BUILDING INFORMATION MODELING (BIM) CAPABILITIES IN QUANTITY SURVEYING PRACTICE DURING PRE-CONSTRUCTION STAGE: THE RELATIONSHIP WITH PROJECT PERFORMANCE

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ABSTRACT

Poor cost performance in the construction industry has been widely reported in numerous studies. Cost overrun and inaccurate estimate are the pitfalls that affect the project performance. It has been noted that quantity surveyors (QSs) play a major role in providing and managing project cost in the construction industry. Several authors have addressed that the traditional manual methods adopted by QSs are inefficient and the accuracy of the project cost is affected. Recent evidences suggest that implementation of building information modeling (BIM) is a potential solution that can rectify the inefficiencies and improve cost accuracy. However, the adoption of BIM among QSs is slow due to lack of awareness and limited study on the BIM capabilities in quantity surveying practice. There have been little discussions pertaining to the relationship between BIM capabilities in quantity surveying practice during pre-construction stage and project performance. Hence, this research developed a framework on the relationships between BIM capabilities in quantity surveying practice during pre-construction stage and project performance for time, cost, and quality aspects. Through the study of this relationship, the effects of the BIM capabilities in quantity surveying upon the project performance had been further investigated. In this research, a mixed method of quantitative and qualitative was adopted. A sequential four-phased research approach was designed for data collection and interpretation. This research began with a detailed literature review and 11 BIM capabilities were discovered in quantity surveying practice. Next, preliminary interviews were conducted with 8 QSs to confirm the identified capabilities. Following this, questionnaires were distributed to 131 quantity surveying organizations after sampling determination. Several analyses were performed to examine the relationship between BIM capabilities and project performance. BIM capabilities were ranked using relative importance index. Correlation analysis was performed to explore the related BIM capabilities to the project performance. Then, logistic regression was conducted to further examine the relationship between BIM capabilities and project performance. At the last phase of the research, qualitative semi-structured interviews were executed to validate the questionnaires survey results. 15 QSs were interviewed to obtain further details on the identified relationship by ascertaining their experiences and views. The findings revealed that BIM capabilities in quantity surveying practice during pre-construction stage were significantly correlated and regressed to the project performance. For time aspect, capabilities of cost checking and visualization affected the performance. For cost aspect, capabilities of generate cost estimate for various design alternatives and automatically quantification for bill of quantities preparation affected the performance. For quality aspect, capabilities of clash detection and visualization affected the performance. These relationships were developed in a framework to depict how BIM capabilities were related to the project performance to facilitate understanding and awareness among QSs. The research findings provided an insight to QSs on how to achieve better project performance by adopting BIM in their practice at an early stage. Thus, QSs should consider the identified BIM capabilities and refer to the relationships portrayed in the framework in their practice at the early stage for better project outcomes.

ABSTRAK

Prestasi kos yang buruk dalam industri pembinaan telah dilaporkan secara meluas melalui pelbagai kajian. Kos terlebih dan anggaran yang tidak tepat adalah jebakan yang mempengaruhi prestasi projek. Ia mencatatkan bahawa juruukur bahan (JUB) memainkan peranan yang penting dalam penyediaan dan pengurusan kos projek dalam industri pembinaan. Beberapa penulis telah menyatakan bahawa kaedah manual tradisional yang digunakan oleh JUB adalah tidak efisien sehingga menjejaskan ketepatan kos projek. Malah, kajian terbaru menunjukkan bahawa pelaksanaan *building information modeling* (BIM) adalah satu potensi penyelesaian yang boleh membaiki ketidakcekapan dan meningkatkan ketepatan kos. Walau bagaimanapun, penggunaan BIM di kalangan JUB adalah berkurangan kerana kurang kesedaran dan tidak banyak kajian yang dijalankan mengenai keupayaan BIM di amalan ukur bahan. Tambahan pula, perbincangan adalah sedikit tentang hubungan keupayaan BIM dalam amalan ukur bahan pada peringkat pra-pembinaan dan prestasi projek. Oleh itu, kajian ini telah dilakukan untuk mengenal pasti keupayaan BIM dalam amalan ukur bahan semasa peringkat pra-pembinaan dan seterusnya melihat hubungan berkaitan dengan prestasi projek dalam aspek masa, kos dan kualiti. Dengan mempelajari hubungan ini, pengaruh keupayaan BIM dalam amalan ukur bahan terhadap prestasi projek boleh diteliti dengan lebih lanjut. Dalam kajian ini, campuran kaedah kuantitatif dan kualitatif telah digunakan. Empat fasa penyelidikan secara berurutan telah dirancang untuk pengumpulan data dan interpretasi. Kajian ini bermula dengan kajian literasi terperinci dan terdapat 11 keupayaan BIM dalam amalan ukur bahan semasa peringkat pra-pembinaan. Seterusnya, temu bual awal telah dijalankan dengan 8 JUB untuk mengesahkan keupayaan BIM yang diperolehi daripada kajian literasi. Berikutan dengan itu, satu set soal selidik telah diedarkan kepada 131 organisasi juruukur bahan

