Gould and Joyce (2003) that change orders in construction projects arise from changes in the scope of the project as a result of changes in the owner’s requirements. Similarly, Alnuaimi et al. (2010) found that modifications and additional work on the design required by the client is the main cause of change orders in public construction projects in Oman. The current study found that the client’s lack of awareness and vision in relation to the project is the second cause of changes in this category, and respondent O mentioned *“lack of client awareness about his requirements which leads to many changes during construction."* Respondent J also felt that *“an owner does not understand his project very well. For example, a client has a certain understanding of the project during the design phase, but during the construction process he is usually surprised at the results that have been achieved. So he issues change orders to make it fit his ideas*.” It is apparent that any naive perceptions on the part of the client will lead to many changes later on. This conclusion is supported by Assbeihat and Sweis (2015), who found that change orders in public projects in Jordan could be because of adjustments made to the client’s plan because of his inability to understand or visualize the design. This failure to understand the project may arise from poor liaison between the project parties and a consequent misunderstanding of the client’s requirements. In this regard Sun and Meng (2009) concluded that poor brief development at the start of the project usually leads to misunderstandings about the client's requirements and mistaken assumptions about key aspects of the project. It is thus very important to ensure that the client understands the construction project and is clear and realistic about his vision, needs and requirements in order to minimize possible changes.

The client’s financial situation is the third factor which could cause a client to demand changes in the Jordanian construction industry. In the interviews, respondent I confirmed that *“change orders may happen due to changes in design because of the financial circumstances of the owners.”* Msallam et al. (2015) also found that a client’s financial problems were a major cause of change orders in highway projects in Jordan. It is thus clear that change orders in the Jordanian construction sector may occur due to changes in a client’s financial situation, either for the better or the worse. For example, if the client’s financial situation improves, there is a possibility to expand or improve the project, and so change orders may be issued.

On the other hand, a reduction in what a client can afford may lead to a reduction in the scope of the project so that many items are eliminated, again leading to change orders. It was also found that change orders in some construction projects may occur because of changes in senior management or in their attitude. Respondent I noted that *"a change in the senior management team might result in a change to the scope and design of the project. In addition changes in attitude are responsible for many change orders in construction projects in Jordan."* Assbeihat and Sweis (2015) concluded that modifications to the project design may also be a result of frequent changes in administration and the merging and splitting of government agencies. In conclusion, the changes demanded by clients are a major cause of change orders in the Jordanian construction industry, and comprise a significant proportion of the client factor category. Factor analysis shows this has a high load, and it also has a significant Severity Index (SI), ranking it as the first cause of change orders in the Jordanian construction sector. Clients request changes for a variety of reasons, including a lack of clarity in their vision and awareness or changes in their financial circumstances. Focusing on such factors, for example by raising the client's level of awareness, will minimize the number of change orders during construction and reduce costs.

Change orders may also be due to the time lag between the project design and construction phases. Factor analysis found that the load for this is 0.605, which is moderately high and goes some way to explaining the significance of the client factors category. The Severity Index (SI) is 70.19%, which ranks it among the three least important causes of change orders in the Jordanian construction sector. In the interviews, only one respondent said that the lag between design and construction in construction projects could lead to change orders. What this means is that change orders in Jordanian construction projects could be a result of the lag between the design and construction phases, but the likelihood of this is very low compared to other reasons. The length of time between the two phases, whether it is long or short, may have a negative impact on a construction project because many changes can be requested. During this period there may be changes for many reasons, such as new requirements or the development of new technologies or materials which the client wants to be used. It can also be the case that pressure from the client means that there is not enough time to produce proper design documents, which can mean that change orders have to be issued later on. Respondent P suggested that *"if there is limited time for the design because of pressure from the client, the design is often not fully completed, or there may be many other problems with it, and this* *can often lead to change orders."* In this context, Koushki et al. (2005) found that change orders could be prevented and a significant reduction in cost overruns and delays in the completion date could be achieved by having a complete design before construction begins. It is clearly important to finish the design work properly before starting construction so as to reduce the need for changes. The research thus shows that a time lag between the design and construction of a project in the Jordanian construction industry could lead to change orders being issued, but that this is not a significant cause. Having a suitable period of time between the design and construction phases will reduce changes arising from new requirements or circumstances, as well as ensuring that designs are completed with minimum errors.

Thirdly, communication in the construction industry is complex because of the many different parties which are involved. Poor communication between these parties could result in many problems (Charoenngam, Coquinco and Hadikusumo, 2003). A need for changes is one of these problems, and this could arise because of failures to share information or ambiguity and misunderstanding. Naoum (1994) and Ibbs et al. (2001) also found that a lack of timely and effective communication and a lack of integration are two common causes of change. In Jordan, the research results shows that the final cause of change orders in the Jordanian construction industry in the client factors category is lack of communication between projects parties. Factor analysis showed that the load for lack of communication is 0.593, which means that it is a significant influence within this category. The Severity Index (SI) of lack of communication is 83.48%, which is significantly high, and ranks this as the fourth main fourth cause of change orders in Jordanian construction projects. In the interviews, five experts confirmed that lack of communication is responsible for many changes in the Jordanian construction sector. According to respondent C, *"lack of communication among project parties is one of the main causes of change orders."* Respondent K said that *"change orders occur as a result of lack of communication between client and designer (engineer)."* The research results are in keeping with Assbeihat and Sweis's (2015) conclusion that insufficient coordination among the parties and with the owner ranks as the fifth main cause of change orders in public projects in Jordan. Msallam et al. (2015) also found that lack of coordination related to the consultant (engineer) is a major cause of change orders in highway projects. In this research, the client is seen to have a key role in communicating effectively with the other project parties to ensure that a project is completed with minimum changes. It is also the client who is responsible for selecting a professional engineer (consultant) and other project parties who are experienced and who are able to communicate effectively with each other. In conclusion, lack of communication is a significant cause of change orders in the Jordanian construction industry in the client factors category. Lack of communication can be between the project parties or between different disciplines within the same group of stakeholders, and result in many changes over the project life cycle.

The analysis showed that there are significant correlations between changes initiated by the client, the time lag between project design and construction and lack of communication. Changes initiated by the client is significantly correlated with the time lag between project design and construction ($r = .49^{**}$, $\rho < 0.01$), which supports the conclusion that a client will demand more changes if the time between the design of the project and the start of construction is not adequate. Changes initiated by the client are significantly correlated with lack of communication ($r = 0.177^{**}$, $\rho < 0.01$), reinforcing the idea that such changes come about because of failures to share information or misunderstanding other project parties. Finally, the time lag between the project design and construction phases is also significantly correlated with lack of communication ($r = 0.219^{**}$, $\rho < 0.01$), which confirms that lack of communication could affect the lag between the design and construction phases and ultimately result in many change orders in the Jordanian construction industry.

To summarize, the research found that the majority of change orders in Jordanian construction projects have to do with clients. Changes initiated by clients are the main cause of change orders in the Jordanian construction sector, and are ranked as such by the Severity Index (SI). This also has a significant factor analysis load. Clients may demand changes to a project because of changes in their requirements, in the scope of the project, their lack of vision, financial problems, or changes in senior management. The time lag between the design and construction phases is the second cause of change orders related to the client factor, as determining the start of both these phases is the responsibility of the client. The time lag may be long or short. A long period makes it more likely that there will be changes in needs, requirements, or in the materials to be used, while a short period could mean that changes are necessary because of errors in the design. However, the research shows that the time lag between the design and construction phases is not a significant cause of change orders in the Jordanian construction industry. It is ranked lower than other causes, and has only a moderately high load. Moreover, in the interviews only one expert mentioned this as a cause of change orders.

Lack of communication is the final cause of change orders in the client factors category in the Jordanian construction industry. The load and Severity Index (SI) showed that lack of communication is a major cause of change orders in the Jordanian construction sector. Lack of communication means that information is not shared and there are misunderstandings between the project parties, so a change order is required to solve the problems which occur as a result. There may be poor communication between different project parties such as the client and the designer, or between different disciplines within the same group, such as civil and mechanical designers. Lack of communication is included as a client factor because of the importance of collaboration and integration between clients and other parties, as well as the fact that the client is responsible for selecting other project parties. The client must choose professional teams so that they communicate effectively with each other and between their own different disciplines in order to minimize errors and misinformation that could result in changes which delay the project and increase its costs. Finally, the causes in this category are significantly correlated with each other, which means that if any one of them causes a change, another change could happen because of another factor. For example, if a change is required as a result of lack of communication between civil and mechanical engineering staff, the change might be one which does not meet the client's needs.

6.2.3 Factors related to the circumstances of the project

Various studies have identified causes of change orders that are not related to the project parties. According to Perkins (2009), different site conditions are one of the main causes of change orders in the United States. The current research has identified the circumstances of the project as the third main cause of change orders in the Jordanian construction industry, and this is related to the construction process. This third group includes shortages of materials and different site condition.

During the project life cycle, changes in the availability of materials, equipment and labour, together with fluctuations in their costs, have a massive impact on the delivery of the project and cause many changes. The research shows a significant load for shortages of materials that slightly exceed (0.90). This means that this factor is highly representative of this category of causes. However, the Severity Index (SI) for shortages of materials is significantly low (just 47.53%), which ranks it as the least important of all the causes of change orders in the Jordanian construction industry. The low value of the Severity Index indicates that a shortage of materials is not a significant cause of change orders in the Jordanian construction sector. The interviews supported this, as this factor was mentioned as a cause of change orders in Jordanian construction projects by one expert only. This compares with the conclusion of Assbeihat and Sweis (2015) that shortages of materials is not a common cause of change orders in public sector projects in Jordan. The conclusion is that although shortages of materials are highly representative of the group of factors and could cause change orders in private construction projects, they are not a significant cause, and were not considered to be by the majority of experts, and the Severity Index is less than 50%.

Changes in construction projects could also be due to specific site conditions, such as safety considerations, ground conditions or other restriction (Hsieh et al., 2004, Wu et al.,2004, Al-Momani, 2000). In the context of Jordan, only two experts were of the opinion that change orders could be issued as a result of different site conditions. The load of different site conditions is 0.804, which is relatively high, and representative of this category. However, the Severity Index (SI) is 62.08%, which ranks it as the eighth cause of change orders in Jordan, meaning it is less significant than other causes. It can thus be concluded that different site conditions are not a significant cause of change orders in the Jordanian construction industry. This result mirrors the findings of Assbeihat and Sweis (2015), they did not include different site condition among the five main causes of change orders in public sector projects in Jordan. Controversially, however, both Msallam et al. (2015) and Al Jaloudi (2012) do see different site conditions as an important cause of change orders in highway projects and in water and waste water projects. The contrast in these findings is related to the difference in the nature of the site of the different projects: neither the sites of highway projects nor of water and waste water projects have a high probability of unforeseen problems, and they differ in nature from the sites of building projects in the private sector, which also have a low probability of occurrence of unforeseen conditions. In short, changes in construction projects could be a result of different site conditions, but the findings show that there are few change orders arising from different site conditions in Jordan.

The analysis shows that there a significant correlation between shortages of materials in construction sites and different site conditions ($r = 0.620^{**}$, $\rho < 0.01$), and this indicates that any difference in site conditions will influence the quantity of the material on the site and there is therefore a high probability of change. This means that although neither different site conditions nor shortages of materials are significant causes of change orders in the Jordanian construction industry, if one of them is present then more change orders will be issued because of the other.

To summarize, the third category of causes of change orders in the Jordanian construction industry is the circumstances of the project, which includes two causes, namely shortages of materials and different site conditions. Both of these have a high factor load, which indicates that they are strongly representative of the category. However, the analysis of the interviews and the Severity Index show that they are not among the main causes of change orders in Jordanian construction projects, and they are ranked as the ninth and eighth causes of change orders respectively. Shortages of materials may occur in construction projects and require change orders in order to adapt to the new circumstances, but in Jordan this cause of change orders is not common and the majority of the respondents did not focus on it, and the Severity Index is less than 50%. The research thus concluded that change orders could be issued in relation to different site conditions, but that the likelihood of this is not high, and the Severity Index is 62.08%. Finally, even though neither of these causes is significant in itself in Jordanian construction projects, if one of them is present, the probability of a change order being issued in response to the other is high, as they there is a significant correlation between them.

6.3 Current levels of awareness of BIM in the Jordanian construction industry

BIM is not only a tool but also a comprehensive process, so the adoption of BIM in the construction industry depends on the level of awareness in the construction sector. According to Ibrahim and Bishir (2012), there is a need for studies to investigate the level of knowledge and use of BIM in order to promote the adoption of BIM by increasing increased awareness - of the techniques, the tools employed and the benefits of adopting BIM. In order to investigate the current status of BIM in the Jordanian construction industry, the interviews and the questionnaire focused on personal levels of awareness of BIM and those of the construction sector as a whole, as well as trying to identify a successful project which had implemented BIM and could serve as a guide for the use of BIM by other firms or projects.

Firstly; in order to assess their understanding of BIM terminology in the Jordanian construction industry, in the interview the respondents were asked the following questions: ‘how would you categorize your understanding about BIM?’ and ‘how would do you define BIM?’ In the questionnaire they were asked ‘do you personally consider your understanding of BIM as good?’ The responses indicate that the personal level of awareness of BIM of the people who participated in the data collection exercise can be categorized into three groups. The first group includes those who have little or no knowledge of BIM, i.e. those who would not be able to use it. For example, respondent participant J admitted *“I have very little awareness of it, which is insufficient.”* This category has the highest number, namely 8 respondents. Overall, 79.6% of the respondents indicated that they did not have enough knowledge of BIM to be able to use it. These results in the context of Jordan parallel what Adebimpe and Moses (2016) found in the Nigerian construction industry, which is also characterized by low levels of awareness of BIM among professionals. According to Newton and Chileshe (2010), the situation in the South Australian construction industry also shows a significant lack of interest and understanding of BIM. The second group is those who have a basic knowledge of BIM, and are able to talk about it. Six of the interview participants were classified in this category, as well as 18.4 % of the questionnaire respondents. The third group involves participants who have a good knowledge of BIM, and could lead the adoption of BIM in Jordan. Only three of the 17 interviewees were able to show detailed knowledge of BIM in the interviews, and only 2% of the questionnaire respondents said they would be able to use BIM on the basis of their current knowledge. It is thus clear that the level of awareness of BIM among individuals working in the Jordanian construction industry is weak, with the majority of those who participated in the interviews and responded to the questionnaire having little or no knowledge or awareness of BIM. The Severity Index (SI) of personal awareness is less than 35%, which is quite low. These findings are similar to those of a survey conducted by Smart Market Report across countries in the Middle East in 2010, which found that Jordan had the lowest number of respondents, only 7% of those who took part in the survey (Building Smart. 2011). The results of this survey together with the findings of this study together offer strong evidence of a lack of awareness of BIM in the Jordanian construction industry on the personal level, which will pose a serious obstruction to the adoption process.

Secondly, the questionnaire sought to determine levels of awareness of BIM across the construction industry. The results show that 79% of participants believe that the understanding of BIM in the Jordanian construction industry as a whole is not enough to implement BIM. The other 21% of respondents were undecided on this question. These percentages help to clarify the low Severity Index (SI), which is less than 35%. The interviews painted the same picture. Respondent F reported that added *"there is a lack of awareness in the Jordanian construction industry about BIM*.", while respondent D felt that *"currently the level of awareness of BIM and its benefits is still low, and not what is required by all stakeholders."* It can therefore be concluded that the level of awareness and knowledge of BIM in the Jordanian construction industry could not be classified as high, and not enough to implement BIM. However, focusing on the benefits of BIM and presenting successful examples from abroad could help to improve awareness and motivate construction firms to implement BIM. Training courses could also be provided, as well as support by the government and professional bodies. Such suggestions echo those of Adebimpe and Moses (2016), who also advocated a focus on the benefits of BIM, increases in government support for using BIM, the involvement of professional bodies and training for both public and private organizations as a way of increasing awareness levels and something which would encourage its adoption in project delivery.

Thirdly, some of the experts saw a link between the low level of awareness of BIM and the fact that it had not been used by construction firms or in successful projects. The lack of awareness and knowledge of BIM discourages private clients from mandating the use of BIM. The Severity Index (SI) of projects which have implemented BIM is less than 35%, which is very low and means that there are very few firms or projects which have used BIM. Yan and Damian (2008) report a similar situation in other countries, finding that "only 26% of companies in the USA, 14% in the UK, and 5% of companies elsewhere report that they are using BIM to design, construct and operate their projects" (p. 3). All 17 experts agreed in the interview that there is not even one construction project in Jordan which has implemented BIM. According respondent C *"there are no adequate guides or advice for implementing BIM in the Jordanian construction industry, nothing which can be taken as a guide for* *implementation."* This explains why the level of awareness in the Jordanian construction industry is low and is not enough to implement BIM. This is similar to the conclusion of Gu and London (2010) that the lack of experience of BIM due to a limited understanding of industry needs and technical requirements is a major factor delaying the advancement and adoption of BIM-related technologies within the Australian construction industry.

The Severity Index (SI) of implementing BIM in construction firms is less than 35%. What is more, not even one of the interviewees believed that constructions firms are currently using BIM. Al Awad (2015) came to exactly the same conclusion, i.e. that the implementation of BIM in small and medium enterprises in Jordan is zero. Similarly, Newton and Chileshe (2010) found that only 17.24% of the firms which participated in their research were using any form of BIM technology, while the majority (82.76%) was not using BIM. The majority of Jordanian construction firms depend on 2D CAD for their work, although some firms are using 3D CAD. Ten of the experts interviewed are working in firms that use only 2D CAD, and seven in firms which use both 2D CAD and 3D CAD. Al Awad (2015) also found that 21% of those surveyed use both 2D and 3D CAD in their activities, while 71% use only the 2D CAD function of AutoCAD.

The correlation test was applied to identify relationships between the two levels of awareness of BIM in the Jordanian construction industry, and found that personal awareness is significantly correlated with the awareness of the construction industry overall and the use of BIM in construction firms or construction projects. The strongest relationship is that with implementing BIM in construction firms ($r = .401^{**}$, $\rho < 0.01$). It was found that there is a lack of awareness of BIM on a personal level and this is reflected in the failure of construction firms to use BIM. Implementing BIM in construction projects is correlated with personal awareness ($r = .361^{**}$, $\rho < 0.01$), which clearly means that for BIM to be implemented in the construction sector, an essential first step is to improve knowledge of BIM on a personal level. Knowledge of BIM in the construction sector is also significantly correlated with personal awareness ($r = .341^{**}$, $\rho < 0.01$). This means that for BIM to be implemented in the Jordanian construction industry personal awareness levels should be improved and that any weakness in one of these factors will have a negative effect on the other.

Furthermore, levels of awareness of BIM in the Jordanian construction industry are significantly correlated with the use of BIM in Jordanian construction firms ($r = .383^{**}$, $\rho <$

0.01), which reinforces the finding that construction firms are currently not using BIM and at the same time do not have any significant knowledge or awareness of BIM. Finally, there is a significant correlation between implementing BIM in construction firms and using it in construction projects (r =.523**, $\rho < 0.01$), which means that the lack of implementation in construction firms will be reflected in a low level of implementation in construction projects, which echoes what was found from the interviews and questionnaire. This leads to the conclusion that, as suggested above, if BIM is to be implemented in the Jordanian construction industry the first step is to develop personal levels of awareness of BIM: personal awareness of BIM can form a foundation for the adoption of BIM in the Jordanian construction industry, in other words. Improving the awareness level across the Jordanian construction industry will serve as a driver for the implementation of BIM in construction firms and construction projects.

6.4 Barriers to the adoption of BIM in Jordan

BIM will not be implemented overnight in the Jordanian construction industry, as there are many barriers which hinder its adoption. According to Arayici et al. (2011), construction companies face challenges and barriers to the adoption BIM technology, as there is no clear guidance or studies of best practice available to learn from and build up their system. This research has investigated in depth the obstructions facing the adoption of BIM in the Jordanian construction industry. The findings indicate that the barriers to the adoption of BIM in Jordan fall into four groups: financial, human, communication and project procurement, and each of these groups have many barriers.

6.4.1 Financial barriers

Finance is a very important factor for the adoption of BIM. The cost of implementing BIM includes a wide range of costs such as the purchase of software, technical support, hardware, training and services. According to Chien et al. (2014), the costs could be higher when BIM is first implemented, as they include expenses related to the model review, staff training and the purchase of software and hardware. BIM software will have to be updated periodically, which means that extra costs will be added (Lee et al., 2012). The research investigated these barriers in order to clarify them and suggest ways of improving the adoption of BIM in the Jordanian construction industry. A factor analysis test was used for the questionnaire findings, which measures the percentage variance and loading value associated with each sub-factor (Field, 2013). This identified financial factors as latent barriers to the adoption of BIM in the Jordanian construction industry. This group has three barriers which are all related to cost of implementing BIM: software costs, hardware costs and training costs. None of these barriers had a load of less than 0.781, which means that each of them is highly representative of the financial barriers as a whole, and affects the other financial barriers to the adoption of BIM in Jordan.

The factor analysis test shows that software costs are first among this set of barriers, with a load of 0.850. This means that these costs are highly representative of the category (financial barriers to the adoption of BIM) (Field, 2013). The cost of software has a Severity Index (SI) of 92.63%, which makes it the third main barrier to the adoption of BIM. According to Love and Irani (2004), software and hardware lie at the heart of the strategic adoption of IT. The results of the statistical analysis confirm the importance of software and hardware costs for the adoption of BIM which was identified in the interviews and questionnaires. In the interviews, 16 of the 17 experts believed that the financial implication of software obstructs the adoption of BIM in Jordan. This was emphasized by respondent H, who said that *"in general, there is a difficulty with accepting BIM, as most people in the Jordanian construction industry are concerned about the costs of software or upgrading hardware."* Software costs are therefore a significant barrier to the adoption of BIM in the Jordanian construction industry, as most construction stakeholders are concerned about the costs of their projects. Software costs are a financial barrier due to their significant load, high Severity Index and what the experts said.