selepas penentuan sampel. Beberapa analisis telah dilakukan untuk mengkaji hubungan di antara keupayaan BIM dan prestasi projek. Keupayaan BIM disusun dengan menggunakan indeks kepentingan relatif. Analisis korelasi telah dijalankan untuk meneroka keupayaan BIM yang berkaitan dengan prestasi projek. Kemudian, regresi logistik telah dilakukan untuk menguji hubungan di antara keupayaan BIM dan prestasi projek. Pada fasa terakhir penyelidikan, temu bual separa berstruktur kualitatif telah dijalankan untuk mengesahkan hasil kajian soal selidik. 15 JUB telah ditemubual untuk mendapatkan maklumat lanjut mengenai hubungan yang telah dikenal pasti dengan melihat pengalaman dan pendapat JUB. Hasil kajian telah menunjukkan bahawa keupayaan BIM dalam amalan ukur bahan pada peringkat pra-pembinaan mempunyai hubungan yang signifikan dan regresi kepada prestasi projek. Dalam aspek masa, keupayaan menyemak kos dan visualisasi mempengaruhi prestasi. Dalam aspek kos, keupayaan menjana anggaran kos untuk pelbagai alternatif reka bentuk dan kuantifikasi automatik untuk penyediaan bil kuantiti mempengaruhi prestasi. Dalam aspek kualiti, keupayaan pengesanan percanggahan reka bentuk dan visualisasi mempengaruhi prestasi. Hubungan ini telah dibina dalam sebuah rangka untuk memberi gambaran tentang keupayaan BIM berkaitan dengan prestasi projek untuk meningkatkan kefahaman dan kesedaran di kalangan JUB. Hasil kajian ini dapat memberi maklumat kepada JUB tentang cara untuk mencapai prestasi projek yang lebih baik dengan menggunakan BIM dalam amalan mereka pada peringkat awal. Oleh itu, JUB harus mengambil kira keupayaan BIM yang dikenal pasti dalam hasil kajian ini dan merujuk kepada rangka hubungan yang direka semasa peringkat awal untuk mencapai pretasi projek yang lebih baik.

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LIST OF SYMBOLS AND ABBREVIATIONS

2D	:	Two-dimensional
3D	:	Three-dimensional
4D	:	Four-dimensional
5D	:	Five-dimensional
AEC	:	Architectural, Engineering and Construction
BCA	:	Building and Construction Authority
BIM	:	Building Information Modeling
BQ	:	Bills of Quantities
BQSM	:	Board of Quantity Surveyors Malaysia
CAD	:	Computer Aided Design
CIDB	:	Construction Industry Development Board
CIFE	:	Center for Integrated Facilities Engineering
CORENET	:	Construction and Real Estate Network
GSA	:	General Services Administration
IAI	:	International Alliance for Interoperability
IFC	:	Industry Foundation Classes
IT	:	Information Technology
LEED	:	Leadership in Energy and Environmental Design
LOD	:	Level of Details
NBIMS	:	National Building Information Model Standard
NIST	:	National Institute of Standards and Technology
PBS	:	Public Buildings Services
PWD	:	Public Works Department
QS	:	Quantity Surveyor

QSs	:	Quantity Surveyors
RIBA	:	Royal Institute of British Architects
RICS	:	Royal Institute of Chartered Surveyors
RII	:	Relative Importance Index
SME	:	Small and Medium Enterprise
SPSS	:	Statistical Package for the Social Science

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

In the construction industry, completing a project on schedule and within cost limit as specified quality standards is a major criterion of success of a project (Chan and Kumaraswamy, 1993). Cost is among the major considerations of client in a construction project as pointed out by several scholars (Azhar et al., 2008c; Forgues et al., 2012; Cheung et al., 2012). It has been regarded as one of the important parameters that drive a project towards success.