Hardware costs are also an issue, as it is necessary either to purchase suitable hardware or upgrade existing hardware so that it is compatible with BIM software. According to Oluwole (2011), the hardware has to have specific features in order to run effectively and work with new application-based programs such as BIM. However, there is a cost associated with these items, and it differs from one product to another, as well as between manufacturers. In Jordan, the factor analysis test showed that the load of hardware costs is 0.848, which is indicative of how far this barrier is representative of the financial barriers as a whole. The highly load comes as a sufficient needs for upgrading most of hardware in Jordanian construction sector to be adapted with BIM software. The SI of the cost of hardware is

83.68%, and shows that this is the fifth barrier to the adoption of BIM in Jordan. What is more, 14 of the 17 experts interviewed felt that the cost of upgrading hardware could prevent the adoption of BIM in Jordan, and this is clearly shown in the opinion of respondent participant H (quoted above). Given these factors, it clearly can be concluded that hardware costs are a major barrier to the adoption of BIM in the Jordanian construction industry, where most firms still use 2D CAD in their daily work, so upgrading for BIM request for upgrade hardware to be attuned with BIM software and more efficient.

When a firm implements BIM, it needs qualified staff who have the ability to use it effectively and successfully. The descriptive results rank training costs as a significant barrier to implementing BIM in the Jordanian construction industry, overall all barriers, and the Severity Index (SI) is 94.74 %. In addition, training costs have a significant load of 0.781, which shows what a large role training costs have among the financial barriers. In the interviews, training costs were seen as one of the main barriers obstructing the adoption of BIM in Jordan. Respondent J answered the question about barriers by saying *"lack of skilled and trained staff to implement BIM, as well as the cost of training."* This is similar to Oluwole's (2011) conclusion that training costs are the third barrier to the adoption of BIM, and this arises from the inability of staff' to use BIM software. In Jordan, staffs in most construction firms are currently unable to use BIM, and so they need professional training courses to use the software effectively and competently, but the costs of this training is a significant barrier.

The correlation analysis results show that software costs are significantly correlated with hardware and training costs ($r = .567$, $\rho < 0.01$) and ($r = .378$, $\rho < 0.01$) respectively. This means that as the software costs increase, there will be a need for upgraded hardware and for special training, so both the hardware and the training costs will also increase. Implementing BIM makes it necessary to purchase the appropriate software, as well as buying or upgrading hardware and training staff so that the software can be used. Different training packages are required for different organization structures, as well as for different categories of staff (Oluwole, 2011). The version of software will determine the criteria for the hardware, and the level to which staff must be trained in order to use it effectively. These requirements are costly, and vary from one organization to another, and in particular the high front-end cost of implementation has been considered a significant barrier to the uptake of BIM in the construction industry (Azhar et al., 2011, Thompson and Miner, 2010, Crotty, 2012, Efficiency and Reform Group, 2011, Giel et al., 2010, Yan and Damian, 2008). There is a significant correlation between hardware costs and trainings costs, where the correlation coefficient r is 0.531 and $\rho < 0.01$. This shows that the hardware and the training are related to the software, as well as to each other. So upgrading hardware requires staff skills to be developed in order be able to use the BIM software effectively.

In summary, it can clearly be concluded that the financial barrier is an important barrier to the adoption of BIM in the Jordanian construction industry. This category includes three main barriers: software costs, hardware costs and training costs. These three barriers all have high loads in factor analysis, and are among the top barriers according to their Severity Indexes (SI), the lowest of which is 83.68%. Such figures show that all of these are major barriers to the adoption of BIM in Jordan. The software costs were ranked as a more important barrier than hardware costs according to the factor analysis test and the Severity Index. This result is perhaps explained by what Oluwole (2011) found, i.e. that the average cost of software represents 55% of the total cost of implementation, and that it was five to seven times higher than the hardware costs in 32 sample cases. The correlation analysis showed that there is a significant positive relationship between these three barriers that should be taken into consideration in the way the adoption process is carried out, as dealing with one barrier helps to resolve the others.

6.4.2 Human barriers

The human factor has a very significant effect on the adoption of BIM in the construction industry, and there are many issues in this category of barriers, including training, awareness, the knowledge, skills and ability to implement BIM, and levels of interest and demand for BIM. According to many researchers (Eastman et al., 2011, Gu and London, 2010, Hardin, 2009, Samuelson and Björk, 2011, Sebastian, 2011, Singh et al., 2011, UK-Gov, 2011a, Rogers, 2013) the human resource capability has to be changed in order to match the new technological or operational process capabilities. Arayici et al. (2012) also suggest that the selection of the staff members to be trained to use BIM has an effect on its implementation. In the Jordanian context, the factor analysis shows that people are a latent factor which hinders the adoption of BIM in the construction industry. Four barriers are grouped under human factors: shortages of skilled and trained staff, lack of interest and demand, dependence on unskilled staff in the construction sector, and lack of awareness.

Firstly, the adoption of BIM in the construction industry requires staff with a high level of skills to drive and implement BIM. Training in using the new technology is sufficient to enable individuals to contribute to the changing work environment when BIM is implemented (Gu et al., 2008, Arayici et al., 2009). This indicates the level of competence required by individual to implement BIM effctively. The analysis of the data showed that a shortage of skilled and trained staff who can take the initiative in the adoption of BIM is a significant barrier in the human factors category. The factor analysis load for this barrier is 0.696, and this is strongly representative of the human factors category. The descriptive results ranked shortages of skilled staff as the sixth main barrier to the adoption of BIM on the basis of a Severity Index (SI) of 83.55%, all of which reinforces the conclusion that it is a significant barrier to the adoption of BIM in the Jordanian construction sector. In research in the Australian context, Aibinu and Venkatesh (2013) similarly concluded that the extent of the adoption of BIM by QS was low due to a shortage of skills. Eadie (2013) also found that a lack of expertise within the project team and the organization are the two main factors for the failure to use BIM. In the interviews, respondent E commented that *"there is a shortage of staff who have the ability to use BIM professionally,"* and respondent J's answer to the question about the barriers was *"the (lack of) availability of skilled and trained staff to implement BIM* ". It can be seen that the Jordanian construction sector suffers from the lack of availability of staff who have the appropriate knowledge and skills to drive the adoption of BIM, and that this skills shortage is a significant factor obstructing the adoption of BIM in Jordan.

The lack of interest and demand in relation to BIM is the second barrier linked to human factors. The factor analysis load is 0.673, which means it is an important barrier, and representative of this category. However, the Severity Index is 73.29%, which puts it in tenth place among the barriers. Although this SI is somewhat low in comparison to other barriers, this does not mean it is not a significant barrier to the adoption of BIM in the Jordanian construction industry, as the factor analysis shows that lack of interest and demand is strongly representative of the human factor category. The lack of interest and demand could be exhibited by clients, engineers, contractors or top management, indicating that these decision makers have little awareness of BIM, or are happy with current practices and do not feel any need to change things. Some evidence for this interpretation is provided by Tse et al. (2005), who concluded that the main reason for the lukewarm attitude of architects towards BIM is the lack of demand from clients and other project team members, and that the majority of architects felt that "existing entity-based CAD systems could fulfil their drafting and design needs". In the interviews, respondent H saw the client as responsible: *"the client is not interested in BIM and does not want to add extra costs to his project by implementing BIM,"* emphasizing the weakness of demand for BIM in the Jordanian construction industry. The research results thus confirm that the lack of interest and demand is a barrier to the adoption of BIM in the Jordanian construction industry, but it is not a significant barrier, and ranks tenth.

Thirdly, the adoption of new technology or processes could be resisted, especially when the staff considers they have been given insufficient training or that their jobs will be threatened (Ruikar et al., 2005, Wilkinson, 2005, Griffiths et al., 2014). In Jordan, recruiting staff in construction sector who do not have the qualifications of skills required for BIM would impeding its adoption it in Jordan. Respondent L explained that *"theoretically, they accept BIM, but the reality is that they don't, because for that to happen we need to change a culture of depending on staff who can only do things other than BIM*." The factor analysis load of dependence on unskilled staff is 0.627, which makes it an important barrier in this category. The Severity Index of this factor makes it the fourth main barrier to the adoption of BIM in the Jordanian construction industry. This makes it clear that Jordanian construction firms are not conducting appropriate training courses for their staff, but use qualified staff only for specific jobs other than BIM, and do not have any staff who are able to implement BIM. De Vos and Willemse (2011) found that construction firms avoid doing training courses by recruiting people with sufficient training. In the interviews, respondent D felt that *"nowadays, most construction firms have unskilled and untrained staff for implementing BIM."* Overall, it is clear that the Jordanian construction industry does hire staff who have the ability to do their current jobs, and they do not need training for this, but they are not able to work with BIM. It can therefore be concluded that the current attitude of construction firms in Jordanian construction manifested in their reluctance to hire or train staff constitutes a barrier to the adoption of BIM.

Lack of awareness is the final barrier to the adoption of BIM in the Jordanian construction industry related to human factors. The load of lack awareness was found to be 0.569, which means that it is representative of the human factor category. The descriptive analysis ranked lack of awareness as the eighth barrier, with a Severity Index 77.5%. These findings confirm that lack of awareness in the Jordanian construction industry is a significant obstruction that hinders the adoption of BIM. The results also suggest that there is a serious lack of awareness of BIM on a personal and organizational level, and the Severity Index of both of these is less than 35%. In the interviews, many of the experts thought that lack of awareness is has a large effect on the adoption of BIM in Jordan. Respondent D confirmed this, saying that *" the current level of awareness of BIM and its benefits is still low, and not what is required for adoption by all stakeholders."* Respondent F agreed that *"there is a lack of awareness of BIM in the Jordanian construction industry about BIM."* The level of awareness and knowledge of BIM in the Jordanian construction industry is thus one of the main barriers hindering its adoption. This conclusion is supported by the findings of Ibrahim and Bishir (2012) that ask for a sufficient level of BIM awareness and knowledge to for improve the process of adopting BIM, and by Al Awad's (2015) conclusion that a lack of awareness of BIM is the main barrier obstructing its adoption by small and medium enterprises in Jordan. Overall the research shows that the lack of awareness of BIM is a significant barrier to its adoption it in the construction sector.

The analysis shows that the shortage of skilled and trained staff has a significant correlation with the lack of interest and demand (.219**), which explains the slightest availability of staff they can implement BIM in Jordan. Its correlation with dependence on unskilled people for implementing BIM is .491**, which means that while construction firms use only qualified staff for their current work, they have few staff who are able to use BIM. The most common reason for not providing any training in the construction sector is the feeling of employers that all their staff are competent, and therefore don't need any training. A further reason is the low demand, and so training is not a priority for the organization (UK Commission for Employment and Skills, 2016). Other studies have also concluded that most Jordanian construction firms depend on specific staff to do specific work, but these staff does not have the skills required for BIM. Lack of awareness is also significantly correlated with the availability of skilled and trained staff (.545**), suggesting that the lack of awareness can decrease the availability of qualified staff who can use BIM in the construction industry.

The lack of interest and demand is significantly correlated (.271**) with dependence on unskilled and untrained staff, which means that as interest in BIM decreases, dependence on unskilled staff who cannot implement BIM will increase, which in the longer term will reduce the availability of skilled and trained who can implement BIM and obstruct the adoption of BIM in the Jordanian construction industry. Correspondingly, dependence on unskilled and untrained staff who do not have the knowledge and experience to implement BIM has a significant correlation with lack of awareness (.242**). This indicates that the lack of awareness of BIM makes firms more dependent on staff who cannot use BIM.

In conclusion, the human factor is a significant barrier to the adoption of BIM in the Jordanian construction industry. The results show that all the barriers in this category impede the adoption of BIM in Jordan. The construction industry depends the staff they currently have available to do day-to-day work, but this staffs is not qualified to use BIM. Dependence on unskilled staff has the highest Severity Index among these barriers, and is significantly correlated to the other three sub-barriers. The shortage of skilled and trained staff is a significant barrier to the adoption of BIM in Jordan, ranking as the sixth barrier overall, and has the highest factor analysis load in of the other three barriers. Moreover, it is significantly correlated with dependence on unskilled staff. The lack of interest and demands may be connected to the lack of awareness of BIM. The results show that lack of interest is obstructing the adoption of BIM in Jordan, and there are many reasons for this which may arise from any of the project parties. The lack of interest clarifies why the Jordanian construction sector is dependent on staff who cannot use BIM. It is also significantly related to the shortage of people who can implement BIM in Jordan, and could be identified as one of factors which minimizes the availability of staff who do have the skills to use BIM. Lack of awareness is the last barrier in the human factor category and has an impact on the dependence on unskilled staff who are able to do only routine work, and thus minimises the number of staff with the appropriate skills in the Jordanian construction sector. Lack of awareness of BIM and of its benefits for construction projects is the main barrier to the adoption of BIM in the Jordanian construction industry, and the results show that this is a significant weakness both on a personal level and across the whole construction sector.

6.4.3 Communication barriers

Communication barriers are related to a range of communication issues between project parties during the different phases of a project. The factor analysis test identified communication factors as a group of latent barriers to the adoption of BIM in the Jordanian construction industry. There are four barriers in this group, weaknesses in communication between project parties, the lack of a legal framework for BIM, the approval system for new projects and traditional work processes.

Firstly, the adoption of BIM necessitates inquiring changes in existing communication processes to facilitate greater collaboration and integration across different disciplines. According to Kiviniemi (2013), the fragmented nature of the construction industry means that there must be changes in the processes which involve all the project parties, as adopting BIM will emphasize integration, collaboration and innovation, which represents a significant cultural change in the industry. Currently, weakness in communication between different project parties is a significant barrier to the adoption of BIM in Jordan. The factor analysis test result indicated a load of 0.785for current weaknesses in communication, which means this is highly representative of this category of barriers. The Severity Index (SI) for current weaknesses in communication between project parties is 65.39%, which is at the lower end of the barriers. In the interviews, respondent E believed that the current communication system is weak and could be an obstacle to the implementation of BIM: *"the current communication system is not integrated across different project parties. For example, the architects design the project without full integration with the structural engineers*." This matches the findings of Choi (2010), Lee et al. (2007, 2009) and SmartMarket Report (2012), cited in Lee et al. (2013), that the lack of effective collaboration between project stakeholders is an obstacle to the implementation of BIM. At the same time, the factor analysis test gives current weaknesses in communication a high load, meaning that it is the main barrier within the communication group. However, the descriptive results showed it to be the least important barrier in this category, with a Severity Index of 65.39%. The difference between these two figures means that weaknesses in communication between projects parties is more efficiently with other barriers in this group, but the low SI shows that it is not significant compared to other barriers. Overall, the adoption of BIM in the Jordanian construction industry could be delayed because of current weaknesses in communication.

The lack of a legal framework for BIM in Jordan emerges as the second barrier in the communication category. The load of this barrier is 0.763, which means that it is a significant barrier, and explains the weak and unclear nature of the relationship among different stakeholders and different disciplines within the same stakeholder group. To overcome this problem, Rizal (2011) suggests the establishment of a multidisciplinary project group for BIM which would provide effective support, with the creation of a new contractual relationship, as well as a change in the role of clients, architects, and contractors. The lack of a legal framework for BIM in Jordan has a Severity Index (SI) of 70.53%, which ranks it at an intermediate level in comparison to others barriers. In the interviews, many experts mentioned the lack of a legal framework and regulations in relation to BIM which cover the relationships and responsibilities of stakeholders. According to the expert A, *"we don't have a framework for legal or contractual issues for BIM in Jordan*." Similarly, respondent M felt that *"the current systems and regulations which the governments and the JEA can be considered as challenges facing the adoption BIM*". This lack of rules and regulations for managing and controlling the use of BIM in the Jordanian construction industry clearly has a negative impact. This conclusion is borne out by the findings of Aibinu and Venkatesh (2013) that the lack standard descriptions and coding systems in relation to BIM, the lack of information on the relevant processes and how to change those processes, and contractual/legal issues generally are obstacles to the adoption of BIM by QS in Australia. The lack of a legal framework, i.e. the weakness in the way BIM is regulated and the ambiguity surrounding the use of BIM, can thus be seen as a major barrier in the Jordanian construction industry.

Thirdly, in order to construct a new project, it is necessary to go through certain procedures to get approval from the particular regulatory bodies. The analysis found that the current approval system is impeding the adoption BIM, and the load of this factor is 0.730, which ranks it high among the barriers in the communication group, and makes it a significant barrier to the adoption of BIM. The Severity Index (SI) of the current approval system for new projects is 70.26%, which puts it in the mid-range of barriers overall. This shows that the approval process for new projects could hinder the adoption of BIM in the Jordanian construction industry, where each regulatory body has its own processes and rules. These variations in processes and rules between organizations are delaying the adoption BIM in Jordan. In the interviews, the experts explained how the current approval impact on the adoption of BIM. According to respondent N, *"we currently need to get approvals from the*

JEA, the Ministry of Public Works and Housing and other government bodies, but these organizations are not able to implement BIM, and do not have staff who have the skills and training to use BIM, so the current approval procedures are hindering the adoption of BIM." In conclusion, it is clear that the current approval system for new projects in the Jordanian construction sector has great weaknesses. The regulatory bodies and organizations are themselves not implementing BIM, and each of them has its own procedures for approving projects. This multiplicity of procedures and lack of understanding is a significant obstacle which prevents the adoption of BIM in the Jordanian construction industry.

The last barrier related to communication factors is traditional work processes. The adoption of BIM requires new and special processes and procedures. According to Arayici et al. (2009) implementing BIM in the construction industry will have a substantial effect on traditional roles and work processes, and this is not easy for those who are uncomfortable with change. A firm which implements BIM will have to address issues of how workflows should be redesigned, how staff is assigned and how to distribute responsibilities. It is clear that the adoption of BIM requires construction firms to change their traditional work process to make them more collaborative and integrative in order to implement BIM effectively. In the Jordanian context, the load of traditional work processes is 0.572, which is the lowest load of the barriers in this category, which means this factor does not fully explain the communication barrier overall. However, the descriptive analysis gave it a Severity Index (SI) of 76.58%, which is the highest in this category. The contrast between these figures does not invalidate the conclusion that traditional work processes are a barrier to the adoption of BIM in Jordan. This is supported by evidence from the interviews, which confirms that traditional process is responsible for hindering the adoption BIM in Jordan. According to respondent C, *"Most firms are using traditional processes in their projects, so there is still a reluctance to upgrade to the level of BIM."* Respondent A further explained that *"current practices and procedures are hindering the adoption BIM. The contractors follow certain routines in the construction process and management, and they don't want to change. In the same way, the consultants follow traditional processes in design and the way they supervise projects, and they don't want to use BIM. So both contractors and consultants find excuses for not going for BIM."* It can thus clearly be concluded that the traditional work processes which are followed in the Jordanian construction industry are an obstruction to the adoption of BIM, as all the project parties are comfortable with what they are currently doing and do not want to change it. This view is similar to Oakley's (2008) conclusion that the adoption of BIM in the UK is slow because of the dependence on traditional 2D CAD by many companies, and the fact that they are happy with this. The current research indicates that most Jordanian construction firms are happy with their current practices and have no plans to change to new processes, while implementing BIM requires a massive to the traditional processes followed in the construction industry. Traditional work processes are obstructing the adoption of BIM in the Jordanian construction industry, and are an intermediate barrier overall.

Correlation analysis was used to determine the relationships between the current weaknesses in communication between stakeholders, the approval system, the lack of a legal framework for BIM and traditional work processes. It was found that the weaknesses in communication has significant positive correlations with the lack a legal framework for BIM issues and the approval system for new projects, which are $.538^{**}$ and $.639^{**}$ respectively, which means that if the weaknesses in communication were reduced, both the lack of a legal framework and the approval system would be less of a barrier. Traditional work processes also have a significant positive correlation with the current communication system ($.295^{**}$), and the lack of a legal framework BIM's has a significant positive correlation with the current approval system ($.501^{**}$), which explains how the lack of rules and regulations regarding BIM is affected by the approval process for new projects in Jordan. This makes it clear that the differences in the approval systems for new projects combine with the lack of a legal framework to prevent the adoption of BIM in Jordan. For example, some organizations might be using BIM while others are not, so to adapt to this situation all organizations push not to use BIM. This relationship also indicates that the lack of a regulatory framework amplifies the weakness of the approval system, which constitutes an even greater obstacle to the adoption of BIM. At the same time, the lack of a legal framework has a significant positive correlation with traditional work processes of $.287^{**}$, and there is also a significant correlation between the approval system and traditional work processes ($.279^{**}$), which means that the traditional work processes in the Jordanian construction industry could make the approval system more complex and a greater obstacle to the adoption of BIM.

To close, this discussion shows what may seem to be discrepancies in the ranking of the barriers in the communication category. Weaknesses in the current communication system between project parties has the highest load according to factor analysis, meaning that it is highly representative of this category, yet it has the lowest Severity Index. On other hand the traditional work processes have the highest Severity Index, but the lowest load of this group of barriers. The other barriers, i.e. the lack of a legal framework for BIM and the current approval system, are somewhere between these two. This diversity in any way reduce the importance of these barriers, but shows how much they can hinder the adoption of BIM in the Jordanian construction industry individually or as group. For example, the current weakness in communication has a strong influence in delaying the adoption of BIM when it is seen as part of the group, but less impact individually. In general, the experts who were interviewed considered all these barriers to be significant for the adoption of BIM in the Jordanian construction industry. Similarly, the load of each barrier is more than 0.5 and the SI is at least 65.39% in each case, and that supports the conclusion that they are all of effective barriers to the adoption of BIM in the Jordanian construction sector. Moreover, regardless of the ordering of these barriers, correlation analysis shows that there are significant correlations between them, meaning that if one of these barriers is significant, the others will be affected in a way which makes them a greater obstacle to the adoption of BIM in Jordan.

6.4.4 Project procurement

Methods of procurement have recently received considerable attention from academics as well as professionals in the construction industry due to the importance of this topic (Ruparathna and Hewage, 2013). In the context of Jordan, the research found that project procurement is the fourth latent factor related to the adoption of BIM. Both the low budget for new projects and the high level of competition in the construction industry are barriers within this category.

Firstly, the use of BIM in a construction project has to do with the project's size and costs. The budget for a construction project may not allow the use of BIM. The analysis found that the Severity Index (SI) for low budget for new projects is 66.32% and the factor analysis load is 0.816, which implies that it could obstruct the adoption of BIM in Jordan. The high load indicates how well the budget factor can explain and represent the category as a whole (project procurement). In the interviews, respondent Q reported that *"the fact that project tendering prices are so low nowadays is considered to be another reason why firms are not using BIM, because the revenue will not cover the costs of BIM, or even part of the costs."*. This echoes the conclusion of Franco et al. (2015) that the size of project affecting the use of

BIM as a way of facilitating collaboration and coordination between the structural, mechanical, plumbing and electrical trades. For example, Paine and Marasini (2013) found that the decision whether to use BIM or not depends on many factors including project costs and the project schedule and delivery method. The budget for new projects in Jordan is thus not a major barrier to the adoption of BIM, but could hinder the adoption of BIM if there is not enough to invest in the implementation of BIM.

Secondly, competition in the construction industry could affect the adoption of BIM either positively or negatively. According to (Chwelos et al., 2001 and Liu et al., 2010), external factors affect the adoption new technology, which that indicates that competitors, collaborators or other parties in the industry segment may also have an influence. Competition has a load of 0.775, which means it is highly representative of this group (project procurement). The Severity Index is 62.24%, which is relatively low in comparison to other barriers. The low SI explains why there were discrepancies in the responses in the interviews – some respondents felt that competition is a positive factor in relation to the adoption of BIM, while others did not. The first group felt that the impact of competition is to put downward pressure on bidding offers, meaning that there is no budget for BIM, while the second group is of the opinion that competition improves awareness of BIM as something which can improve work quality and hence the firm's reputation. In interviews, respondent A said *"if I am a developer and want to invest millions in a project, I will go for companies which are using BIM because it will help me to control the project cost and update it frequently, especially if I am depending on a mortgage."* The reputation of construction firms will improve if they use BIM for their projects, and this will push other firms to use BIM. According to respondent F, "*implementing BIM will enhance the quality of the firm, and that will be reflected by an increase in their profits."* However, it was the negative effect which was shown in the research, i.e. that competition in the Jordanian construction sector is hindering the adoption of BIM. This is in keeping with Labib's (2016) conclusion that the traditional contract is the most common method of project procurement in the Jordanian construction industry, where 60% of contracts are design – bid - build. This traditional type of bidding increases competition between constructions firms because the contract is awarded to the firm which offers the lowest price. Overall, the competition between Jordanian construction firms nowadays can be considered a barrier to the adoption of BIM, but it is not a major barrier. The research shows that there has not been any successful implementation of

BIM in Jordan, and the competition is therefore between firms that do not use BIM. All of this supports the conclusion that competition is hindering the adoption of BIM in the Jordanian construction industry. This is further confirmed by the correlation analysis, which shows a significant correlation (0.515^{**}) between the low budget for new projects and the level of competition in the industry, which means that if the budget for new projects is low, competition between construction firms will be high. High competition minimizes the probability of implementing BIM in Jordan.

To summarize, briefly, the project procurement category in the Jordanian construction industry includes two barriers, the low budget for new projects and high competition between construction firms. The current situation in Jordan is that the budget of new projects together with the high competition obstructs the use of BIM. However, the Severity Index (SI) of both these barriers is rather low in comparison to other barriers, and less than 50% of the respondents identified them as barriers. Taken together, this evidence indicates that the low budget for new projects and competition between constructions firms are weak barriers in the Jordanian construction sector.

6.5 Reducing the cost of change orders by utilizing BIM

The analysis of the data from the interviews and questionnaire indicated that utilizing BIM in the Jordanian private construction sector will minimize the cost of change orders by reducing the causes of change orders. The research identified nine causes of change orders in the Jordanian construction industry. It also indicated that there are thirteen significant barriers to the adoption of BIM in Jordan, as well determining the level of awareness of BIM in the Jordanian construction sector. Correlation analysis was used to investigate the relationships between the causes of change orders, the level of awareness of BIM and barriers to the adoption of BIM in Jordan. Table 5.11 shows the correlations between the sum of these factors based on respondents' answers.

First of all, the results show a significant correlation between the causes of change orders in the Jordanian construction sector and barriers to the adoption of BIM ($r = .512^{**}$, $\rho < 0.01$).

This means that as the number of change orders increases in the construction industry, the adoption of BIM becomes more challenging. The causes of change orders, i.e. engineering factors, client factors and the circumstances of the project, are supporting and increase hindering of the adoption of BIM in Jordan. This indicates that there is clearly and indirect but significant relationship between the benefits of adopting BIM and change orders in the Jordanian construction sector. The hidden relationship between the benefits of BIM and change orders suggests that the adoption of BIM will reduce change orders in the Jordanian construction industry, as well as minimizing their impact. This supports the findings of Conover et al. (2009), that using BIM decreases the need for change neither in design nor in construction phases because BIM facilitates effective collaboration between the project parties at an early stage of the project life cycle. It is also confirmed by the interviews, in which all the experts said they believed that the adoption of BIM will reduce the cost of change orders in Jordan.

The research found that changes initiated by the client are the major cause of change orders in the Jordanian construction industry, so implementing BIM will minimize this significant factor. Clients will have a clear and comprehensive idea about the project in terms of its design, budget and cash flow, among other things, so the probability of them requiring changes will be reduced. What is more, BIM improves communication between the project parties, minimizing errors, mistakes and changes which arise from weaknesses in communication. It also allows different options to be compared before decisions are made, thus minimizing one cause of inappropriate decisions. Gailo et al. (2013) also concluded that one benefit of BIM for projects is to improve collaboration in the working environment and help clients to develop a clear understanding of the project’s nature, needs, and scope. Lack of communication ranked as the fourth main cause of change orders in construction projects, so implementing BIM will reduce the number of change orders that arise from this. A good example is the study by Autodesk (2009), which found that the Gilbane building company was able to identify and resolve thousands of design clashes before the start of construction, and reduce the number of RFIs and change orders by up to 70 %. The adoption BIM in the Jordanian construction industry will therefore minimize the number of change orders related to the first and fourth causes of change orders, namely changes initiated by the client and weaknesses in communication between project parties.

Design errors and inconsistencies between contract documents are also significant causes of change orders in the Jordanian construction sector which increase the costs and duration of projects. The interviews indicated that BIM is particularly efficient in reducing design errors, as well as improving clash detection. These benefits of BIM will be reflected in reducing the number of change orders which arise from design errors and inconsistencies in contract documents, as well as their impact.

Incomplete designs and estimation errors are the fifth and sixth main causes of change orders in the Jordanian construction industry. Like design errors and inconsistencies between contract documents, these will be significantly reduced by the use of BIM. The benefits of BIM include minimizing errors in estimation as well as identifying incomplete designs before construction work starts. It can thus be clearly concluded the adoption of BIM in Jordan will effectively minimize change orders arising from engineering causes such as design errors and incomplete designs, estimation errors and inconsistencies between contract documents.

The third category of causes of change orders in the Jordanian construction industry the circumstances of the project. This is not a major problem in Jordan, but BIM could nevertheless minimize its impact on construction projects by updating all documents to minimize clashes and reduce misinformation and so on. This is supported by Autodesk (2011), which concluded that implementing BIM will eliminate problems related to traditional approaches through the use of an intelligent model that enables a project to be constructed faster, economically, and with less environment impact. The use of BIM in the Jordanian construction industry will be more efficient for controlling and eliminating changes arising from the circumstances of a project circumstances by providing a basis for managing the project more effectively and economically. Finally, it can be concluded that the relationship between the causes of change orders and the benefits of BIM mean that using BIM in the Jordanian construction industry will help to control and reduce the causes of change orders and minimize their costs.

The research identified a significant inverse correlation between awareness of BIM in Jordan and barriers of adoption BIM ($r = -.296^{**}$, $\rho < 0.01$). This indicates that as the awareness of BIM on an individual level and across the construction sector decreases, the barriers to the adoption of BIM will become more consolidated. The research found a significant weakness in the awareness and knowledge of BIM both in individuals and in the construction industry as a whole, and that this cannot be a driving factor for the adoption of BIM in the Jordanian construction sector. Only 2% of the 155 questionnaire respondents participants and three of the 17 experts interviewed have a good understanding of BIM. It was also found that there are many barriers to the adoption of BIM in the Jordanian construction industry and that there are currently no projects which are using BIM nowadays which could serve as a guide for the adoption of BIM in Jordan. These findings are similar to those of Building Smart (2011), which indicated that in a survey conducted by Smart Market Report Jordan had the lowest number of respondents in middle east countries, with only 7% of total respondents taking part in the survey. They also reinforce Al Awad's (2015) conclusion that lack of awareness is one of the main barriers to the adoption of BIM in small and medium enterprises in Jordan, and that there is zero implementation of BIM. Thus it can be clearly concluded that as the lack of awareness of BIM increases, the extent to which BIM is adopted in the construction industry will decline. In this context, Chewlos et al. (2001) found that private clients are not mandating the use of BIM in their projects as a result of their low level of awareness of the applications and benefits of BIM. This also explains the fact that research findings attribute the absence of any project in the Jordanian private construction industry which has used BIM to two of the main barriers to the adoption of BIM, namely the lack of awareness of BIM and the lack interest and demand in relation to BIM. It also explains why there is project which has used BIM recently in Jordan which could serve as a guide for the adoption BIM. Finally, it should be pointed out that the non-existence of such projects results in a lack of understanding of the technical requirements, which also works as barrier to adoption of BIM. Gu and London (2010) conclude that the lack of experience in using BIM is due to a limited understanding of industry needs and technical requirements and is a major factor which hinders the adoption BIM in the Australian construction industry.

In conclusion, the research has found great weaknesses in the understanding and awareness of BIM in the Jordanian construction industry, and identified many significant obstructions to the adoption of BIM. This has also clarified the inverse relationship between the awareness of BIM and barriers to the adoption of BIM in the Jordanian construction industry, which means that as the level of awareness of BIM decreases, the barriers to the adoption of BIM will be consolidated.

6.6 Drivers of the adoption of BIM in Jordan

The adoption of BIM in the Jordanian construction industry will not run smoothly, and influential bodies in the construction industry drivers should take the lead in this regard. The research results identified eight drivers which could lead the adoption of BIM in the Jordanian construction industry: the Jordanian Ministry of Public Works and Housing (JMPWH), the Jordanian Engineering Association (JEA), the Jordanian Construction Contractors' Association (JCCA), clients, engineering firms, contractors, universities and construction management firms.

When asked about who should drive the adoption of BIM in the Jordanian construction industry, the majority of the respondents mentioned the Jordanian Ministry of Public Works and Housing (JMPWH) as the body which should be the main driver of the adoption of BIM in the Jordanian construction industry, and this was the choice of 147 of the 155 participants. This is a clear indication of the status of the JMPWH in the construction industry, as well as the significant influence it could have for the adoption of BIM in Jordan. It is thus unlikely that the adoption of BIM will not succeed without an effective contribution by the JMPWH. The analysis of the data suggests that the JMPWH could further contribute to the adoption of BIM by increasing levels of awareness of BIM and issuing regulations which would encourage the construction sector to adopt BIM. In the context of Singapore, Teo et al. (2015) found the take-up of BIM was facilitated a framework set up by the Singapore government. A number of studies of the Malaysian construction sector have come to similar conclusions to this research, where according to Jaafar et al., 2007, Zakaria et al., 2013 And Zahrizan et al., 2014, the absence of governmental support is an obstacle to the adoption of BIM, while encouragement and enforcement at government level is the most important factor. Without the influence of the government, implementing BIM will be slow, and it is clear how much efforts by the government could accelerate the adoption of BIM in the construction industry. In the Jordanian context, the research findings indicate that without an effective contribution from the JMPWH, the adoption of BIM will be extremely slowly, and there is a significant probability that it will fail. This conclusion is in line with Al Awad's (2015) findings that the Jordanian government could encourage influence the adoption of BIM by small and medium enterprises.

The research also identified the Jordanian Engineering Association (JEA) as the second most important driver of the adoption of BIM in Jordan, and this was indicated by 140 respondents in the questionnaires. Like the JMPWH, the JEA undertakes initiatives to improve the level of awareness of BIM in the construction sector and provides training courses to upgrade staff skills for construction firms. It can also be suggested that there should be collaboration between the JMPWH and the JEA to increase the chances of success. This idea was supported in the interviews, where many experts suggested that the adoption of BIM should start with the JMPWH and the JEA. Participant (P) felt that *”the Jordanian Ministry of Public Works and Housing and the JEA must adopt BIM in their own areas of expertise and train their staff to use BIM first, and then ask construction firms to implement it."* Other experts also recommended cooperation between the JMPWH and the JEA in promoting the adoption of BIM. According to participant K, *"the Jordanian Ministry of Public Works and Housing must collaborate with the JEA as a team to support the adoption of BIM.”* The support of the JMPWH and the JEA is thus regarded as essential for the adoption of BIM in the Jordanian construction industry. Cooperation between these bodies is necessary to for encourage the adoption of BIM, which means that the results will be disappointing if only one of them takes responsibility for the adoption process or if they do not cooperate with each other effectively. This conclusion is similar to Al Awad’s (2015) findings that the Jordanian government had the greatest influence of the adoption of BIM by small and medium enterprises in Jordan, followed by Jordanian construction associations. On this context, Jordanian construction associations are the Jordanian Engineering Association (JEA) and the Jordanian Construction Contractors’ Association (JCCA), each of which focuses is on a specific group in the Jordanian construction industry. The current research indicates that the JEA is the second driver of the adoption of BIM in Jordan. However, Al Awad (2015) did not find that communication and collaboration between the government and the JEA was an essential factor for the successful adoption of BIM by small and medium enterprises in Jordan, while the current does suggest strongly that collaboration and communication between these two influential bodies is a major factor that could lead to the successful adoption of BIM across the whole of the Jordanian construction industry.

The third and fourth drivers of BIM in Jordan are the Jordanian Construction Contractors’ Association (JCCA) and clients respectively. The JCCA was identified as a driver by 126 respondents, and clients by 123 respondents. These different levels of support between these two drivers are not significant, suggesting that each of them has the same importance for the adoption of BIM in Jordan. In the interviews, the experts tended to highlight the role of the JEA rather than the JCCA for the adoption of BIM. Participant A mentioned *"improving the participation of public associations such as the JEA and the JCCA in promoting the adoption of BIM, and especially JEA."* However, this emphasis reflects the current focuses of the two associations in the construction sector. The JEA concentrates on improving engineers' skills in different areas, as well as working with the Jordanian government on giving approvals for new projects, while the focus of the JCCA is on contractors' work during the construction phase, managing construction contractor firms in Jordan, and providing approvals for new projects.

The research also found highlighted the importance of clients providing support for adoption the adoption of BIM in Jordan. This could take the form of including BIM in contract documents, with a requirement that other project parties should use it. According to participant I, *"clients or their representatives (construction managers) could play a part in encouraging the adoption of BIM by putting it as requirement in the project contract,"* and participant J added that "*owners and developers are responsible for implementing BIM.*" Such findings indicate the important role which clients might play in Jordan for the adoption of BIM, by asking for it to be implemented in their projects. What is more, this conclusion is the same to those of Rodgers et al. (2015) and Elmualim and Gilder (2014), who found that pressure from client is one of the main factors encouraging the use of BIM in Iran. It can thus obviously be concluded that in the Jordanian construction industry, clients are an essential driver in that they can call for the use of BIM in their projects. Pressure from the client arises from the benefits they stand to gain by implementing BIM in construction projects in terms of reducing delays and cost overruns. This is supported by to Al Awad (2015), who ranked clients as the third driver of the adoption of BIM by small and medium enterprises in Jordan by 13% of respondents.

The research identified engineering firms (designers and consultants) as the fifth driver of the adoption of BIM in the Jordanian construction sector, and contractors as the sixth driver. In the questionnaires, 105 respondents indicated that the use of BIM by engineering firms would improve the adoption of BIM overall in the Jordanian construction sector, and 104 respondents felt that the same was true of contractors. This suggests that these two drivers have the same role in the adoption of BIM, as there was only a difference of one response. The respondents' views parallel those expressed in the interviews, in which some experts said that the adoption of BIM in Jordan should start in large construction firms (contractor or engineering). According to participant A, *"large construction firms in the Jordanian construction industry (contractor or engineering [consultant]) should be aware of BIM and participate by adopting it."* This shows that contactors and engineering firms could be effective drivers of the adoption of BIM in Jordan, even though they were ranked at the bottom of the list of drivers. The adoption of BIM by engineering firms or contractors comes about as a result of competition with other firms. This is clarified by the findings of Gilkinson et al. (2015) that construction firms adopted BIM to remain competitive in the market. Eadie et al. (2013) also found that the most important drivers of the adoption of BIM in government, competitors and clients. Such research indicates that competition is a significant factor which forces engineering firms and contractors to use BIM in order to improve their reputation, the quality of their work, and to gain other benefits. Yet in Jordan the research found that the competition factor does not drive the adoption of BIM, but is categorized as a barrier. Many firms try to reduce the cost of new projects, and for this reason do not use BIM, which is considered relatively costly. This conclusion is similar to those of Al-Awad (2015), in whose survey only 4% of participants thought that large construction firms should drive the adoption of BIM by small and medium enterprises in Jordan. Thus engineering firms and contractor are drivers of the adoption of BIM in the Jordanian construction industry as they can play an effective part in promoting the adoption of BIM in Jordan. However, their role is a minor one, and they were ranked as the fifth and sixth drivers respectively, indicating the low level of influence they have.

The education system is a very important sector in Jordan, and supplies the construction sector with competent and skilled staff. In the questionnaires, 95 respondents believed that universities in Jordan should play a significant part in driving the adoption of BIM. Universities support the adoption of BIM by providing special programmes that focus on BIM technology. This echoes the conclusion of Zahrizan et al. (2014), who suggest that local universities could play a major role in promoting BIM by providing courses related to BIM in Malaysia. Such courses will provide students with a good foundation of knowledge, practical skills and ideas in relation to BIM at an early stage. It is therefore obvious how much universities can support the construction sector and encourage it to use BIM in Jordan. However, universities currently have very little involvement in BIM in Jordan, but it is felt that they could do more. According to participant M, *"universities are not supporting the use of BIM, and should do more to promote its use."* The research suggests that to support the adoption of BIM, universities must include BIM in their programs and provide training courses that supply the construction sector with skilled and trained workers who can use BIM effectively. This conclusion is supported by Teo et al. (2015), whose findings suggest that there should be cooperation between academic institutions and industry to address the shortage of BIM practitioners by developing syllabuses that are in line with developments in industry procedures and practices. All this highlights the role of universities in alleviating the shortage of skills and trained staff who are able to use BIM in the construction sector. The participation of universities would accelerate the adoption of BIM and overcome major barriers such as the shortage of skills and lack of awareness. However, universities were ranked as the seventh driver of the adoption of BIM in Jordan, which implies they contribute little to the adoption of BIM. Indeed, Al-Awad (2015) did not count universities as drivers of BIM in small and medium enterprises in Jordan. Hence, it is clear that universities are currently playing a minimal role in promoting the use of BIM in the Jordanian construction industry, but are important in that they could provide the knowledge and awareness that will drive the processes of adoption.

Finally, the research found that construction management firms are the last driver of the adoption of BIM in Jordan. These firms are not significant drivers of the adoption of BIM in Jordan, and were mentioned by only one participant in the interviews. Participant A suggested that *"construction managements firms could advise clients to use BIM in their construction projects, and include this in the contract documents."* Similarly, only 22 of those who completed the questionnaire chose construction management firms as one of the drivers of BIM in Jordan, and Al Awad (2015) found that construction management firms are not seen as a driver of the adoption of BIM in small and medium enterprises in Jordan, which supports the conclusion of the current research that these firms cannot be a significant driver of the adoption of BIM in the Jordanian construction industry. The only role they might play as a minimum is to advise clients of the benefits BIM can offer in terms of saving time and cost, and of quality.

6.7 Conclusion

This chapter has provided a critical discussion of the findings developed from the data collected in the interviews and questionnaires and linked them to the literature on change orders and BIM in the construction industry within the framework of the aim and objectives of this research. The discussion chapter identifies the major causes of change orders in the Jordanian construction industry, as well as current levels of awareness of BIM, barriers to the adoption of BIM, the benefits of BIM in terms of reducing the cost of change orders in the Jordanian construction industry, and drivers of the adoption of BIM in Jordan. Overall, the chapter suggests answers to the research problem, and effectively fulfills the aim and objectives of the research.

The analysis concluded that change orders are common in Jordanian construction projects, and have a negative impact in the form of cost overruns and delayed completion. The research investigated the main causes of change orders in the construction industry. These were categorized into three groups: engineering factors, client factors and the circumstances of the project. Each group contains a number of causes. Firstly, the engineering category contains four causes: design errors, estimation errors, inconsistencies between contract documents and incomplete design. It was found that design errors are a significant cause of change orders in the Jordanian construction industry, and were ranked second in the opinion of the experts, with a factor analysis load of 0.823 and a Severity Index of 91.23%. Design errors could occur for many reasons, including the use of unqualified staff. Inconsistencies between contract documents are the second main cause of change orders in the engineering category. In terms of the Severity Index (88.0%), this is the third main cause of change orders in the Jordanian construction industry, and the factor analysis load is significantly high (0.805). There are many forms of inconsistency between contract documents; for example, there could be inconsistencies between drawings and specifications, or between different drawings. The third main cause of change orders in this category is estimation errors. Although estimation errors have a quiet factor analysis load more than inconsistencies between contract documents, at 72.65% the Severity Index is much lower, and so inconsistencies must be seen as a more significant cause. Finally, incomplete design is the last main cause of change orders related to the engineering factor. Incomplete design is ranked as the fifth main cause of change orders, and its Severity Index (SI) is 75.61%. In addition, it has a high factor analysis load which is highly representative of this category (engineering) as a whole. Like inconsistencies between contract documents, incomplete designs rank more highly than estimation errors and have a higher Severity. What this means is clearly that there will be fewer change orders arising from estimation errors in Jordanian construction projects than those related to other causes in the engineering group. Finally, it was found that there is a significant correlation between all the causes in this group, which means a number of changes may happen consecutively.