However, the construction industry often suffers from dilemma such as project abandonment due to poor cost performance, cost overrun, and delays in project delivery (Puspasari, 2005; Baloi and Price, 2003; Olatunji et al., 2010a). In fact, several scholars have highlighted the pitfalls of cost overrun. Latham (1994) and Egan (1998) argued that construction costs are unable to create value for money due to high in cost, inconsistency and inefficiency of cost. Besides, Peeters and Madauss (2008) indicated that the biggest factor that causes budget overrun is inaccurate estimation of the initial cost of a project. Variation over 40% of the initial budget frequently happens in the construction industry (Flyvbjerg et al., 2003, Winch, 2010). Meanwhile, Ali and Kamaruzzaman (2010) discovered two variables that contributed to cost overrun in

Malaysian construction projects, which are poor estimation of original project cost, and underestimation of the construction cost by quantity surveyors (QSs). Evidently, the construction industry is still facing problems pertaining to inefficient cost management. Thus, a better solution is required to improve accuracy in costing and estimating for better project cost performance.

In addition, QS is important in providing cost management services in the construction industry. QSs carry out various tasks, but measurement, bills of quantities preparation, and estimating and pricing cost of construction projects are among the important tasks performed by QSs. These tasks are tedious and time consuming which are susceptible to human error. Besides, it has been noted that QSs still rely on manual measurement although they are under increasing pressure to measure quantities within shorter time (Tse and Wong, 2004; Smith, 2011). Moreover, the amount of time spent by the estimator differs by project, but around 50 to 80% of the time that is needed to create a cost estimate is spent on quantification (Autodesk, 2007a). In any project, especially big and complex project, items can be easily overlooked and miscalculated and this can lead to a detrimental effect on project performance. Hence, there is indeed a need for effective cost management and control system by the QSs to eliminate these problems.

However, these tedious and time consuming tasks can be eradicated by implementing Building Information Modeling (BIM). BIM is a solution that can assist QSs to generate precise quantity takeoff and accurate cost estimates throughout the lifecycle of a project. Perera et al. (2012) have addressed this point by stating that BIM eliminates many daunting tasks of traditional quantity surveying, such as quantity takeoff and the production of bills of quantities (BQ), by automating these tasks. On the other hand, Aouad et al. (2007) conveyed a similar view that BIM is able to automate quantification and facilitate the preparation of accurate estimates. BIM is an innovative and a collaborative tool that provides the greatest scope for this cost efficient to be achieved. As affirmed by Yin and Qian (2013), construction project cost management with BIM is an effective solution to improve the efficiency and the profits in the construction industry. Therefore, BIM has penetrated and changed the way of quantity surveying practice, and eventually has enhanced the accuracy in costing and estimating.

Despite of the wide coverage on the potentials and advantages of BIM application, the adoption rate has been rather lethargic especially in quantity surveying practice. Ho (2012) highlighted that QSs are lagged behind compared to architects and engineers in BIM implementation. Lovegrove (2011) commented that the discipline of cost management has been slow to exploit advances in BIM technology and to involve in the new practice of digitally-based collaborative workflows. According to a survey conducted by the Royal Institute of Chartered Surveyors (RICS), 10% of QSs used BIM regularly (RICS, 2011). In addition, a further 29% of QSs had limited involvement with BIM application. This survey revealed low BIM usage and awareness as only a few QSs recognize its potential benefits and even fewer invested time and money on this application (Pittard, 2011). Martin (2011) viewed that there is low adoption of BIM by cost consultants due to lack of awareness. Besides, Tan (2011) revealed that the level of awareness towards the technology of BIM among QSs in Malaysia was relatively low. As a result, it reflected on the low use of BIM and slow adoption among QSs due to lack of awareness.

Therefore, it is crucial to increase understanding among QSs pertaining to this technology in adhering to the requirements expected by clients and industry. As pointed out by RICS (2011), QSs should adopt BIM into practice to gain cost effective and provide more value added services as expected by the client. Furthermore, Ho (2012) provided an insight that QSs will be in a disadvantage position in the future if they do not adopt BIM for practice, whereas architects and engineers are catching up with the pace of BIM technology. Olatunji (2010b) highlighted BIM has the potential to revolutionize quantity surveying practices, and hence the influence of BIM on this profession is considerable. With regard to this, this research conducts a study on the quantity surveying practice associated to BIM application.