The second category of change orders in the Jordanian construction industry is related to clients. The findings identified three causes related to clients, namely changes initiated by the client, a time lag between the design and construction phases, and lack of communication between the project parties. Changes initiated by the client are a significant cause of change orders in this category, with a factor analysis load of 0.869, which means that they are truly representative of the category as a whole. They are also ranked as a major cause of changes in construction projects because they have a Severity Index (SI) of 93.42%. This means that a large number of change orders occur because of changes in the client's requirements or needs, the client's lack of vision and awareness in relation to his project, changes in the scope of the project or the fact that the client's is experiencing financial problems.

A lack of communication between parties belongs in this category because the client is responsible for selecting other project parties, and they should be able to communicate and cooperate effectively with each other in efficient manner, as well as with the client. Lack of communication is the second main cause of changes orders related to client factors in Jordanian construction projects, and it is the fourth main cause of change orders overall. That is because the factor analysis load is 0.593, and the Severity Index (SI) is relatively high at 83.48%.

The final cause of change orders in the client factor category in the Jordanian construction industry is time lags between the design and construction phases. This period can be long or short, but in both cases it may lead to change orders. For example; if there is an extended time lag, there may be changes in the client's requirements and needs, and so he may ask for changes to be made. If it is short because of time pressure from the client, the design is likely to have errors and may not comply with local regulations. A time lag between the design and construction phases has a Severity Index (SI) of 70.19%, so it is not a major cause of change orders in construction projects, and most of the experts did not mention it as a cause of change orders in the interviews. The correlation analysis showed significant relationships between all the factors related to the client, meaning that if one of these factors is present, the others might also be found.

The third group of causes of change orders in the Jordanian construction industry is the circumstances of the project. The research identified two causes in this category, shortages of materials and different site conditions. The factor analysis load for both of these is relatively high, showing how fully representative they are of the category as a whole. However, change orders arising from circumstances of the project circumstances are not common, and they were ranked as the last causes of change orders in Jordan. The Severity Index (SI) for shortages of materials is less than 50%, and that of different site condition is 62.08%, which is not significant. Therefore it can clearly be concluded that change orders arising from shortages of materials or different site conditions are not common in construction projects in Jordan. However, if one of them is encountered, the other is also likely to be found because they are significantly correlated.

The research investigated the current level of awareness of BIM in the Jordanian construction industry, and it was found that it is significantly low: only 2% of the questionnaire respondents and three of the 17 experts interviewed have a very good knowledge of BIM. Moreover, the majority of people working in the Jordanian construction knowledge do not have a basic knowledge of BIM, and this constitutes a significant barrier to the adoption of BIM in Jordan. Additionally, the overall level of awareness of BIM in the Jordanian construction sector is insufficient for it to be adopted. The level of implementation of BIM in construction firms is currently zero, and for the most part Jordanian construction firms still use 2D CAD as the main software for design, with few firms using 3D CAD. At the same time, the research found that there are no projects in Jordan which have implemented BIM and could serve as a guide for the adoption of BIM. In general, the Jordanian construction industry is characterized by a significant lack of awareness of BIM, and this was confirmed by the fact that 86.7% of the respondents to the questionnaire believed that this lack of awareness of BIM is the main barrier to the adoption of BIM in Jordan. What is needed to improve the level of awareness of BIM and encourage its use in the Jordanian construction industry is a focus on the way it can control the costs of change orders in terms of the time needed for a project and its costs and quality, the provision of training sessions, and the support of government and regulatory organizations supports. Finally, the awareness of BIM on a personal and industry-wide level and the implementation of BIM in construction firms and construction projects are all significantly correlated, which means that they all affect each other.

The research also classified the barriers to the adoption of BIM in the Jordanian construction industry into four main groups: financial, communication, human and project procurement. Each of these groups is made up of barriers which are significantly correlated with each other. These are training costs, and the costs of software and hardware for BIM. Together, these are the main barrier to the adoption of BIM in the Jordanian construction industry, and each has a relatively high factor analysis load. In addition, the Severity Index (SI) of each of the three barriers is significantly high, which ranks them among the main five barriers to the adoption of BIM in Jordan. Focusing on financial factors is thus essential as a first step in promoting the adoption of BIM in the Jordanian construction industry.

The human factor is the second main barrier to the adoption of BIM in Jordan. This includes a shortage of skilled and trained staff, dependency on staff who are not able to use BIM, a lack of interest and demand to, and a lack of awareness. The factor analysis load for all these barriers is over 0.5, which indicates that they are significant barriers in the Jordanian construction industry and each is highly representative of the human factor group as a whole. The questionnaire results supported this conclusion, and the Severity Index (SI) in each case is over 70%, putting them in the first 10 barriers to the adoption of BIM in Jordan. The barriers in this group are significantly correlated, which means that they mutually reinforce each other. Lack of interest and demand results in the employment of staff for work which is not related to BIM, so that they will develop only the skills they need for that work, which in turn means that there will still be no staff who have the knowledge and ability to implement BIM. Similarly, construction firms do not organize training courses for their staff for a variety of reasons, and so they continue to depend on skilled staff only for other types of work. Finally, the human factor is affected by levels of awareness of BIM. A poor understanding of the benefits can offer in the construction industry drives project parties to seek other options instead of BIM, which again minimizes the number of staff who are able to use BIM. The lack of awareness also means that construction firms depend on the available staff, and avoid running training sessions.

Communication is the third group of factors which prevent the adoption of BIM in the Jordanian construction industry. Weaknesses in communication between project parties, the lack of a legal framework for BIM, the approval system for new projects and traditional work processes all fall within this group. The relationships between these barriers are significant, which means that they work with each other as one body against the adoption of BIM in Jordan. The factor analysis shows a high load of more than 0.7 for all these barriers expect for traditional work processes, for which the load is 0.572. However, the Severity Index (SI) ranked only traditional work processes among the ten main barriers to the adoption of BIM in Jordan. Therefore, it can be concluded that the factors in the communication group are a real barrier to the adoption of BIM in Jordan, but their effect is moderate, and they come after financial and human factors, which are more important.

Finally, project procurement is the last category of factors which prevent the adoption of BIM in the Jordanian construction industry. The traditional form of contract, design – bid - build, is common in the construction sector as a result of the competition between construction firms to get projects. Projects are awarded to the bid with the lowest price. That is why the low budget for new projects and high competition between construction firms have been classified as barriers in the project procurement category. The Severity Index (SI) for both these barriers is below 70%, which ranks them as 13th and 16th, meaning that these are less prominent than other barriers. However, the factor analysis load is relatively high (more than 0.75) for both barriers, so they have an important role in the project procurement category.

There could be different views of the competition barrier. It could be seen as having a positive effect for the construction industry, in that it might push construction firms to try to improve their reputation and the quality of their work. But it could also work in the other way, by pushing firms to submit the lowest possible bid in order to secure the contract, which means that there is no budget for the implementation of BIM. This research shows that competition does push construction firms to offer the lowest price for projects, and that this is therefore a barrier to the implementation of BIM. The correlation of these two barriers also supports this view, and can be expressed as follows: 'in Jordan, as the budget for projects decreases, competition between construction firms increases, which ultimately obstructs the adoption of BIM.'

The factor analysis test terminate a further three barriers: the duration of training, reluctance on the part of senior management, and the length of time required for the preparation of infrastructure for BIM. These barriers were not classified under any group, which means that they do not work with other barriers. However, duration of training was classified the second main barrier, with a Severity Index of 93.03%. This shows the important of the time required for training, as an individual barrier, in obstructing the adoption of BIM in the Jordanian construction industry, where most construction firms avoid offering training of an appropriate duration. Moreover, this barrier could be seen in terms of the cost of training rather than the time it takes, and some organizations may consider that the time required for training results in a reduction of productivity and imposes costs on the organization, so the duration of training could be categorized under training costs. Reluctance on the part of senior management is at an intermediate level in the barriers to the adoption of BIM in the Jordanian construction industry on the basis of its Severity Index. Reluctance on the part of senior management is thus not an important barrier to the adoption of BIM, and it is clear that presenting BIM to decision makers will encourage the use of BIM in the Jordanian construction industry. Finally, the Severity Index ranked the length of time required for the preparation of infrastructure for BIM infrastructure as the last barrier to the adoption of BIM, and was also apparent in the interviews, where one expert mentioned this barrier. The time it takes to prepare the infrastructure for BIM could therefore obstruct the adoption of BIM in the Jordanian construction industry, but it is not an important barrier.

The factor analysis indicated a significant relationship between the causes of change orders in the Jordanian construction industry and barriers to the adoption of BIM. This means that as the causes of change orders increase, it becomes more difficult to implement BIM. The findings suggest that this is an indirect relationship. That is, the adoption of BIM will minimize change orders in Jordanian construction projects because it will help to improve the client's awareness and understanding of his project, and so changes will be reduced to a minimum. The use of BIM also minimizes clashes and inconsistencies between contract documents, which is also considered a significant cause of change orders in Jordan, and improve communication and collaboration between the project parties, which is categorized as the fourth cause of change orders. Furthermore, it helps to improve the design quality and thus reduce design errors, incomplete designs and estimation errors, which will reduce change orders in the engineering category. The third main group of causes of change orders causes is the circumstances of the project, and BIM can minimise the changes that may arise in this category in that it is an intelligent model that updates and manages information immediately and economically. The research found a significant inverse relationship between the level of awareness of BIM in the Jordanian construction industry and the barriers to the adoption of BIM. This awareness level is low and not sufficient to support the adoption of BIM, and there are currently no projects which have used BIM that could serve as a model for adoption. At the same time, the barriers to the adoption of BIM are formidable. This indicates that as the level of awareness decreases, the barriers will be reinforced. It is therefore clear that the adoption of BIM will have a positive influence on reducing the cost of change orders in the Jordanian construction industry.

Finally, the research identified eight drivers of the adoption of BIM in the Jordanian construction industry. These drivers are the Jordanian Ministry of Public Works and Housing (JMPWH), the Jordanian Engineering Association (JEA), the Jordanian Construction Contractors' Association (JCCA), clients, engineering firms (consultants), contractors, universities and construction management companies. Both the JMPWH and JEA are significant drivers in Jordan, and they could contribute by raising levels of awareness level of BIM in the construction sector, providing training courses and issuing regulation which would require the use of BIM. Cooperation between the JMPWH and JEA is essential for the successful adoption of BIM in Jordan, for without such collaboration, the adoption process could take a very long time. The Jordanian Construction Contractors' Association and clients are the third and fourth drivers. The research shows that the JEA is more influential than the JCCA in this context,. Clients are the fourth significant driver of the adoption of BIM in Jordan. It was found that the adoption process could be accelerated dramatically if clients make the use of BIM a requirement in contracts. However, clients' lack of awareness of the benefits of BIM benefits is currently an obstruction to the adoption of BIM in the Jordanian construction sector. Engineering firms and contractors are the fifth and sixth drivers which could lead the adoption of BIM. However, the research does not indicate that either of these groups could make a significant contribution in support of the adoption process, and both have a minor role. Although competition between construction firms could be a significant factor in support of the adoption of BIM, it has been shown that in Jordan the opposite is the case that is competition between construction firms, including engineering firms and contractors, obstructs the adoption of BIM, as they try to minimise the costs of new projects in order to get contracts.

The seventh driver of the adoption of BIM in the Jordanian construction industry is educational establishments. These are very important sector because they supply the Jordanian construction industry with skilled and trained workers. The importance of universities lies in the fact that they could help increase levels of awareness and knowledge of BIM, but the research concluded that Jordanian universities make a very low contribution in this area, and so they are ranked seventh among the drivers. In order to promote the adoption of BIM in Jordan, universities should collaborate with the construction industry to improve the level of awareness and knowledge of BIM, as well as supplying the construction sector with skilled and trained staff who can use BIM efficiently. Finally, the last driver of the adoption of BIM in Jordan is construction management firms. However; the research found that construction management firms are not a significant driver of the adoption of BIM as their contribution is only to advise to clients to use BIM in construction projects.

CHAPTRE SEVEN: VALIDATION

7.1 Introduction

The previous chapter presented a critical discussion of the literature and the data which was collected in relation to the significant causes of change orders in the Jordanian construction industry, as well as current levels of awareness and knowledge of BIM, barriers to the adoption of BIM, the effects of BIM on reducing the cost of change orders, and drivers for the adoption of BIM. The research employed mixed methods for gathering data, namely interviews with 17 experts and a questionnaire which was completed by 155 respondents. The research offers a critical explanation of the main causes of change orders in the Jordanian construction industry. It also identifies the current level of awareness and knowledge of BIM in the construction sector, which is relatively low, and identifies the factors that are hindering the adoption of BIM in Jordan. It was found that implementing BIM in the Jordanian construction industry will minimize the cost of change orders by reducing key causes of change orders.

It is essential to validate the findings on the relationship between the causes of change orders and BIM, as well as the factors that obstruct the adoption of BIM in the Jordanian construction industry. Several tools were used in this research, including the House of Quality and Interpretive Structural Modelling (ISM). The Analytic Hierarchy Process (AHP) is a method of selecting the best choice from a set of alternatives based on several criteria (Wang et al, 2003). According to Kubler et al (2016), AHP is one of the most widely applied Multiple Criteria Decision-Making (MADM) techniques, whose main strength lies in its impartial and logical grading system which reduces personal bias and allows dissimilar alternatives to be compared. Furthermore, Gutierrez-Bucheli et al (2016) argues that AHP makes it possible to involve principal project stakeholders in the process of decision-making. Decision-makers draw on their knowledge and experience to compare several alternatives based on simple indicators. On the basis of stakeholders' quantitative and qualitative opinions, the different criteria and sub-criteria within the hierarchy are arranged to enable alternatives to be compared and assessed. AHP is thus a suitable tool for comparing barriers to the adoption of BIM in the Jordanian construction industry and identifying those barriers which are significant. However, AHP does not identify the relationships between barriers which may be at the same level. It is also not effective in dealing with uncertainty when decision-makers choose a number on the fundamental scale of 1 to 9 (Lee, 2016). On the other hand, ISM is capable of identifying the relationships between criteria which have individual or group dependence on each other (Beikkhakhian et al, 2015). ISM is considered to be a better approach for dealing with the complexity of relationships involving many elements (Mathiyazhagan & Haq, 2013). ISM enables individuals and groups to develop a map of the multiple relationships between many elements involved in a complex situation (Ansari et al, 2013). It is therefore appropriate to use ISM rather than AHP to identify significant barriers and define the relationships between these barriers.

This chapter therefore uses House of Quality and Interpretive Structural Modelling (ISM) to validate these results and build a valid model of the barriers to the adoption of BIM. The chapter will first introduce House of Quality, which is the first stage of Quality Function Deployment (QFD). This clarifies the relationships between the features of BIM and the ways in which it minimizes the causes of change orders, and this is set against the background of current practices for minimizing change orders in the construction industry. The chapter then outlines the Interpretive Structural Modelling technique (ISM) as a valuable tool that will provide an explanation of the interactions among barriers to the adoption of BIM and their level of importance in the Jordanian construction industry in order to assess the current situation and gain a better understanding of these barriers. Then MICMAC analysis will be used to identify the nature and salience of the barriers to the adoption of BIM and categorize them as either independent barriers or dependent according to their driving and dependency power. Finally both of these tools are used as a validation method to scrutinize the research findings.

7.2 The focus group

It is very important to choose an appropriate method so that the findings will be validated effectively. This research chose the focus group method (see 3.4.1.1.2 above) to validate the research findings, using House of Quality and ISM. A focus group was formed by inviting seven experts from the construction industry. The experts represented different disciplines in the Jordanian construction sector and they haven't participated in any of the previous rounds of data collection: there were two contractors and two engineers, one academic and two clients. The experts were asked to describe the impact of BIM on change orders in Jordan by clarifying the relationships between the causes of change orders and the functions and features of BIM. In addition, they were asked to rank the barriers to the adoption of BIM in the Jordanian construction industry, and to explore the interaction between these barriers by creating an ISM model. A focus group is particularly useful when researching collective learning as it allows participants to interact in a stimulating atmosphere while a researcher elicits opinions, mental models and the attitudes of the interviewees (Pahl-Wostle and Hare, 2004).

The fundamental data produced by this technique were the transcripts of the group discussions and the moderator's reflections and notes. During the discussion, the benefits and barriers to the adoption of BIM were debated in depth. The experts supported their opinions with evidence from their long experience. Generally, the seven experts agreed that BIM has a massive influence on minimizing change orders and their costs by controlling and reducing the causes of change orders in construction projects. They also put the costs of software and training at the top of the major barriers to the adoption of BIM in Jordan, as well as ranking both the low budget for new projects and competition in the construction industry as the lowest barriers to the adoption of BIM. The time required for training was a controversial topic, as four of the experts saw it as a training cost, which should thus be in the category of financial rather than time barriers. However, the other three believed that the time required for staff to acquire the skills needed to use BIM is a separate barrier which obstructs the adoption of BIM in the Jordanian construction sector. In broad terms, the views put forward by the experts matched the research findings closely, and can be seen as a significant confirmation of the conclusions in relation to the major barriers to the adoption of BIM in the Jordanian construction industry and the influence of BIM on minimizing change orders and their costs in construction projects. The next section presents House of Quality and ISM in detail.

7.3 House of Quality (HOQ)

The first technique used to validate the research findings is House of Quality, which is the first stage of Quality Function Deployment (QFD). Quality Function Deployment (QFD) is considered one of the most powerful tools for enhancing customer satisfaction (Aghdam et al., 2015). QFD is powerful proactive decision-support method that uses a relationship-wise context and is based on a sequence of bi-dimensional mathematical matrices. The purpose is to rank indicators numerically so that they are useful for decision makers by presenting them graphically and making the database easy to understand (Maritan, 2015). It also translates subjective quality criteria into objective ones which can be qualified and measured (Reilly, 1999). The principal tasks in using QFD include determining the customer requirements (CRs), the design requirements (DRs), the relationship between the customer and design requirements, the correlations among the customer requirements and among the design requirements. This converts the difficult-to-understand customer requirements into measurable technical characteristics by cascading them through a series of relationship matrices (Gilbert III et al 2016).

House of Quality is the first phase of QFD, and most studies focus exclusively on the House of Quality phase (Chan and Wu, 2005). House of Quality is a QFD tool that employs a matrix to list implementation priorities by degree of importance, as well as to undertake quality conversion (Dror and Sukenik, 2011). House of Quality has been used in construction projects by many researchers; for example, Dikmen et al. (2005) used HOQ as a strategic decision making tool in the Turkish house-building sector to design marketing plans. Similarly, as Delgado-Hernandez et al. (2007) point out, there has recently been an increase in the construction projects that have used QFD. These draw on several advantages of QFD, and in this regard Maritan (2015) summarize the benefits of using QFD as follows:

1. QFD uses objective mathematical methods;
2. It finds correlations between non-homogeneous items such as customer requirements and product characteristics;
3. It helps decision-makers to take decisions that can be put into action, and to make any necessary compromises. Moreover, QFD provides a solid and complete pathway to follow based on clear indications;
4. It simplifies foggy and complex problems into smaller chunks which are structured in an orderly way and are thus much simpler to resolve.

House of Quality is thus the most appropriate tool for exploring the relationship between the causes of change orders and the use of BIM in Jordan, as it uses a matrix that relates customer requirements, which in this case means clients’ desire to minimize change orders by minimizing their causes, to the features and functions of BIM, and compares the results with current practices which are not based on BIM. This research will therefore use HOQ to clarify the impact of using BIM in the Jordanian construction industry on the causes of change orders, with the following aims:

1. To determine the impact of adopting BIM in the Jordanian construction industry on change orders, and to compare this with current practices for controlling change orders in construction projects;
2. To simplify the relationship between BIM and change orders in the construction industry;
3. To use the findings of HOQ for decisions relating to the use of BIM.

7.3.1 House of Quality methodology

The name 'House of Quality' derives from the fact that when presented in diagrammatic form, it has the shape of a house (see Figure 7.1). HOQ is a combination of sub-matrices, and is divided into six sections as follows:

- **Section I:** Customer needs and requirements
- **Section II:** Technical measures
- **Section III:** Planning matrix
- **Section IV:** Relationship matrix
- **Section V:** Correlation matrix
- **Section VI:** Weights, benchmarks and targets

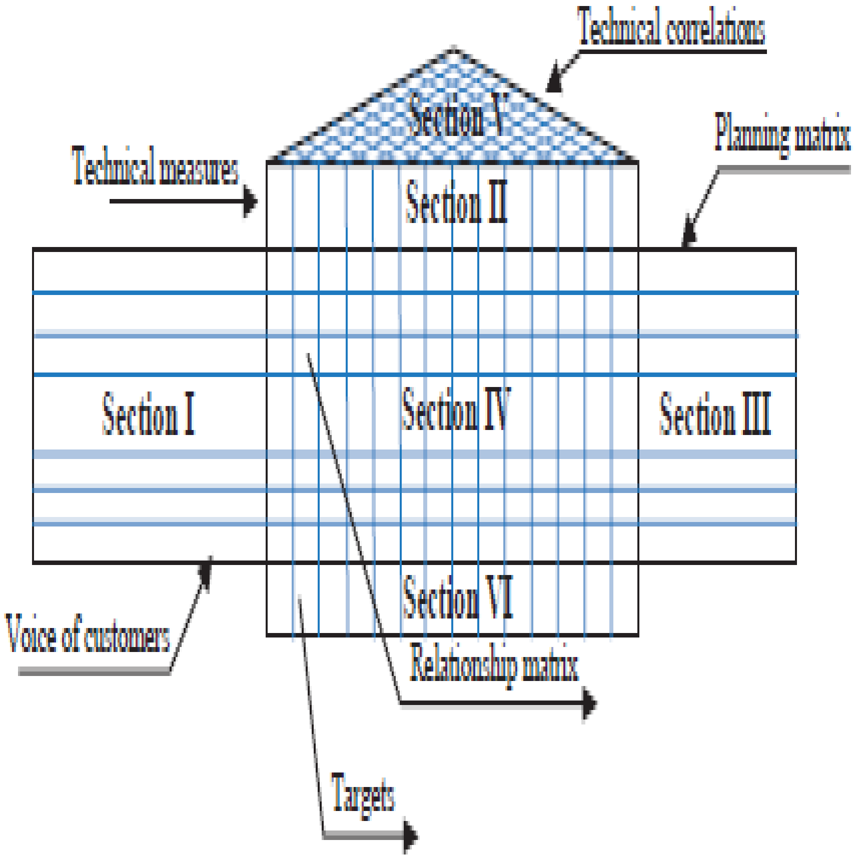


Figure 7.1: The basic House of Quality matrix (Hauser and Clausing, 1988, cited in Dikmen et al., 2005)

The House of Quality (HOQ) methodology involves a number of interconnected steps which lead to a final conclusion. To determine the relationship between the causes of change orders and BIM, the House of Quality method was applied step by step, following Dikmen et al. (2005). The first step was to form a focus group by inviting seven professionals from the Jordanian construction sector to define customer requirements, technical requirements and fill in the matrices. Customer requirements (‘Voice of customers’) denotes customers' needs and what they want from a product or service. The experts agreed that clients in construction projects feel it is important to reduce the number of change orders, so minimizing the causes of change orders will meet customer needs and reduce the cost of change orders. The focus group thus identified the causes of change orders that emerged in the interviews and questionnaires as a key to meeting customer requirements. Table 7.1 shows these causes of change orders in relation to customer requirements;

Table 7.1: Client requirements (Section I of House of Quality)

Causes of change Orders	Client (Customer) Requirements
Changes initiated by clients	Minimize client's lack of awareness/ knowledge
	Minimize client's financial problems
	Minimize changes in senior management
	Minimize influence of attitudes on decisions
	Minimize changes in client's requirements
	Minimize client's lack of vision
Design errors and incomplete design	Minimize failure to follow regulations and requirements
	Minimize time limits for design and construction
	Minimize time pressure from client
	Minimize use of unqualified staff
Inconsistencies between contract documents	Minimize inconsistencies between contract documents
Lack of communication between project parties	Minimize lack of communication between project parties
Estimation errors	Minimize estimation errors
Time lag between design and construction phases	Minimize the effects of time lag between design and construction phases
Different site conditions	Minimize different site conditions

Shortages of materials	Minimize shortages of materials

Technical requirements are aspects of the product or services that can be measured. Technical measures reflect the solutions selected to meet customers' needs. These measures could be added or created to ensure that the product meets customers' requirements. In the current research, the technical measures which were identified by the focus group are the functional features of BIM, as presented in Table 7.2. The third step is thus to measure the impact of BIM on minimizing the causes of change orders. The of each technical descriptor may be 'maximize', 'target' or 'minimize', and the symbols used for these are presented in Table 7.3.