1.2 Problem Statement

Researches that look into trends regarding BIM implementation have increased in the recent years. However, the implementation of BIM in quantity surveying practice has not explored yet. Nevertheless, there is a surge of studies that has reported the BIM implementation from design perspective in architectural and engineering practices by several scholars (Staub-French and Khanzobe, 2007; Moum, 2010; Cetiner, 2010; Xie et al., 2011; Arayici, 2009). Olatunji et al. (2010a) and Mitchell (2013) also highlighted that most studies have focused on BIM application in design phase of a project. There is a dearth of research on investigations into potential of BIM in cost management activities such as cost planning, estimation and quantification related services provided by the quantity surveying profession (Olatunji et al., 2010b; Wong et al., 2011; Perera et al., 2012; Mitchell, 2013), which result in low awareness among QSs. A research carried out by Perera et al. (2012) concluded that a majority of quantity surveying practitioners are unsure of BIM development, usage, and impact in their practice which result in low awareness. There is lacking of information regarding the characteristics and the appropriate uses of nD modeling (Sexton and Barrett, 2004;

NAHB, 2001; Anumba, 1998). In addition, Thurairajah and Goucher (2013) undertook a study and concluded that QSs are generally aware of BIM, but there is an overall lack of knowledge and understanding of what it is. Lack of studies makes it extremely difficult for QSs to fully understand the application of BIM which results in doubts about the capability of BIM in their practice. Furthermore, QSs who are unfamiliar with BIM application would tend to adapt back to conventional working method. Lack of information regarding BIM application in quantity surveying practice, along with uncertain capability from this has caused reluctance among QSs to implement the new technology.

In order to improve this situation, Pittard (2011) has addressed this point by stating that the focus has to be on awareness to promote potential of BIM within the surveying profession. Additionally, there is a need to create greater awareness of the potential and the benefits of BIM technology in order to stimulate demand and ensure implementation (RICS, 2011). Alufohai (2012) reinforced this view by stating that the first strategy in promoting the adoption of BIM is to increase awareness of the technique, the tools employed, and their benefits. Meanwhile, Nagalingam et al. (2013) urged that understanding of how BIM can help to perform quantity surveying tasks is vital. Taiebat and Ku (2010) also pointed out that lack of understanding of what BIM is, what it can do and what its capabilities are, had been important factors that prevent the construction industry players from adopting BIM. Thus, it is imperative to identify the capabilities offered by BIM application in quantity surveying practice to gain understanding among QSs.

This study has reviewed the prior studies of BIM application in QSs-related tasks and cost management aspect. In reviewing the literature, little studies have provided a comprehensive list of capabilities of BIM in quantity surveying practice during pre-construction stage. As pointed out by Wang et al. (2014), the full capabilities of BIM in five-dimensional (5D) aspects have not been well explored. Besides, many studies (Suermann and Issa, 2007; Griffis et al., 1995; Fischer and Koo, 2000; Eisenmann and Park, 2012; Parvan, 2012; Sacks and Barak, 2008; Sun and Zhou, 2010; Yang et al., 2007) have examined the relationship between BIM application and project performance, but little attention has been given to link the BIM capabilities in quantity surveying practice during pre-construction stage to project performance in the construction industry.

It is noted that it has remained unclear to which capability of BIM in quantity surveying practice has an impact and is related to project performance. As highlighted by Wang et al. (2014), the studies of how BIM application can help the QSs in a project are limited. Insufficient understanding on the impacts of BIM application may result in poor performance that could cause a project to face the risk of failure due to lack of knowledge on the impact (Eisenmann and Park, 2012). Besides, the lack of focus on the BIM capabilities in quantity surveying practice and project performance hinders QSs from utilizing the BIM application. Limited research is carried out regarding this area, thus creating the need for further investigation. In tandem with this, relationship between capabilities of BIM in quantity surveying practice during pre-construction stage and project performance will need to be investigated to extend knowledge in this area. With regard to this matter, this research was undertaken to identify the capability of using BIM in quantity surveying practice during pre-construction stage and the effect it has on the project performance. This is because, realized in capabilities of BIM will allow QSs to gain understanding on the potential of BIM technology in their practice and also how BIM adoption in their practice may impact the project performance. It is within this context, this research proposed to develop a relationship framework to facilitate understanding and awareness among QSs on the BIM capabilities and their effect on project performance.

1.3 Aim and Objectives

This study aims to develop a relationship framework between BIM capabilities in quantity surveying practice during pre-construction stage and project performance in time, cost, and quality aspect.