Table 7.2: Technical measures (functional features of BIM)

No.	Functional Features of BIM
1	Visualization
2	3D parametric modelling
3	4D - scheduling and sequencing
4	5D - estimating and cost management
5	Clash detection
6	Collaboration and communication
7	3D coordination
8	Constructability
9	Code checking against national regulations
10	6D – operations/facilities usage
11	6D – procurement/supply chain
12	optimization for energy efficiency/environmental sustainability

Table 7.3: Direction of improvement

Maximize	↑
Target	o
Minimize	↓

The next step in constructing House of Quality is determining customers' importance ratings. In this stage the focus group identified the importance of each customer requirement on a scale of 1 - 5, where 1 is low importance, and 5 high importance. Then the focus group specified the relationship between the customers' requirements and the technical descriptors in the relationship matrix. This step is essential in order to understand the contribution which each technical measure makes to the overall customer satisfaction level as well as to see how the technical measures may help to satisfy all the expectation of the customers. The relationships specified can be ‘none’, ‘weak’, ‘moderate’, or ‘strong’, and have a numerical value attached to them of 0, 1, 3, or 9 respectively.

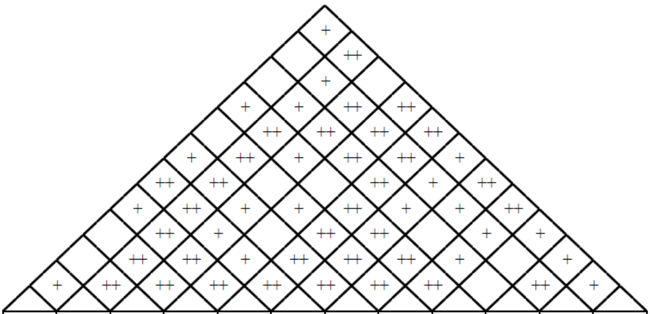
The next step was to calculate the performance of BIM in meeting client requirements and compare it with that of competitors. In this case, what was assessed was how well BIM is able to minimize or eliminate the causes of change orders, and ‘performance of competitors’ refers to how the systems currently in place – i.e. systems which do not use BIM – combat the causes of change orders. Specific values were then determined for the technical descriptors of the competitors, and the experts examined the relationship between the technical measures in the ‘roof’ of the House of Quality. Five symbols were used to denote the correlation of these features (see Table 7.4). The weighting of the technical measures was calculated by multiplying each customer requirement by the relationship score on the same raw and adding them in columns. These calculations made it possible to identify the most important technical requirements that affect the causes of change orders, and the sequence in which measures need improvement to provide what the customers wants.

The House of Quality diagram presented in Table 7.5 has been completed to show the effect of implementing BIM in the Jordanian construction industry on minimizing the causes of change orders, and Table 7.6 shows a comparison between current practices and BIM as ways of reducing change orders in the Jordanian construction industry.

Table 7.4: Correlations between technical measures

Strongly positive	++	Strongly negative	--
Positive	+	Negative	-
None			

Table 7.5: House of Quality for minimizing the causes of change orders through the use of BIM



		Visualisation	3D Parametric Modelling	4D - Scheduling and sequencing	5D- Estimating and cost management	Collaboration and Communication	Clash Detection	3D Coordination	Code checking against national regulations	Constructability	6D – supply chain (procurement)	6D – operations (facilities usage)	Optimised for environmental sustainability			
Desired Direction of Improvement		↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑			
		BIM Capabilities and Features												**Satisfaction Ratings**		
Causes of Change Orders in Jordan	**Customer Importance Rating**	**Visualisation**	**3D Parametric Modelling**	**4D - Scheduling and sequencing**	**5D- Estimating and cost management**	**Collaboration and Communication**	**Clash Detection**	**3D Coordination**	**Code checking against national regulations**	**Constructability**	**6D – supply chain (procurement)**	**6D – operations (facilities usage)**	**Optimised for environmental sustainability**	**Our Customer Satisfaction (CS) Rating**	**Current Practices**	**CS - Max(Competitor Rating)**
Minimize client's lack of awareness/knowledge	5	9	9	9	9	9	9	9	3	1	3		3	5	1	4
Minimize client's financial problems	4	3	9	9	9	9			1	3	9	9	3	4	2	2
Minimize changes by senior management	3	1		1	3	3					1			3	1	2
Minimize influence of attitudes on decisions	3	9	9	3	9	9		9	1		9	1	1	3	1	2
Minimize changes in client's requirements	5	9	9	3	9	9	3	9	9	3	9	3	9	5	3	2
Minimize client's lack of vision	4	9	9	9	9	9	9	9	1	1	9	3	9	4	2	2
Minimize failure to follow regulations and requirements	5		3	1	1	3		9	9	3	1	1	3	5	2	3
Minimize time limits for design and construction	3	9	9	9	9	9	9	9	3	3			3	3	1	2
Minimize time pressure from client	3	9	9	9	9	9	9	9	3	3	3	1	1	3	1	2
Minimize use of unqualified staff	3													3	1	2
Minimize inconsistencies between contract documents	5	1	9	3	3	9	9	9	9	9	3		3	5	2	3
Minimize lack of communication between project parties	4	3	9	1	1	9	3	9	3	3	3	3	3	4	2	2
Minimize estimation errors	3	1	9	3	9	9	9	9	3	9	3	1	3	3	1	2
Minimize time lag between design and construction phases	2		9	3	3	3		3						2	1	1
Minimize different site conditions	2		1			3		3			1	3	1	2	1	1
Minimize shortages of materials	2		1	9	9	3		3	3	3	9	9	3	2	1	1
Raw Score		242	388	255	327	393	234	378	206	159	232	113	182			
Rank		6	2	5	4	1	7	3	9	11	8	12	10			

Table 7.6: The causes of change orders with importance ratings for BIM and current practices

No.	Customers' needs	Importance rating (BIM)	Importance rating (current practices)
1	Minimize client's lack of awareness/knowledge	5	1
2	Minimize client's financial problems	4	2
3	Minimize changes in senior management	3	1
4	Minimize influence of attitudes on decisions	3	1
5	Minimize changes in client's requirements	5	3
6	Minimize client's lack of vision	4	2
7	Minimize failure to follow regulations and requirements	5	2
8	Minimize time limits for design and construction	3	1
9	Minimize time pressure from client	3	1
10	Minimize use of unqualified staff	3	1
11	Minimize inconsistencies between contract documents	5	2
12	Minimize lack of communication between project parties	4	2
13	Minimize estimation errors	3	1
14	Minimize time lag between design and construction phases	2	1
15	Minimize different site conditions	2	1
16	Minimize shortages of materials	2	1

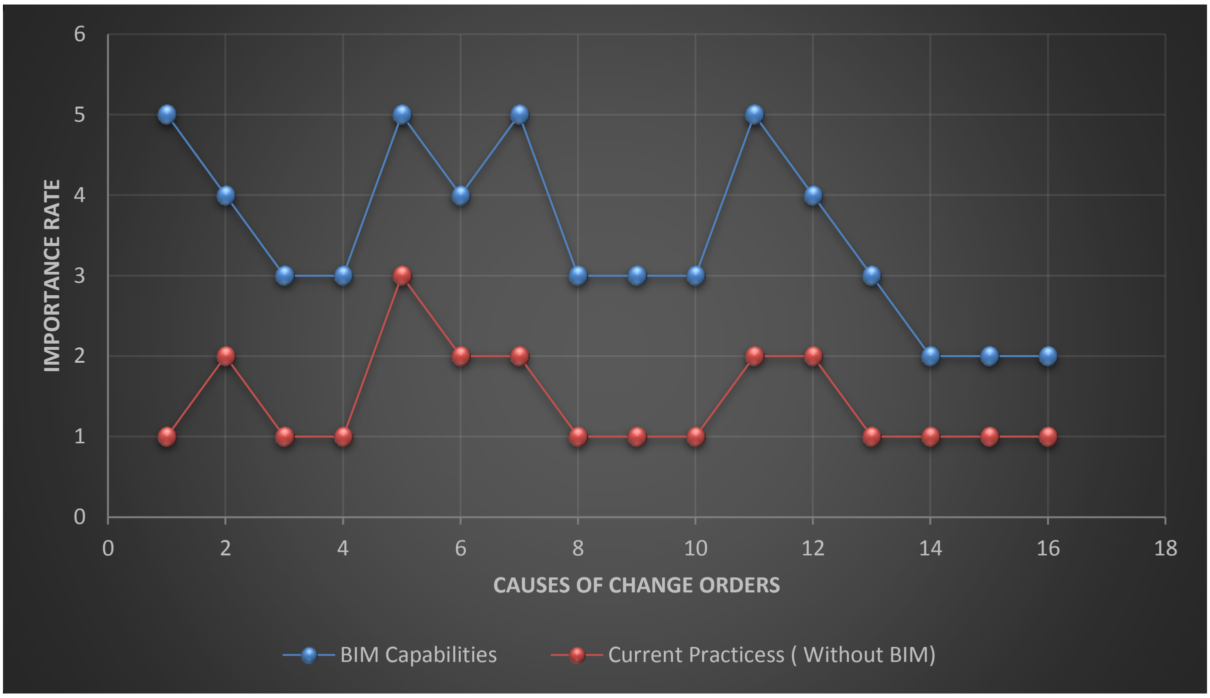


Figure 7.2: Comparison between of BIM and current practices for minimizing the causes of change orders in Jordan

7.3.2 House of Quality: conclusion

House of Quality is a tool that explains the impact of BIM on change orders in Jordanian construction projects, as well as measuring this impact objectively rather than subjectively, and describes relationships in a way which is simple and easy to understand. The great advantage of House of Quality is that it defines the ways in which the use of BIM affects the causes of change orders in construction projects, as well as comparing the results with current practices in the Jordanian construction sector. What is more, it provides a basis for decision makers to advocate the adoption of BIM because of the great benefits which could be gained.

The results of the House of Quality analysis presented above explain the relationship between the major causes of change orders in the Jordanian construction industry - as identified from the interviews and the questionnaire – and the functions and features of BIM. These results (see Figure 7.2) are similar to those presented in the conclusion of the previous chapter, which indicate that implementing BIM in the Jordanian construction industry will minimize change orders dramatically, reducing their costs and thus the cost of the project overall. House of

Quality therefore shows that the main benefit of implementing BIM in Jordan is to increase the client's knowledge and awareness of the project, as it shows that the difference between the importance rating for BIM and current practices is 4, which is relatively high, and which suggests that clients are not fully aware of the implications of current practices. The adoption of BIM as a way of minimizing any change orders could be an issue which is related to clients. This conclusion is supported by the discussion results, which indicate that the client’s lack of awareness and knowledge about the project is one of the main causes of change orders, and so implementing BIM will significantly reduce a major cause of change orders. The results also show that a reduction in change orders arising from inconsistencies between contract documents and not taking Jordanian codes and regulations into consideration in project design is the second main benefit of implementing BIM, as the difference in importance ratings between BIM and current practices in both cases is 3. These were both classified as major causes of change orders in Jordan, so in this area too implementing BIM will massively decrease change orders as well as their costs.

The other causes of change orders affected by BIM are financial problems experienced by the client, changes in senior management, the influence of attitudes on decisions, changes in the client’s requirements, the client’s lack of vision, time limits for design and construction, time pressure exerted by the client, the use of unqualified staff, lack of communication between project parties, and estimation errors. The influence of BIM on these causes varies. In general, however, the use of BIM has a slightly greater effect than current practices on controlling and minimizing change orders. However, these causes, together with the previous two groups, are responsible for the majority of change orders in the Jordanian construction sector, and so implementing BIM will result in a significant reduction of change orders and cost overruns. Finally, the House of Quality analysis shows that implementing BIM has a weak influence on those change orders which occur because of time lags between the design and construction phases, different site conditions or shortages of materials, as the difference in importance ratings for each of these is 1. However, the discussion results also found that these were not major causes of change orders in Jordanian construction projects. The minimal effect which BIM has on these causes therefore does not reduce the overall benefits of using BIM.

The House of Quality analysis also shows the adoption of BIM could significantly reduce change orders in the Jordanian construction industry which arise from poor collaboration and communication, for which the total weighting of collaboration and communication is 396. 3D parametric modelling is the second important feature of BIM which could reduce change orders, with a weighting of 388. 3D coordination is the third feature of BIM which has a great impact, and could decrease change orders in Jordanian construction projects. It is clear that these features can improve communication and collaboration between project parties, and give a clear picture of the project design which will both reduce design errors in contract documents and therefore minimize the need for change orders. BIM also provides a basis for managing the costs of a construction project at all stages, and this has a relatively high weighting of 327. The 5D function gives an accurate estimate of project costs and the payments which are required, so if the client has a clear idea about these it will encourage him to manage the cash flow and avoid critical situations which might require change orders to be issued.

A further important benefit of BIM is that it can simulate the construction sequence and approach in visual form, which shows the constructability of the project and helps to keep it on schedule, facilitates a good understanding of the construction procedures, and generally improves the project parties' understanding of the project. This feature is the fifth main feature of BIM, with a weighting of 255. Visualization is the sixth important features of BIM, as it enables change orders to be controlled by giving the project parties a picture of the project as a whole and allowing any modifications to be made before the start of the construction process, which costs less than if they were carried out during construction. The ability to detect clashes, for example between design drawings, is the seventh features of BIM which can reduce change orders in the Jordanian construction sector, and this has a weighting of 234. Inconsistencies between contract documents and design errors are among the three top causes of change orders in Jordan, so the clash detection feature will result in a dramatic decline in change orders and their costs.

Improve the supply chain (procurement) in the construction process has a total weight of 232, which is slightly lower than that of clash detection and ranks it as the eighth benefit of BIM which could greatly minimize change orders. BIM can also check codes for a project against national standards and regulations, and this is the ninth important feature which can minimize the causes of change orders. Design errors could result from discrepancies between the design and national standards, and these will need to be rectified during the construction process, so code checking makes it possible to avoid this sort of change and again reduce costs.

The final three important features of BIM relate to environmental sustainability, constructability and 6D operations (facilities usage), with weightings of 182, 159 and 113 respectively. These weightings mean that these features have a minimal effect on change orders in comparison to the others. Most interactions between BIM capabilities and features are strongly positive and positive, and there are no negative or strongly negative interactions. This is because these are built on customized software which is completely different from that for designing other things such as cars. It is thus clear that any improvement in one feature will be positively reflected in improvements in other features, which would minimize change orders in the Jordanian construction industry.

Finally, the conclusions from the House of Quality analysis support those of the discussion in the previous chapter, i.e. that the adoption of BIM in the Jordanian construction industry will significantly reduce the costs of change orders by minimizing the main causes of change orders.

7.4 Interpretive Structural Modelling (ISM)

ISM is a better tool for resolving the complex relationships among a large number of elements. It is often used to help develop a fundamental understanding of complex situations, as well helping to formulate a course of action to solve problems. Attri et al (2013) define Interpretive Structural Modelling (ISM) as a process which aims to help people achieve a better understanding of what they know, and to recognize clearly what they do not know. ISM enables individuals or groups to develop a map of the complex relationships between multiple factors involved in a complex situation. The basic idea of ISM is to draw on experts' practical experience and knowledge to deconstruct a complicated system into several sub-systems (elements) and construct a multi-level structural model (Anantatmula and Kanungo, 2005, Warfield, 1976 cited in George and Pramod, 2014). In participating in the House of Quality exercise, the focus group provided the experience and knowledge for ISM. ISM also transforms an unclear and poorly articulated system into a visible and well defined model (Diabat and Govindan, 2011).

ISM is an influential approach which can be applied in various fields. For example, Labib (2016) used ISM methodology to develop a hierarchy model for the challenges affecting logistics in the Jordanian construction industry. Hashmi (2015) utilized ISM to build a hierarchy of factors to implement the market orientation concept. The Interpretive Structural Modelling (ISM) approach was also used by Mudgal et al. (2010) to model and analyze the key barriers to green supply chain practices. The fact that ISM has been used in such a variety of fields testifies to the numerous benefits it can offer. According to George and Pramod (2014), ISM can offer the following advantages:

- It presents the original problem situation graphically in the form of a structural model that can be communicated more effectively to others;
- The ISM process is effective depending on the use and setting of transitive inference;
- ISM is a learning tool that leads people to develop a deep understanding of the meaning and significance of the elements of a situation and their relationships;
- It identifies particular areas for policy action in a form which offers advantages or leverage in pursuing specified objectives;
- It increases the quality of interdisciplinary and interpersonal communication within the setting of the problem situation, as all the participants are focusing on one specific question at the same time;
- It encourages the analysis of issues by allowing participants to explore the adequacy of a proposed list of systems elements
- No knowledge of the underlying process is required of the participants.

Because of these advantages, the current research used ISM to develop a deeper understanding of the barriers to the adoption of BIM in the Jordanian construction industry and to clarify the relationships between these barriers in order to determine which are the most significant. A group of seven experts were therefore selected, each of whom had a great deal of experience in the Jordanian construction industry and a high level of skills in construction, and they were invited to explain the barriers in detail, and to use the direction symbols to indicate the interaction and then the level of the barriers. The barriers to the adoption of BIM were identified in the research, and the 16 barriers were analyzed by ISM. Using the ISM process will provide a model which indicates suitable actions for the successful adoption of BIM. The ISM model proposes a hierarchical structure by prioritizing, sequencing and categorizing the barriers to the adoption of BIM in the Jordanian construction industry and classifies them as independents and dependents, and structures them hierarchically. The next section offers a step-by-step explanation of the ISM methodology for building a final model of the barriers to the adoption of BIM in the Jordanian construction industry.

7.4.1 The ISM methodology

The ISM method provides an interpretation which is based on the judgment of the experts of whether and how the barriers are related to each other. It can act as a tool for imposing order and direction on the complexity of relationships between the elements of a system (Banga Chhokar, 2010). In this case, it structures the barriers to the adoption of BIM in the Jordanian construction industry which are derived from the literature and the findings of the research into a comprehensive systematic model. The procedures described by Ravi and Shankar (2005) will be adopted to develop an ISM model of the barriers to the adoption of BIM in the Jordanian construction industry as follows:

Step 1: the 16 barriers to the adoption of BIM in the Jordanian construction industry are listed.

Step 2: once all the barriers are identified and listed (in Step 1), a set of contextual relationships is established among the barriers, on the basis of which pairs of barriers are examined.

Step 3: a Structural Self-Interaction Matrix (SSIM) is developed for the variables, which indicates pair-wise relationships among the variables of the system under consideration. Table 7.7 shows the SSIM for the barriers to the adoption of BIM in the Jordanian construction industry. Following Jharkharia and Shankar (2005), the following four symbols are used, which are the main symbols of SSIM, and which indicate the direction of the relationship between variables:

- V: Barrier i influences barrier j
- A: Barrier j influences barrier i
- X: Barriers i and j influence each other
- O: there is no relation between Barriers i and j.

Table 7.7: Structural Self-Interaction Matrix (SSIM) for the Barriers to the Adoption of BIM in the Jordanian Construction Industry

	Shortage of skilled and trained staff	Low budget for new projects	Costs of hardware	Lack of a legal framework for BIM	Costs of training	Weakness in communication between project parties	Approval system for new projects	Reluctance on the part of senior management	Costs of BIM software	High competition in construction industry	Lack of interest and demand	Dependence on unskilled staff	Time required for training	Time required for preparation of BIM infrastructure	Lack of awareness	Traditional processes
Shortage of skilled and trained staff	X	A	X	V	X	V	V	V	X	V	V	X	V	V	A	V
Low budget for new projects		X	A	A	A	A	A	A	A	X	A	A	A	A	O	A
Costs of hardware			X	V	X	V	V	V	X	V	V	A	X	V	X	X
Lack of a legal framework for BIM				X	A	V	X	V	A	V	X	V	V	V	A	X
Costs of training					X	V	V	V	X	V	V	X	X	V	X	V
Weakness in communication between project parties						X	A	X	A	V	A	A	A	X	A	V

Approval system for new projects							X	V	A	V	X	A	A	V	A	X
Reluctance on the part of senior management								X	A	V	A	A	A	X	A	A
Costs of BIM software									X	V	V	X	X	V	X	X
High competition in construction industry										X	A	A	A	A	A	A
Lack of interest and demand											X	A	A	V	A	X
Dependence on unskilled staff												X	X	V	X	X
Time required for training													X	V	A	V
Time required for preparation of BIM infrastructure														X	A	A
Lack of awareness															X	V
Traditional processes																X

Step 4: a Reachability Matrix is developed from the SSIM by transforming the information in each cell of the SSIM into binary digits (0 or 1). The transformation is performed by substituting the symbols V, A, X and O by 0 or 1 as follows:

1. If the cell (i, j) has 'V', then it will change to '1', and the cell (j, i) is converted to 0
2. If the cell (i, j) has 'A', then it will change to '0', and the cell (j, i) is converted to '1'
3. If the cell (i, j) has 'X', then it will change to '1', and the cell (j, i) is converted to '1'
4. If the cell (i, j) has 'O', then it will change to '0', and the cell (j, i) is converted to '0'.

Participants in the focus group check the matrix for transitivity. 'Transitivity' means that if there a straight relationship between A and B, and there is a straight relationship between B and C, then A has a relation with C. In this research, all the participants in the focus group agreed to do the transitivity check concurrently with the previous step. Table 7.8 presents the reachability matrix for the barriers to the adoption of BIM in the Jordanian construction industry

Table 7.8: Reachability matrix for the barriers to the adoption of BIM in the Jordanian construction industry

		Shortage of skilled and trained staff	Low budget for new projects	Costs of hardware	Lack of a legal framework for BIM	Costs of training	Weakness in communication between project parties	Approval system for new projects	Reluctance on the part of senior management	Costs of BIM software	High competition in construction industry	Lack of interest and demand	Dependence on unskilled staff	Time required for training	Time required for preparation of BIM infrastructure	Lack of awareness	Traditional processes
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Shortage of skilled and trained staff	**1**	1	0	1	1	1	1	1	1	1	1	1	1	1	1	0	1
Low budget for new projects	**2**	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Costs of hardware	**3**	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1
Lack of a legal framework for BIM	**4**	0	1	0	1	0	1	1	1	0	1	1	1	1	1	0	1
Costs of training	**5**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Weakness in communication between project parties	**6**	0	1	0	0	0	1	0	1	0	1	0	0	0	1	0	1
Approval system for new projects	**7**	0	1	0	1	0	1	1	1	0	1	1	0	0	1	0	1
Reluctance on the part of senior management	**8**	0	1	0	0	0	1	0	1	0	1	0	0	0	1	0	0
Costs of BIM software	**9**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
High competition in construction industry	**10**	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Lack of interest and demand	**11**	0	1	0	1	0	1	1	1	0	1	1	0	0	1	0	1
Dependence on unskilled staff	**12**	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1
Time required for training	**13**	0	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1
Time required for preparation of BIM infrastructure	**14**	0	1	0	0	0	1	0	1	0	1	0	0	0	1	0	0
Lack of awareness	**15**	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Traditional processes	**16**	0	1	1	1	0	0	1	1	1	1	1	1	0	1	0	1

After constructing the reachability matrix, both the independent and the dependent powers are recognized. The driving power (independent barrier) is indicated by summation value ‘l’ in the row for each related component, while the reliant power (dependent barrier) is indicated by summation '1' value in the column for each related component (Mandal and Deshmukh, 1994). Table 7.9 shows the reachability matrix for barriers with driving and reliance powers.

Table 7.9: Reachability matrix with independence power and dependence power for the Barriers to the Adoption of BIM in the Jordanian construction industry

		Shortage of skilled and trained staff	Low budget for new projects	Costs of hardware	Lack of a legal framework for BIM	Costs of training	Weakness in communication between project parties	Approval system for new projects	Reluctance on the part of senior management	Costs of BIM software	High competition in construction industry	Lack of interest and demand	Dependence on unskilled staff	Time required for training	Time required for preparation of BIM infrastructure	Lack of awareness	Traditional processes	**Independence Power**
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	
Shortage of skilled and trained staff	**1**	1	0	1	1	1	1	1	1	1	1	1	1	1	1	0	1	**14**

Low budget for new projects	**2**	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	**3**
Costs of hardware	**3**	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	**15**
Lack of a legal framework for BIM	**4**	0	1	0	1	0	1	1	1	0	1	1	1	1	1	0	1	**11**
Costs of training	**5**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**16**
Weakness in communication between project parties	**6**	0	1	0	0	0	1	0	1	0	1	0	0	0	1	0	1	**6**
Approval system for new projects	**7**	0	1	0	1	0	1	1	1	0	1	1	0	0	1	0	1	**9**
Reluctance on the part of senior management	**8**	0	1	0	0	0	1	0	1	0	1	0	0	0	1	0	0	**5**
Costs of BIM software	**9**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**16**
High competition in construction industry	**10**	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	**2**
Lack of Interest and Demands	**11**	0	1	0	1	0	1	1	1	0	1	1	0	0	1	0	1	**9**
Dependence on unskilled staff	**12**	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	**15**

Time required for training	**13**	0	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	**13**
Time required for preparation of BIM infrastructure	**14**	0	1	0	0	0	1	0	1	0	1	0	0	0	1	0	0	**5**
Lack of awareness	**15**	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**15**
Traditional processes	**16**	0	1	1	1	0	0	1	1	1	1	1	1	0	1	0	1	**11**
Dependence Power		**7**	**14**	**8**	**9**	**7**	**13**	**11**	**14**	**8**	**16**	**11**	**8**	**8**	**14**	**5**	**12**	

Step 5: the reachability matrix obtained in Step 4 is partitioned into different levels, where the reachability set, antecedents set and intersection set are constructed (Warfield, 1974, Farris and Saga, 1975). In other words, a reachability set, antecedents set and intersection set for the barriers to the adoption of BIM in the Jordanian construction industry are established from the reachability matrix. The reachability set for the barriers has the '1' value in each row, while the antecedents set has the '1' value in each column. Subsequently, the intersection of the reachability and antecedent sets is derived for all the barriers, and the levels of the different barriers are determined. Those barriers for which the reachability sets and the intersection sets are identical are assigned to the top level in the ISM hierarchy. The top-level barriers to the adoption of BIM are those that will not lead the other barriers to be above their own level in the hierarchy. Once the top-level BIM barriers are identified, they are set aside and not included in further hierarchical analysis, and other top-level barriers in the remaining sub-group are found. This process is iterated until the level of each barrier has been determined (Tables 7.10 to 7.16). The process of identifying levels of within these sub-groups is completed in seven iterations.

Table 7.10: First Iteration

Barrier						
Shortage of skilled and trained staff	**1**	1,3,4,5,6,7,8,9,10, 11,12,13,14,16	1,2,3,5,9,12,15	1,3,5,9, 12	**5**	
Low budget for new projects	**2**	1,2,10	2,3,4,5,6,7,8,9,10,11, 12,13,14,16	2,10	**2**	**1**
Costs of hardware	**3**	1,2,3,4,5,6,7,8,9, 10,11,13,14,15,16	1,3,5,9,12,13,15,16	1,3,5,9, 13,15,16	**7**	
Lack of a legal framework for BIM	**4**	2,4,6,7,8,10,11, 12,13,14,16	1,3,4,5,7,9,11,15,16	4,7,11,16	**4**	
Costs of training	**5**	1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16	1,3,5,9,12,13,15	1,3,5,9, 12,13,15	**7**	
Weakness in communication between project	**6**	2,6,8,10,14,16	1,3,4,5,6,7,8,9,11,12, 13,14,15	6,8,14	**3**	

Approval system for new projects	**7**	2,4,6,7,8,10, 11,14,16	1,3,4,5,7,9,11,12,13, 15,16	4,7,11,16	**4**	
Reluctance on the part of senior management	**8**	2,6,8,10,14	1,3,4,5,6,7,8,9,11, 12,13,14,15,16	6,8,14	**3**	
Costs of BIM software	**9**	1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16	1,3,5,9,12,13, 15,16	1,3,5,9,12, 13,15,16	**8**	
High competition in construction industry	**10**	2,10	1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15,16	2,10	**2**	**1**
Lack of interest and demand	**11**	2,4,6,7,8,10,11,14,16	1,3,4,5,7,9,11,12, 13,15,16	4,7,11,16	**4**	
Dependence on unskilled staff	**12**	1,2,3,5,6,7,8,9,10, 11,12,13,14,15,16	1,4,5,9,12,13,15,16	1,5,9,12, 13,15,16	**7**	
Time required for training	**13**	2,3,5,6,7,8,9,10, 11,12,13,14,16	1,3,4,5,9,12,13,15	3,5,9,12,13	**5**	
Time required for preparation of BIM infrastructure	**14**	2,6,8,10,14	1,3,4,5,6,7,8,9,11,12, 13,14,15,16	6,8,14	**3**	
Lack of awareness	**15**	1,3,4,5,6,7,8,9,10, 11,12,13,14,15,16	3,5,9,12,15	3,5,9,12, 15	**5**	
Traditional processes	**16**	2,3,4,7,8,9,10, 11,12,14,16	1,3,4,5,6,7,9,11, 12,13,15,16	3,4,7,9,11, 12,16	**7**	

Table 7.11: Second Iteration

Barrier	No.	Reachability set	Antecedents set	Intersection	T	Level
Shortage of skilled and trained staff	**1**	1,3,4,5,6,7,8,9,10, 11,12,13,14,16	1,2,3,5,9,12,15	1,3,5,9, 12	**5**	
Costs of hardware	**3**	1,2,3,4,5,6,7,8,9, 10,11,13,14,15,16	1,3,5,9,12,13,15,16	1,3,5,9, 13,15,16	**7**	
Lack of a legal framework for BIM	**4**	2,4,6,7,8,10,11, 12,13,14,16	1,3,4,5,7,9,11,15,16	4,7,11,16	**4**	
Costs of training	**5**	1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16	1,3,5,9,12,13,15	1,3,5,9, 12,13,15	**7**	
Weakness in communication between project parties	**6**	2,6,8,10,14,16	1,3,4,5,6,7,8,9,11,12, 13,14,15	6,8,14	**3**	
Approval system for new projects	**7**	2,4,6,7,8,10, 11,14,16	1,3,4,5,7,9,11,12,13, 15,16	4,7,11,16	**4**	
Reluctance on the part of senior management	**8**	2,6,8,10,14	1,3,4,5,6,7,8,9,11, 12,13,14,15,16	6,8,14	**3**	
Costs of BIM software	**9**	1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16	1,3,5,9,12,13, 15,16	1,3,5,9,12, 13,15,16	**8**	
Lack of interest and demand	**11**	2,4,6,7,8,10,11,14,16	1,3,4,5,7,9,11,12, 13,15,16	4,7,11,16	**4**	
Dependence on unskilled staff	**12**	1,2,3,5,6,7,8,9,10, 11,12,13,14,15,16	1,4,5,9,12,13,15,16	1,5,9,12, 13,15,16	**7**	

Time required for training	**13**	2,3,5,6,7,8,9,10, 11,12,13,14,16	1,3,4,5,9,12,13,15	3,5,9,12,13	**5**	
Time required for preparation of BIM infrastructure	**14**	2,6,8,10,14	1,3,4,5,6,7,8,9,11,12, 13,14,15,16	6,8,14	**3**	
Lack of awareness	**15**	1,3,4,5,6,7,8,9,10, 11,12,13,14,15,16	3,5,9,12,15	3,5,9,12, 15	**5**	
Traditional processes	**16**	2,3,4,7,8,9,10, 11,12,14,16	1,3,4,5,6,7,9,11, 12,13,15,16	3,4,7,9,11, 12,16	**7**	

Table 7.12: Third Iteration

Barrier	No.	Reachability set	Antecedents set	Intersection	T	Level
Shortage of skilled and trained staff	**1**	1,3,4,5,6,7,8,9,10, 11,12,13,14,16	1,2,3,5,9,12,15	1,3,5,9, 12	**5**	
Costs of hardware	**3**	1,2,3,4,5,6,7,8,9, 10,11,13,14,15,16	1,3,5,9,12,13,15,16	1,3,5,9, 13,15,16	**7**	
Lack of a legal framework for BIM	**4**	2,4,6,7,8,10,11, 12,13,14,16	1,3,4,5,7,9,11,15,16	4,7,11,16	**4**	
Costs of training	**5**	1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16	1,3,5,9,12,13,15	1,3,5,9, 12,13,15	**7**	
Approval system for new projects	**7**	2,4,6,7,8,10, 11,14,16	1,3,4,5,7,9,11,12,13, 15,16	4,7,11,16	**4**	
Costs of BIM software	**9**	1,2,3,4,5,6,7,8,9,10,	1,3,5,9,12,13,	1,3,5,9,12,	**8**	

		11,12,13,14,15,16	15,16	13,15,16		
Lack of interest and demand	**11**	2,4,6,7,8,10,11,14,16	1,3,4,5,7,9,11,12, 13,15,16	4,7,11,16	**4**	
Dependence on unskilled staff	**12**	1,2,3,5,6,7,8,9,10, 11,12,13,14,15,16	1,4,5,9,12,13,15,16	1,5,9,12, 13,15,16	**7**	
Time required for training	**13**	2,3,5,6,7,8,9,10, 11,12,13,14,16	1,3,4,5,9,12,13,15	3,5,9,12,13	**5**	
Lack of awareness	**15**	1,3,4,5,6,7,8,9,10, 11,12,13,14,15,16	3,5,9,12,15	3,5,9,12, 15	**5**	
Traditional processes	**16**	2,3,4,7,8,9,10, 11,12,14,16	1,3,4,5,6,7,9,11, 12,13,15,16	3,4,7,9,11, 12,16	**7**	

Table 7.13: Fourth Iteration

Barrier	No.	Reachability set	Antecedents set	Intersection	T	Level
Shortage of skilled and trained staff	**1**	1,3,5,9, 12,13,16	1,3,5,9,12,15	1,3,5,9, 12	**5**	
Costs of hardware	**3**	1,3,5,9, 13,15,16	1,3,5,9,12,13,15,16	1,3,5,9, 13,15,16	**7**	
Costs of training	**5**	1,3,5,9, 12,13,15,16	1,3,5,9,12,13,15	1,3,5,9, 12,13,15	**7**	
Costs of BIM software	**9**	1,3,5,9, 12,13,15,16	1,3,5,9,12,13, 15,16	1,3,5,9,12, 13,15,16	**8**	

Dependence on unskilled staff	**12**	1,3,5,9, 12,13,15,16	1,5,9,12,13,15,16	1,5,9,12, 13,15,16	**7**	
Time required for training	**13**	3,5,9, 12,13,16	1,3,5,9,12,13,15	3,5,9,12,13	**5**	
Lack of awareness	**15**	1,3,5,9, 12,13,15,16	3,5,9,12,15	3,5,9,12, 15	**5**	
Traditional processes	**16**	3,9, 12,16	1,3,5,9, 12,13,15,16	3,9, 12,16	**4**	**4**

Table 7.14: Fifth Iteration

Barrier	No.	Reachability set	Antecedents set	Intersection	T	Level
Shortage of skilled and trained staff	**1**	1,3,5,9, 12,13	1,3,5,9,12,15	1,3,5,9, 12	**5**	**5**
Costs of hardware	**3**	1,3,5,9,13,15	1,3,5,9,12,13,15	1,3,5,9,13,15	**6**	
Costs of training	**5**	1,3,5,9,12,13,15	1,3,5,9,12,13,15	1,3,5,9,12,13,15	**7**	
Costs of BIM software	**9**	1,3,5,9,12,13,15	1,3,5,9,12,13,15	1,3,5,9,12,13,15	**7**	
Dependence on unskilled staff	**12**	1,3,5,9,12,13,15	1,5,9,12,13,15	1,5,9,12,13,15	**6**	
Time required for training	**13**	3,5,9,12,13	1,3,5,9,12,13,15	3,5,9,12,13	**5**	**5**
Lack of awareness	**15**	1,3,5,9,12,13,15	3,5,9,12,15	3,5,9,12,15	**5**	**5**

Table 7.15: Sixth Iteration

Barrier	No.	Reachability set	Antecedents set	Intersection	T	Level
Costs of hardware	**3**	3,5,9	3,5,9,12	3,5,9,	**3**	**6**
Costs of training	**5**	3,5,9,12	3,5,9,12	3,5,9,12	**4**	
Costs of BIM software	**9**	3,5,9,12	3,5,9,12	3,5,9,12	**4**	
Dependence on unskilled staff	**12**	3,5,9,12	5,9,12	5,9,12,	**3**	**6**

Table 7.16: Seventh Iteration

Barrier	No.	Reachability set	Antecedents set	Intersection	T	Level
Costs of training	**5**	5,9	5,9	5,9	**2**	**7**
Costs of BIM software	**9**	5,9	5,9	5,9	**2**	**7**

Steps 6, 7 and 8: the next steps in constructing the ISM model is to draw a graph and remove the transitive links based on the relationships given in the reachability matrix. The resultant digraph is then converted into the ISM model by replacing variable nodes with statements. Finally, the ISM model which has been developed in step 7 is revised to check for conceptual inconsistency and to ascertain if any modifications are required. Figure 7.3 shows the final ISM model of the barriers to the adoption of BIM in the Jordanian construction industry.

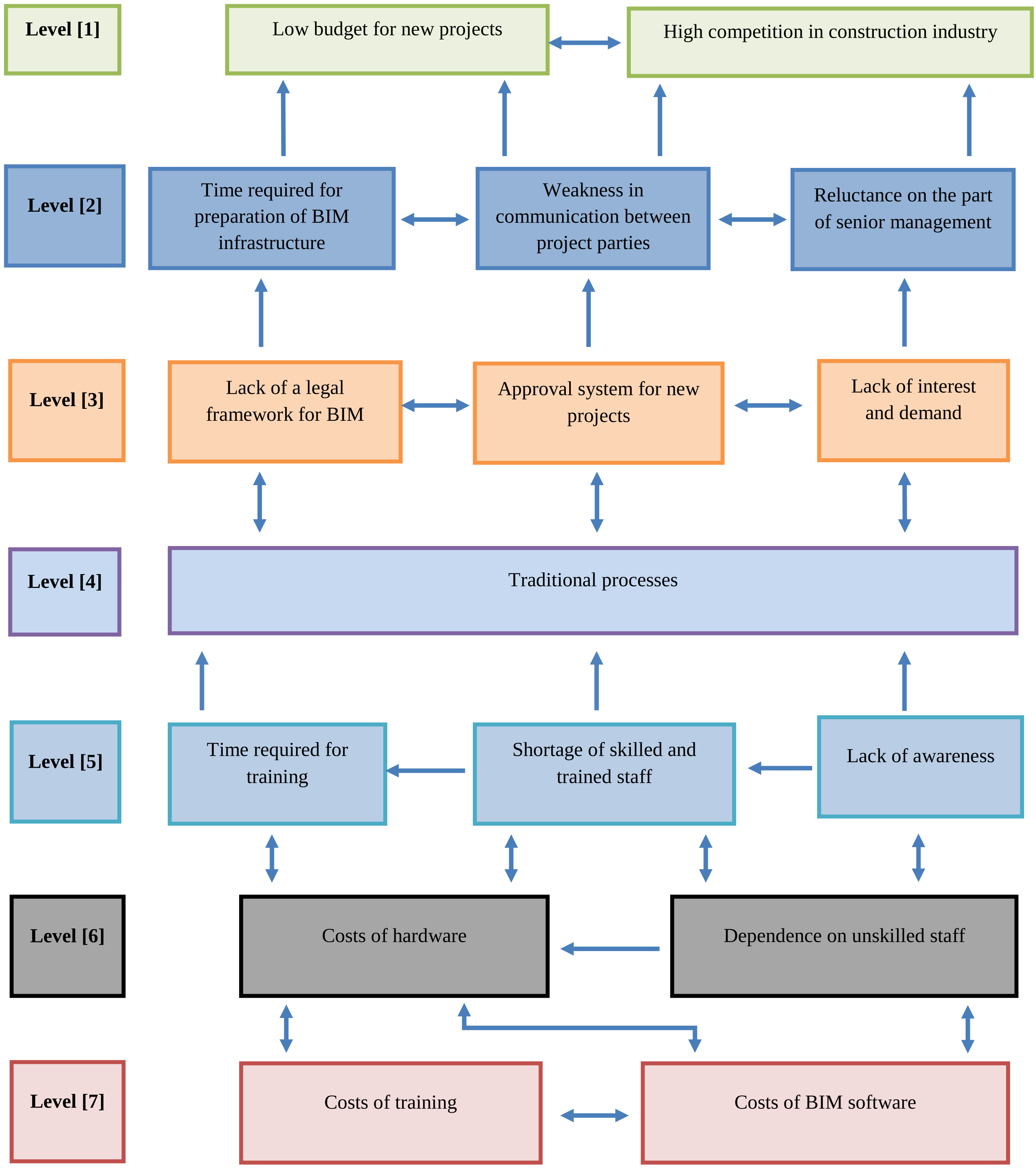


Figure 7.3: Final ISM Model of the barriers to the adoption of BIM in the Jordanian construction industry, with the relationships between the barriers

7.4.2 Description of the ISM model

The final model obtained by the ISM method presents a hierarchy of the barriers to the adoption of BIM in the Jordanian construction industry. The major contribution of the ISM model is to establish a contextual association among the different levels of barriers in a single structural system. The usefulness of this ISM model is that it determines the levels of complexity and the relationships between the barriers, which should help managers and decision makers in supporting the adoption of BIM in Jordan, as well as enabling them to understand the relationships between the barriers. The hierarchy explains the effect of each barrier to the adoption BIM. Those at Level 1 thus have the lowest influence of all the barriers, while those at Level 7 have the greatest influence. What this means is that solving problems at Level 7 will help to solve problems at the next level, and so on, which will support the implementation of BIM in the Jordanian construction sector.

The results obtained by the use of ISM, as shown in Figure 7.3, are very similar to the outcomes of the discussion chapter. Some slight differences are apparent in comparison with the data in the discussion chapter, however. The experts prefer to place 'time required for training' at the fifth, level of barriers, after 'costs of BIM software', 'dependence on unskilled staff' and 'costs of hardware'. However, factor analysis did not show the time required for training as a major barrier, while the Severity Index ranked it as the second main barrier. Likewise, 'reluctance on the part of senior management' is at Level 2, i.e. just before the top level. Here there is some similarity, in that factor analysis did not indicate that senior management's reluctant was a major obstruction to the implementation of BIM, and the Severity Index classified it at an intermediate level. ISM places the other barriers at the same levels as those discussed in the previous chapter.

Both 'costs of training' and 'costs of BIM software' are placed at the bottom level (Level 7) in the ISM model, which means they are major barriers to the adoption of BIM in the Jordanian construction industry. Moreover, they have a two-way relationship with each other, as well as two-way relationships with the barriers at Level 6, 'costs of hardware' and 'dependence on unskilled staff'. The key finding of ISM model is that the financial barriers represented by the costs of training, software and hardware are the main barriers to the adoption of BIM in Jordan, and should thus be dealt with as a priority. These barriers force the construction sector to depend on unskilled staff in order to minimize costs. The model also shows that the costs of software have a greater effect than the costs of hardware, and this is because software has to be updated more frequently than hardware, and hardware may work with many versions of the software.

Level 6 in the ISM model includes 'costs of hardware' and 'dependence on unskilled staff'. These barriers have a one-directional relationship, which starts from 'dependence on unskilled staff'. This indicates that using specific staff who cannot use BIM leads to dependency on specific hardware, so upgrading to BIM will require staff with specific skills, as well as new hardware, which will be costly. Moreover, 'costs of hardware' and 'dependence on unskilled staff' have two-way relationships with 'lack of awareness', 'time required for training' and 'shortage of skilled and trained staff'. This indicates that using staff who are not able to use BIM will reinforce the low level of awareness and knowledge of BIM.

As a result of this, Level 5 in the ISM model includes 'lack of awareness', 'time required for training' and 'shortage of skilled and trained staff'. 'Lack of awareness' has a one-way direct relationship with both 'time required for training' and 'shortage of skilled and trained staff', starting with 'lack of awareness', which means that the lack of awareness has an impact on both of these barriers. In other words, the lack of awareness of BIM has the effect of increasing the shortage of skilled people who can use BIM. Furthermore, 'shortage of skilled and trained staff' has a one-directional link to show that it affects 'time required for training'. This explains that if skilled staffs are not available, then lengthy training will be needed to give existing staff the skills they need to use BIM. These two barriers are strongly linked with each other and hinder the adoption of BIM. Finally, these barriers also help to shape attitudes towards BIM in the Jordanian construction sector, and this is shown in their one-way relationship with 'traditional processes' at Level 4.

The only barrier at Level 4 is 'traditional processes'. This is influenced by the lack of awareness of BIM, the unavailability of staffs who are able to use BIM, and the amount of training required. These barriers have a great influence on the construction industry in that they reinforce attitudes and processes which obstruct the adoption of BIM. It can also be concluded that the influence of traditional work processes in the construction sector means that managers do not concern themselves with new processes or technologies such as BIM, which in turn leads to a lack of interest and demand, and ultimately the poor approval system and the lack of a legal framework. This effect of ‘traditional processes’ is shown by its two-way relationships with ‘lack of interest and demand’, ‘lack of a legal framework for BIM’, and ‘approval system for new projects’ at Level 3. Overcoming the barrier of traditional work processes will therefore help to remove the barriers at Level 3.

At Level 3, there are two-way relationships between ‘lack of a legal framework for BIM’ and ‘approval system for new projects’ and ‘lack of interest and demand’. These relationships indicate that the lack of desire to use BIM in Jordan results in the lack of rules and standards related to BIM in the construction industry. These barriers also result in an inappropriate approval system for new projects, which also obstructs the adoption of BIM. Moreover, these barriers have a one-way link to barriers at Level 2, meaning that the lack of interest and demand makes managers reluctant to use BIM and to rely on methods which are not dependent on BIM. In addition to this, the lack of a legal framework for BIM and the current approval system in the construction industry exacerbate the poor communication between project parties, and increase the overall time it takes to develop the appropriate overall infrastructure and environment for BIM.

At Level 2, ‘weakness in communication between project parties’, ‘reluctance on the part of senior management’ and ‘time required for preparation of BIM infrastructure’ are strongly linked with each other by two-way relationships. This shows that the way decisions are made by top management in the construction industry makes communication with other project parties worse. All this means that getting the construction industry to a stage at which it can implement BIM will take a long time. All the barriers at previous levels put pressure on construction management to offer the lowest prices they can in order to get new projects. In most cases the price offered for the project would not cover the costs of implementing BIM, and this is illustrated in one-way links with ‘high competition in construction industry’ at Level 1. On top of this, the poor communication between project parties means that there may be little certainty about the total costs of construction projects, which could also reduce the funds for a project to a level at which it could not cover the costs of implementing BIM.

At Level 1, the ISM model includes ‘low budget for new projects’ and ‘high competition in construction industry’. These barriers have a two-way link with each other which explains the powerful relationship between them, and means that low budgets for new projects forces competitors to submit bids at the lowest possible price, and so BIM is not used in order to minimize total costs. The ISM model also indicates that these barrier are the weakest of all the barriers and do not constitute a major obstacle to the adoption of BIM in Jordan, so they should have a low priority.

To summarize, the ISM model provides a clear categorization of the barriers to the adoption of BIM in the Jordanian construction industry. These barriers vary in the extent of their independence and dependence. Overall, what the use of the ISM method shows is similar to what was discussed in the previous chapter, and this validates the findings of this research.

7.4.3 Classification of factors using MICMAC analysis

After using the ISM method to analyze the barriers to the implementation of BIM and identify the relationships among them, the next step is to ascertain the strength of those relationships. The MICMAC principle (Matrice d’Impacts Croisés Multiplication Appliquée à un Classement) will be used to achieve this objective. According to Sharma and Bhat (2014), MICMAC is a powerful tool for analyzing the driving (independent) power and the dependence power. The driving power is the summation of binary digit '1' in the corresponding row for each barrier in the final reachability matrix, while the dependence power of each element is obtained by the summation of binary digit '1' in the corresponding factor column. Drawing on Table 7.9, the independence and the dependence power for each barrier is determined as shown in Table 7.17, and then all the barriers are plotted using an X - Y coordinate system. Finally, based on the driving power and the reliance power, a graph is plotted, which classifies the barriers into four clusters as follows:

- **First cluster:** this cluster includes weak independence powers and weak dependence powers, which are called ‘autonomous factors’. These factors may be strong but have few links, and in general they are relatively disconnected from the system;

- **Second cluster:** this cluster includes weak independence powers and strong dependence powers, which are called 'dependent factors';
- **Third cluster:** this cluster includes 'linkage factors'. Strong independence factors and dependence factors are included in this category. These factors are unstable as a result of the fact that any action on them will have an effect on other factors, as well as feedback on themselves;
- **Fourth cluster:** the last cluster includes strong independence factors and weak dependence factors, which are called 'independence factors'.

Table 7.17: The independence powers and dependence powers of barriers to the adoption of BIM in the Jordanian construction industry.

Barrier		Dependence	Independence
Shortage of skilled and trained staff	1	7	14
Low budget for new projects	2	14	3
Costs of hardware	3	8	15
Lack of a legal framework for BIM	4	9	11
Costs of training	5	7	16
Weakness in communication between project	6	13	6
Approval system for new projects	7	11	9
Reluctance on the part of senior management	8	14	5
Costs of BIM software	9	8	16
High competition in construction industry	10	16	2
Lack of interest and demand	11	11	9
Dependence on unskilled staff	12	8	15
Time required for training	13	8	13
Time required for preparation of BIM	14	14	5
Lack of awareness	15	5	15
Traditional processes	16	12	11

Based on Table 7.17, Figure 7.4 shows all the independence barriers and dependence barriers in four clusters. The independence and dependence barriers to the adoption of BIM in the Jordanian construction industry are classified as follows:

Second cluster (dependence barriers):

1. **Barrier 2** (low budget for new projects)
2. **Barrier 6** (weakness in communication between project parties)
3. **Barrier 8** (reluctance on the part of senior management)
4. **Barrier 10** (high competition in construction industry)
5. **Barrier 14** (time required for preparation of BIM infrastructure)

The barriers in this second cluster are considered significantly dependent. At the same time, they have little influence on other barriers, and consequently on the ISM model. Moreover, these barriers are particularly sensitive to the evolution of the independence factors.

Third cluster (barriers which are both strong dependent and independent):

1. **Barrier 4** (lack of a legal framework for BIM)
2. **Barrier 7** (approval system for new projects)
3. **Barrier** 11 (lack of interest and demand)
4. **Barrier 16** (traditional processes)

These barriers have both reliance and driving powers. In other words they occupy a midway position, as they are dependent on another factor, but at the same time other factors depend on them. As well as this, the overlap between these powers creates a particular link for these barriers in the model

Fourth cluster (independence barriers):

1. **Barrier 1** (shortage of skilled and trained staff)
2. **Barrier 3** (costs of hardware)
3. **Barrier 5** (costs of training)
4. **Barrier 9** (costs of BIM software)
5. **Barrier 12** (dependence on unskilled staff)
6. **Barrier 13** (time required for training)
7. **Barrier 15** (lack of awareness)

These barriers are independence powers, with minimal dependence, and are considered as the core of the ISM model as most of the rest of the system depends on them. It can also be claimed that the other barriers depend on how far these driver barriers could be controlled and improved.

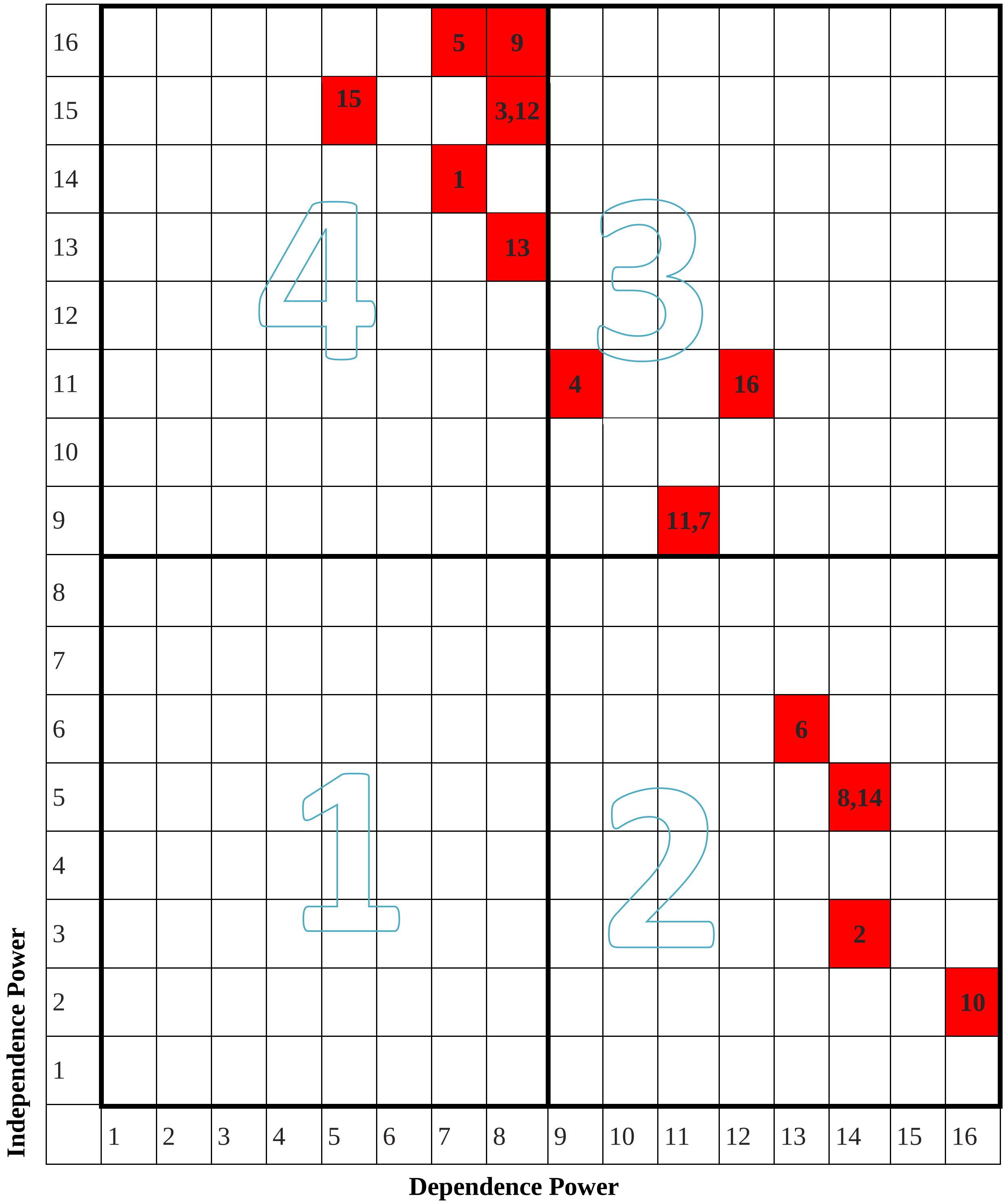


Figure 7.4: MICMAC analysis of barriers to the adoption of BIM in the Jordanian construction industry

In summary, the MICMAC analysis presented in Figure 7.4 supports the findings discussed in the previous chapter. It shows that the shortage of skilled and trained staff, the costs of hardware, training and BIM software, dependence on unskilled staff, the time required for training and lack of awareness are the core barriers to the adoption of BIM in the Jordanian construction industry. These barriers are categorized in Cluster 4, which includes those barriers which have high independence power and weak dependence power, and affect other barriers in the Jordan construction sector. Furthermore, the analysis shows that the Jordanian construction industry has five dependent barriers to the adoption of BIM, namely the low budget for new projects, weakness in communication between project parties, reluctance on the part of senior management, high competition in the construction industry, and the time required for the preparation of BIM infrastructure. Four barriers to the adoption of BIM are classified as linkage factors: the lack of a legal framework for BIM, the approval system for new projects, the lack of interest and demand, and traditional work processes. These barriers have high independence and dependence powers. Finally, the MICMAC analysis does not identify any autonomous barriers to the adoption of BIM in Jordan.

7.5 Conclusion

This validation chapter has used House of Quality and Interpretive Structural Modelling (ISM) techniques to examine the findings of the research. Firstly, the research found that utilizing BIM will minimize the cost of change orders in the Jordanian construction industry, so House of Quality was used to validate this conclusion. The House of Quality analysis indicates that BIM offers functions and features which are able to minimize the key causes of change orders effectively. Enabling collaboration and communication, 3D parametric modelling and 3D coordination are the three main features of BIM which can minimize the causes of change orders, followed by 5D (cost estimation and management) and 4D (scheduling and sequencing), visualization, clash detection, supply chain (procurement) and code checking. These features will increase the client's knowledge and awareness of their project and will have the effect of reducing the number of changes they require. Furthermore, they will also reduce design errors and inconsistencies between contract documents, which together with changes initiated by clients are regarded as the major causes of change orders in the Jordanian construction industry. Although the other features of BIM, 6D (for optimized environmental sustainability and constructability) and 6D (for operation), have less influence on the causes of change orders, they are nevertheless better than current practices in this regard. House of Quality found strongly positive and positive interactions between different features of BIM, which means that an improvement in one feature will reflect positively on other features and this in turn will further minimize the causes of change orders in Jordanian construction projects. Finally, it can be concluded on the basis of the findings discussed here and validated by the House of Quality analysis that the adoption BIM will significantly reduce the costs of change orders in the Jordanian construction industry.

The ISM model shows that there is a hierarchy of barriers to the adoption of BIM in the Jordanian construction industry, and establishes the relationships between these obstructions in a single model. This model has seven levels, the first of which contains the barriers with the least influence in relation to the adoption BIM, while the seventh level contains the most significant barriers. The model shows that resolving problems in the seventh level will help to resolve problems in the next level, and so on. The seventh level includes the costs of training and the costs of BIM software, followed by dependence on unskilled staff and the costs of hardware in Level 6. Generally, the ISM model shows that financial issues are the major barriers to the adoption of BIM in the Jordanian construction industry. Lack of awareness, the time required for training and the shortage of skilled and trained staff are at the fifth level, followed by traditional work processes at Level 4. Lack of interest and demand, the lack of a legal framework for BIM and the approval system for new projects are Level 3 barriers.

Weakness in communication between project parties, reluctance on the part of senior management and the time required for the preparation of BIM infrastructure are shown to be second level barriers. The top level includes high competition in the construction industry, which leads firms to submit the lowest possible bids in order to secure jobs, and the low budget for new projects. These two barriers are considered the weakest barriers to the adoption of BIM in the Jordanian construction industry. The MICMAC analysis shows that the costs of training, the costs of BIM software, dependence on unskilled staff, the costs of hardware, the shortage of skilled and trained staff, the time required for training and lack of awareness are the major barriers facing the adoption of BIM in the Jordanian construction industry, so they have priority as issues to be resolved in order to facilitate the adoption BIM in Jordan. Finally, the results of the ISM analysis validate what the research identified as the main barriers to the adoption of BIM in the Jordanian construction industry. This means that to facilitate the adoption of BIM and ensure its effectiveness, it is first of all essential to overcome the major barriers at Level 7 in the ISM model before attempting to deal with the other barriers at other levels.

CHAPTRE EIGHT: CONCLUSION

8.1 Introduction

This chapter summarizes the research outcomes and highlights the findings which achieve the research aim and objectives. The critical review of the literature presented in Chapter 2 identified major problems related to the cost of change orders in the Jordanian construction industry (Al-Momani, 1996, Swies, 2008, Sweis et al., 2013, Anti-Corruption Commission, 2013). Several researchers have examined the causes of change orders in the public sector, in water and waste water projects and in other sectors with a view to minimizing change orders and their impact on construction projects. However, these studies do not propose the use of BIM as a way of reducing change orders. What is more, several studies have found that there have been no projects which have used BIM in the Jordanian construction industry, and that there is a significant lack of awareness and knowledge of BIM across the Jordanian construction sector.

The aim of this research is therefore to develop a model for assessing the adoption of BIM in the Jordanian construction industry to reduce the cost of change orders. To achieve this aim, five objectives were proposed. This chapter rigorously examines how the research process has achieved each of these objectives. It also outlines the contribution the research makes, discusses the limitations of the research and makes recommendations for future research.

8.2 Research objectives

The specific objectives of this research are:

Objective 1: to investigate the main causes of change orders in the Jordanian construction industry which are responsible for cost overruns;

Objective 2: to explore current perceptions of BIM within the Jordanian construction industry;

Objective 3: to identify the barriers to the adoption of BIM within the Jordanian construction industry;

Objective 4: to develop an approach incorporating the adoption of BIM in the Jordanian construction industry in order to assess the influence of BIM on minimizing the costs of change orders;

Objective 5: to validate the model and provide recommendations.

Objective 1: to investigate the main causes of change orders in the Jordanian construction industry which are responsible for cost overruns.

In order to fulfil the first objective, the research critically reviewed the literature as a basis for examining the causes of change orders in the construction industry across the world, as well as in the Jordanian construction sector. This identified a number of significant factors which are responsible for cost overruns in construction projects. The researcher also drew on the literature to investigate perceptions of change orders and to design the interview questions. Data was then collected, using a mixed method.

In the first stage, the researcher asked 17 experts from the Jordanian construction industry about the major causes of change orders. It was found from the interviews that change orders are a major problem in the Jordanian construction industry, and that they have various causes. The majority of the interviewees believed that design errors and changes initiated by clients are the two main causes of change orders. Design errors may occur for a number of reasons: pressure from the client to finish the project, not following Jordanian regulations and requirements, limited time for design and construction, and the use of unqualified staff. Clients may also make changes due to their lack of awareness or knowledge, their mindset or attitude, their financial circumstances, changes in their requirements, a change in the senior management team or their own lack of vision. An in-depth analysis of the experts' opinions also revealed other important causes of change orders, such as incomplete designs, estimation errors, inconsistencies between contract documents, lack of communication between project parties, time lags between project design and construction, different site conditions, and shortages of materials.

These findings were then drawn upon to design a questionnaire which was used in the second phase of data collection. The questionnaire was distributed across the Jordanian construction industry to further investigate these causes. A statistical and descriptive analysis of the questionnaire responses classified the causes of change orders into three groups: client causes, engineering causes and factors relating to the circumstances of the project. It was found that design errors and inconsistencies between contract documents are the major causes of change orders in the engineering category, and that changes initiated by clients and lack of communication between project parties are the major causes relating to the client. Incomplete design and estimation errors, in the engineering category, could cause changes orders, but are not among the four major causes. The number of change orders related to the circumstances of the project and to time lags between project design and construction is not high in the Jordanian construction industry, but these causes are still significant, as shown by the results of the factor analysis test. Based on this discussion, the first objective of the research has been fulfilled.

Objective 2: to explore current perceptions of BIM within the Jordanian construction industry.

The second objective of the research is to examine the current level of awareness and knowledge of BIM in the Jordanian construction industry, as well as the awareness of BIM as something which can reduce change orders in construction projects. To achieve this objective, the researcher critically explored the literature on the awareness and knowledge of BIM. It was found that there are significant weaknesses in the understanding of BIM in many countries, which leads to delays in the effective adoption of BIM. This finding helped the researcher to formulate the interview questions which had the purpose of exploring levels of awareness of BIM both among individuals and across the whole construction sector, and to investigate whether there were any projects which had recently used BIM. The interviews showed that the majority of the experts lacked sufficient understanding of BIM to be able to use it. There is also a significant lack of awareness across the Jordanian construction sector, which hinders the adoption of BIM, and most construction firms still use 2D CAD in their work. At the same time, it was found that there are no projects or construction firms which are currently using BIM, and there is no legal framework for BIM in Jordan. The interview findings thus make it clear that there is a significant lack of awareness of BIM in the Jordanian construction industry, and this includes a failure to understand the benefits of BIM in terms of reducing the number of change orders.

In the second phase of data collection, the researcher drew on the interview results to design a questionnaire which investigated levels of awareness and knowledge of BIM across the Jordanian construction industry. The questionnaire findings supported the interview outcomes. Specifically, they also found a significant weakness in the awareness of BIM among individuals and across the construction sector as a whole. Furthermore, it was confirmed that BIM has not been used in any construction project which could be serve as a guide for the adoption of BIM in the Jordanian construction industry.

Overall, this research indicated that there is a significant lack of awareness and knowledge of BIM in the Jordanian construction industry. Thus the second objective of the research has been fulfilled.

Objective 3: to identify the barriers to the adoption of BIM within the Jordanian construction industry.

The third objective of the research focuses on the barriers which hinder the adoption of BIM in the Jordanian construction industry. It seeks to identify a basis for improving the use of BIM by identifying the significant barriers which should be dealt with as a priority in any attempt to achieve this goal. The researcher therefore explored the literature on barriers to the adoption of BIM in the construction industry, which identified a number of barriers which vary in importance from one country to another. These variations arise from the special characteristics, environment and nature of the construction sector of each country. In general, however, there are three main groups of barriers to the adoption of BIM, namely product, process and people. In the first stage of data collection, the researcher investigated the barriers to the adoption of BIM in the Jordanian construction industry by conducting interviews with 17 experts. The interviews indicated that there are16 factors which hinder the adoption of BIM in Jordan. In the product category, the barriers are the cost of software, the cost of hardware and training costs. The process group includes lack of awareness, dependence on unskilled staff, weaknesses in communication between project parties, the reluctance of senior management, traditional work processes, lack of standards and regulations for BIM, high competition in the construction industry, low budgets for new projects, the current approval system for new projects, the amount of time required for training, and the time required for preparing the required infrastructure for BIM. The third group includes shortage of skilled and trained staff.

The next stage of data collection examined these barriers in the Jordanian construction industry by means of a questionnaire, which was 294nalysed descriptively and statistically. Factor analysis categorized these barriers in four main groups, namely financial, human and communication barriers, and barriers related to project procurement. The financial group includes the costs of BIM software, the costs of hardware and the costs of training. These barriers are major barriers to the adoption of BIM in the Jordanian construction industry, and are among the top five barriers.

There are four barriers related to human factors: the shortage of skilled and trained staff, lack of awareness, dependence on unskilled staff, and lack of interest and demand. Like the financial barriers, these human barriers are significant in the Jordanian construction industry, and this is shown by the Severity Index results. The third group, communication, includes weaknesses in communication between project parties, the approval system for new projects, traditional work processes, and lack of a legal framework for BIM. It was found that the barriers in this category have less effect in obstructing the adoption of BIM than the financial or human barriers. The last group, relating to project procurement, has two barriers, which are low budgets for new projects and high competition in the construction industry. This group can be considered to be the least effective in hindering the adoption of BIM in Jordan.

The research identified correlations between the barriers in each group, as presented in the questionnaire and discussion chapters. However, it was found that three of the barriers have no significant impact on the adoption BIM, and these are reluctance on the part of senior management, and the time required for preparing a suitable environment for the adoption BIM. While the time required for training could prevent adoption BIM. In conclusion, the research identified and categorized the barriers to the adoption of BIM in the Jordanian construction industry. Therefore, the third objective of the research has been fulfilled.

Objective 4: to develop an approach for the adoption of BIM in the Jordanian construction industry in order to assess the influence of BIM on minimizing the costs of change orders

In order to fulfil this objective, the researcher followed the sequence used in the questionnaire. The researcher drew on the findings of the interviews to design a questionnaire which included several key issues to investigate the causes of change orders in the Jordanian construction industry, including the level of awareness of BIM, barriers to the adoption of BIM, factors driving the use of BIM, and the effects of using BIM on change orders. I55 participants completed the survey, which is considered a large enough sample for this purpose. The questionnaire used simple and direct language in order to minimize ambiguity and avoid misunderstandings and confusion. A pilot study was carried out before the questionnaire was distributed to assess its strengths and weaknesses. This led to a revision of vaguely worded questions, and resulted in overall improvements. Cronbach's alpha was used to test the reliability of the questionnaire, and the score for each section was over 0.7, which means the data obtained is reliable. The next stage was to analyse the questionnaire descriptively and statistically in order to build a reliable and valid approach to the adoption of BIM in the Jordanian construction industry. First of all, the questionnaire findings identified the main causes of change orders in the Jordanian construction industry, thus achieving Objective 1. These findings are presented in full under Objective 1 above. Secondly, the questionnaire findings indicated a significant lack of awareness and knowledge of BIM in the Jordanian construction industry. This result achieved Objective 2 and contributed to the achievement of Objective 4. Thirdly, the questionnaire findings identified the major causes of change orders in the Jordanian construction industry, and categorized these barriers into four main groups, namely financial, human, communication, and those related to project procurement. Within each of these groups there are several barriers adoption of BIM in Jordan. These barriers were significantly clarified in the achievement of Objective 3. It is thus clear that the first, second and third objectives are effectively developed a suitable approach to the adoption of BIM in the Jordanian construction industry as a means of reducing the costs of change orders in a sequence of steps. The process started with the identification of the major causes of change orders in Jordan which are responsible for cost overruns (Objective 1). The researcher then determined the current level of awareness and knowledge of BIM in Jordan (Objective 2), and this was followed by an in-depth examination of the barriers to the adoption of BIM in the Jordanian construction industry (Objective 3).

The researcher also investigated the relationship between the use of BIM and change orders. The literature review indicated that the use of BIM in construction projects will significantly minimize change orders, and lead to a significant reduction in their impact. The interview findings also indicated that the costs of change orders will be decreased as a result of using BIM. This reduction arises from a number of benefits which BIM has in terms of change orders, including reducing design errors, improving communication and collaboration between project parties, and improving the client’s understanding of the project by providing a virtual model of the building together with all relevant details before construction starts. Moreover, implementing BIM will help the project parties to take appropriate decisions within the project budget and timescale, which will also minimize the need for changes, as well as improving clash detection and supporting the process of construction. Overall, the interview findings identified various benefits of implementing BIM in Jordan that will significantly minimize the costs of change orders by reducing the causes of change orders.

Likewise, the questionnaire examined the relationship between BIM and the costs of change orders statistically by determining the correlations between the barriers to the adoption of BIM and the causes of change orders. The statistical analysis found a significant positive correlation between them. This indicates that there is a significant negative relationship between utilizing BIM, i.e. by minimizing the barriers to the adoption of BIM, and the causes of change orders. This means that using BIM in the Jordanian construction industry will result in a significant reduction in the costs of change orders.

Finally, in the interviews, the participants mentioned several organizations which could further the adoption of BIM in the Jordanian construction industry. These organizations were examined to rank them in terms of their role in relation to the adoption of BIM. The questionnaire results identified both the Jordanian Ministry of Public Works and Housing (JMPWH) and the Jordanian Engineering Association (JEA) as having an essential part to play in leading the adoption of BIM in the Jordanian construction industry. These two organizations were followed by the Jordanian Construction Contractors’ Association (JCCA), clients, engineering firms, contractors and universities. Objective 4 is therefore fulfilled.

Objective 5: to validate the model and provide recommendations.

In order to accomplish this objective, the research findings which achieved Objectives 1, 2, 3 and 4 were validated by the application of House of Quality and Interpretive Structural Modelling (ISM). First of all, the main causes of change orders in the Jordanian construction industry were identified, and the features and functions of BIM were reviewed, which indicated that House of Quality was an appropriate method for identifying the relationships between these causes and what BIM could offer, as this method examines the relationships objectively rather than subjectively. House of Quality takes into account customer needs and requirements, and uses technical tools such as a planning matrix, a relationship matrix, a correlation matrix, and weights, benchmarks and targets. The customer requirements section is completed by entering clients' requirements for minimizing the causes of change orders. These causes were identified in achieving Objective 1. The planning matrix includes BIM capabilities and features, and the relationship matrix determines the relationship between the causes of change orders and the functions and features of BIM. The results of the House of Quality analysis showed that utilizing BIM would have a significant effect on the causes of change orders, and that using BIM would be more efficient than current practices at reducing change orders and their impact. This result validated the conclusion presented in the discussion chapter that BIM would have a significant impact on reducing the cost of change orders in Jordan.

ISM was then used to validate the barriers to the adoption of BIM. ISM is considered to be a suitable technique for providing a fundamental understanding of complex situations and dealing with complex relationships among a large number of barriers. The ISM model identified and assessed the barriers to the adoption of BIM in the Jordanian construction industry, and supported the overall approach of using BIM to minimize the cost of change orders. The ISM methodology comprises a sequence of steps, which start with identifying the barriers (Objectives 3), and then determining the relationships between these barriers. The final ISM model categorized the barriers on the basis of their independence power. The MICMAC principle (Cross-Impact Matrix Multiplication Applied to Classification) was then used to determine the driver power (independence) and reliance power (dependence) of all the barriers to the adoption of BIM in the Jordanian construction industry. Therefore, the fifth objective of the research has been fulfilled.

The achievement of Objectives 1,2,3,4 and 5 provides valuable answers to the research questions, as well as achieving the aim of the research to develop a model for assessing the adoption of Building Information Modelling (BIM) in Jordanian construction organizations as a means of minimizing the costs of change orders. It can therefore be concluded that at this stage of the research the answers to the research questions are provided by the findings in relation to the following three issues:

- The first issue is the question of whether the use of BIM can bring about change. It was necessary to focus on identifying the effects of utilising BIM in construction projects as a means of minimizing the costs of change orders. The research examined both the main causes of change orders in the construction industry and levels of awareness and knowledge of BIM, and this gave a clear indication of how the costs of change orders could be minimized by using BIM in the Jordanian construction industry. This provides an answer to Question 1.

- The second issue is the barriers to change. The research clarified the barriers to the adoption of BIM in the Jordanian industry in order to facilitate the effective adoption of BIM and all the changes to be implemented. This answers Question 2.

- The third issue is the approach to making change. This area has assessment to create the approach for adoption BIM in the Jordanian construction industry to minimize the costs of change orders. In other words, this is about the way to change (employing a bottom-up approach). The stakeholders in the Jordanian construction industry must have a clear picture of the effects of utilizing BIM as a means of minimizing the costs of change orders, and so House of Quality was used to assess the benefits of this, which provided a concrete validation of the research results. It is necessary that stakeholders should have a full awareness and understanding of the barriers to the adoption of BIM, and of the way they interact to prevent the use of BIM in Jordan. The ISM model provides a basis for moving towards BIM by assigning the barriers to different levels and then dealing with them in sequence from the bottom level to the top. Stakeholders in the Jordanian construction industry are therefore advised to take these three issues into consideration to assess their current situation in relation to BIM so that they can move forward in this respect. This answers Question 3.

8.3 Research contribution

The Jordanian construction industry currently faces the significant challenge of reducing the costs of change orders. Cost overruns resulting from change orders amounted to 8.3% of total project costs in 1996 (Al-Momani, 1996), and this increased to 17% in 2013 (Anti-Corruption

Commission, 2013). Change orders are one of the main causes of cost overruns in the Jordanian construction industry (Sweis et al., 2013) and are therefore a critical problem in Jordan. Several researchers have investigated the causes of change orders in various areas, as well as suggesting different solutions to reduce them and their impact. For example; Al Jaloudi (2012) examined the causes of change orders in water and wastewater projects in Jordan, and proposed a framework for controlling changes. Also, Assbeihat and Sweis (2015) identified the major causes of change orders in public projects, and Msallam et al. (2015) clarified the causes of change orders in highway projects. However, the approaches which have been proposed do not take BIM into consideration as a solution for reducing the impact of change orders. At the same time, BIM has great potential for reducing changes in construction projects and minimizing project costs. Kuehmeier (2008) found that BIM eliminates change orders and RFIs (Requests for Information) relating to missing information in the construction documents in construction projects. Carbonari et al. (2015) also argued that the use of BIM has a positive impact in terms of saving costs and time, and reducing errors, omissions and reworking. A few studies have investigated BIM in the Jordanian construction industry, and found a significant lack of awareness and knowledge of BIM. According to Al Awad (2015), there is a huge discrepancy between the adoption of BIM in the construction industry in the west and its uptake in Jordan. He also found that that there was no use of BIM by small and medium enterprises (SMEs) and contractors in Jordan.

It can be concluded that there is a great need for research into the influence of BIM on change orders in the Jordanian construction industry as a means of minimizing costs, as well as into the ways in which the use of BIM might be promoted. The aim of the current research is therefore to develop a model for assessing the adoption of Building Information Modelling (BIM) in Jordanian construction organizations as a means of minimizing the costs of change orders. House of Quality established the key relationships between the main causes of change orders in the Jordanian construction industry and the functions and features of BIM, and highlighted the great benefits which BIM offers in terms of reducing project costs. The use of the ISM technique also indicated that there is a hierarchy of barriers to the adoption of BIM in the Jordanian construction industry, which suggests the sequence of steps which managers and practitioners should follow in overcoming these barriers. Together, these techniques suggest an appropriate approach to resolving the problem of the costs of change orders by offering a process for the adoption of BIM.

This research also offers academics and practitioners the following:

- Stakeholders in the construction industry will gain further awareness of the benefits of BIM for reducing the costs of change orders in construction projects, and with this growth in knowledge and awareness will develop strategies to further the adoption of BIM.

- Stakeholder in the construction industry will gain a fuller understanding of the major causes of change orders in the Jordanian construction industry, and this will prompt them to reassess their current practices in relation to change orders.

- An increased understanding of BIM will give practitioners a fuller picture of all relevant issues, including the barriers which BIM faces, the benefits it offers, and the driving forces, which will enable them to develop their professional practice in the long term by using BIM.

- Academics will be able to use the findings of this research as a benchmark to assess the progress of the Jordanian construction industry in controlling and reducing change orders.

- Academics will be able to use the findings of this research as a benchmark to assess the progress of the Jordanian construction industry in the adoption of BIM.

- This research encourages developing countries to conduct research on the influence of BIM on change orders in their own construction industry and to assess their current practices.

- International academics can use the findings of this research for making comparisons between developing countries or between developed and developing countries.

- Several studies have investigated the use of BIM in construction sectors around the world, so this research has added significantly to this body of knowledge.

- The research findings of House of Quality and the ISM model are particularly beneficial for large construction firms. They provide a basis for effectively assessing the influence of current practices on the costs of change orders, as well as indicating the main barriers to the use of BIM. They will thus further the adoption of BIM in construction projects, which will minimize the costs of change orders, improve project quality, and reduce project costs and time.

- This research investigates two issues in the construction industry and their interrelationship. The first of these is the main causes of change orders in the Jordanian construction industry, and the second is the adoption of BIM.

8.4 Limitations of the research and recommendations for future research

This research focuses on providing a model for assessing the adoption of BIM as a means of reducing the costs of change orders in the Jordanian construction industry. The research has successfully answered the research questions, and achieved the research aims and objectives. Nevertheless, the research has some limitations. These are set out below, and this is followed by recommendations for future research.

- During the data collection phase, the researcher was unable to gain sufficient of significant items of literature on the adoption of BIM in the Jordanian construction industry, as well as specific studies in the research area. Moreover, some participants were reluctant to take part in the questionnaire survey, which increased the time it took to collect the data.

- This research used a mixed method for data collection, namely interviews and a questionnaire. However, it is recommended that future research could use other methods such as action research in order to assess the adoption process in the construction industry and the benefits of BIM in terms of reducing the costs of change orders.

- A correlation test and exploratory factor analysis were used in this research. In order to confirm the findings of this research, any further studies should be use different analytical techniques such as conformity factor analysis.

- This research was limited to large organisations, so further research could investigate the same issues in medium and small organizations. The research also focused on the building sector in the Jordanian construction industry, so future research could focus on the adoption of BIM as a means of minimizing the costs of change orders in other sectors such as highway projects.

- Change orders have several effects on construction projects. This research concentrated on their impact on change orders, so future research could investigate the influence of BIM on other aspects of change orders such as time overruns or disputes.

- The majority of the participants in this research were working for private firms, so this study concentrated on the Jordanian private sector. Future studies could therefore investigate the same subject in other sectors such as the public or non-profit sector. Furthermore, they could draw comparisons between the findings of the different studies.

- Due to the limited time for the research, this study focused only on Jordan. Therefore future studies could examine the same issues in various other countries and identify similarities and differences.

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APPENDICES

APPENDIX (A): Ethical Approval

Research, Innovation and Academic Engagement Ethical Approval Panel

Research Centres Support Team
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6 January 2016

Dear Alshdiefat,

RE: ETHICS APPLICATION ST15/65 – Strategic Framework for Adoption Building Information Modelling (BIM) to Control Cost of Change Orders In Jordanian Construction Industry

Based on the information you provided, I am pleased to inform you that your application ST 15.65 has been approved.

If there are any changes to the project and/ or its methodology, please inform the Panel as soon as possible by contacting S&T-ResearchEthics@salford.ac.uk

Yours sincerely,

Prof Mohammed Arif
Chair of the Science & Technology Research Ethics Panel
Professor of Sustainability and Process Management,
School of Built Environment
University of Salford
Maxwell Building, The Crescent
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APPENDIX (B): Interview Questions

General Questions

1. What is your position in the company or institution?

2. How many years have you been in construction industry?

Change Orders

1. Do you thinks the change orders in Jordanian construction industry classified as preferable or not?

2. Is the change orders is major problems in construction industry?

3. What are the causes of change orders that take major responsible of cost overrun?

Awareness

1. How would you categorize your understanding about BIM? What do you define the BIM?

2. Does your company use the BIM? 3D CAD? Or 2D CAD?

3. Is there adequate guides and advice for successful implementation of BIM to reduce cost of change orders in Jordanian construction industry?

4. Does implementing BIM will reduce cost of change orders in Jordanian construction industry, and how?

Barriers

1. What are the barriers of adoption BIM in Jordanian construction industry?

2. Is the BIM implementation in Jordanian construction industry is expensive?

3. Are the current practices in Jordanian construction industry are hindering adoption BIM to reduce change orders?

4. Have the Jordanian construction firms enough number of skilled and trained staff for full implementation of BIM?

5. Is the legal and contractual issues that related to BIM are clear in Jordanian construction industry?

Drivers

1. Who should lead adoption BIM in Jordanian construction industry?

APPENDIX (C): Questionnaire Answers

1. Please select the type of industry sector you work in

A. Public Sector [27]

B. Private Sector [128]

2- Please indicate the type of organization you work in

A. Government [16]

B. Regularity (JEA, JCCA, etc) [12]

C. Educational (Universities, Colleges, etc) [11]

D. Engineer (Architect, Civil, Designer, Mechanical, Electrical, Consultancy) [52]

E. Contractor [40]

F. Clients [15]

G. Construction Management Firms [9]

G. Other ……….. [0]

3- How many years have you been in construction industry?

A. 0-5 [13]

B. 6-10 [22]

C. 11-15 [46]

D. 16-20 [43]

E. >20 [31]

4. In orders to determine the main causes of change orders in Jordanian construction industry. Please tick (√) for the suitable place indicate your level of agreement with the following causes that are responsible for most of change orders cost in Jordanian construction projects;

	Strongly disagree	Disagree	Moderately Agree	Agree	Strongly Agree	Missing
Design errors	2	2	1	52	98	0
Incomplete design	1	3	42	92	17	0
Lack of communication between project parties	0	3	10	99	43	0
Time lag between design and construction phases	0	11	59	80	5	0
Estimation errors	1	8	49	86	11	0
Changes initiated by clients	1	1	10	23	117	3
Inconsistency between contract documents	1	1	6	74	73	0
Different site conditions	1	26	85	40	2	1
Shortages of materials	20	67	56	11	0	1

Other Causes (If it is not above): ……………………………………….

5- In orders to determine the awareness level about BIM in Jordanian construction industry to minimize cost of change orders, Please tick (√) for <u>the suitable place indicate your level of agreement with the following questions;</u>

	Strongly disagree	Disagree	Neither agree or disagree	Agree	Strongly Agree	Missing
Do you personally consider your understanding about BIM as good knowledge	83	38	28	3	0	3
The awareness of BIM in Jordanian construction organizations are suitable and have sufficient knowledge to implement it	84	36	32	0	0	3
Nowadays, the driver's firms (Large Companies) in Jordanian construction industry are using BIM	80	33	39	0	0	3
There adequate guides and advice (Project Implemented BIM) for successful implementation of BIM In Jordan to control cost of change orders	77	38	37	0	0	3

Other (If it is not above): ……………………………………….

6. In orders to determine the barriers to adopting BIM in Jordanian construction industry. Please tick (√) for the suitable place indicate your level of agreement with the following barriers;

	Strongly disagree	Disagree	Neither agree or disagree	Agree	Strongly Agree	Missing
Costs of BIM software	0	2	9	32	109	3
Costs of hardware	0	4	16	80	52	3
Shortage of skilled and trained staff	0	3	12	92	45	3
Costs of training	0	2	3	28	119	3
Time required for training	0	1	2	46	103	3
Weakness in communication between project parties	1	25	60	64	2	3
Approval system for new projects	0	13	51	85	3	3
Traditional processes (like depending on 2D CAD) nowadays	1	5	28	103	15	3
Dependence on unskilled staff	0	0	3	108	39	5
Reluctance on the part of senior management	0	6	12	89	45	3
Lack of interest and demand	0	6	64	57	25	3
Lack of awareness	0	5	23	110	14	3

Lack of a legal framework for BIM	1	14	49	80	8	3
Low budget for new projects	2	17	68	61	4	3
High competition in construction industry	3	30	69	47	3	3
Time required for preparation of BIM infrastructure	0	10	101	40	1	3

Other Barriers (If it is not above): ……………………………………….

7. Who should drive the adoption BIM in Jordanian construction industry?

A. Jordanian Ministry of Public Works and Housing [147]

B. The Jordanian Engineers Association (JEA) [140]

C. The Jordanian Construction Contractors Association (JCCA) [126]

D. Clients [123]

E. Engineering Firms [105]

F. Construction Management Firms [22]

F. Contractors [104]

G. Universities [95]

G. Other ……….[0]