The study is an attempt to examine how the adoption of BIM at the early stage in quantity surveying practice impacted project performance in time, cost, and quality aspects, which in turn formulate into a relationship framework. It has been noted that BIM application in quantity surveying practice during pre-construction stage can have significant effect on the project performance which can shape the outcome of a project (Mitchell, 2012).

In order to achieve the aim, the objectives of the study are structured as in the followings:

i. To identify the BIM capabilities in quantity surveying practice.
ii. To examine the extent to which these BIM capabilities in quantity surveying practice have an impact on project performance.
iii. To establish the relationship between BIM capabilities in quantity surveying practice and project performance.

1.4 Research Scope

This research studied the BIM application in quantity surveying practice by looking into the perspectives of QSs. Therefore, the target respondents and interviewees were QSs who were employed as client consultants, with primary roles of managing and controlling project costs. Moreover, BIM application in this research had mainly focused on three-dimensional (3D) and five-dimensional (5D), as these are relevant to the quantity surveying practice.

Furthermore, in order to gain better understanding of the roles of QSs in their practice, this research referred to the Royal Institute of British Architects (RIBA) Plan of Work 2013 because quantity surveying is an important profession that provides cost management services along the RIBA Plan of Work. Subsequently, it guides to identify the BIM capabilities at each work stages. Thus, the identified BIM capabilities will be placed in context of work stages within the quantity surveying practice. As such, the identified BIM capabilities engage in a structured and clearer manner.

In addition, this research focused on the capabilities of BIM in pre-construction stages. The pre-construction stage is an influential stage and it is a foundation for a successful project as many decisions on cost and time are made during this early stage, which give impacts on the project performance. By identifying the capabilities of BIM during this early stage and highlighting them to QSs, it is hoped that these capabilities would contribute to better project performance when QSs adopt BIM at the pre-construction stage.

1.5 Research Methodology

This research was carried out by four phases to achieve the research aim and objectives. In ***Phase 1***, BIM capabilities were identified through review of the literature. RIBA Plan of Work was used as a template to understand the tasks provided by the QSs, and subsequently the BIM capabilities were identified at each work stage. Various means were used to gather information to build the foundation of the study, such as books, academic journals, articles, library searches, electronic journal databases, conference proceedings, theses, and industrial and organizational reports that focused on BIM application in cost aspect or QSs related tasks. A list of capabilities was generated after the review of literature was conducted. This formed the basis for the development of a conceptual framework of the relationships between the capabilities of BIM in quantity surveying practice and project performance. In supporting the findings from the literature, ***Phase 2*** of the research involved preliminary interview with 8 QSs who adopted BIM in their practice. The purpose was to confirm and to validate the capabilities of BIM if they are relevant to quantity surveying practice. The conceptual framework was refined after semi-structured interviews. The list of the BIM capabilities was extracted from literature reviews and preliminary interview, to be included in the next phase.

In ***Phase 3***, the questionnaire design was developed to examine the relationship between BIM capabilities and project performance. 131 questionnaires were sent to quantity surveying organizations after sampling determination. Before the questionnaire was sent out, the questionnaire was designed and refined after content validation and pilot study. The results were analyzed by using Statistical Package for the Social Science (SPSS). The relative level of importance of BIM capabilities was determined in order to rank the capabilities. Correlation analysis was performed to assess the relationship between BIM capabilities and project performance in time, cost, and quality aspects while logistic regression was employed to examine the extent to which these BIM capabilities have an impact on project performance in time, cost, and quality aspects.

Next, in order to validate the results obtained from the questionnaire, ***Phase 4*** was carried out. It involved semi-structured interview with 15 QSs to obtain further detailed information about the capabilities of BIM and their identified relationships to the project performance. The purpose of validation is to check on the quality of the data and results so that they are valid and reliable. In sum, a mixed method of quantitative and qualitative approaches was employed to achieve the research aim and objectives. With the findings, the relationship between BIM capabilities and project performance was established and developed into a framework. The details for each research methods, research design and justification are presented in Chapter 4. The summary of research procedure in phases is shown in Figure 1.1.

Phase 1 *Literature review*	**Phase 2** *Preliminary interview*	**Phase 3** *Questionnaire survey*	**Phase 4** *Semi-structured interview*
<u>Objective 1</u> To identify the BIM capabilities in quantity surveying practice.		**<u>Objective 2</u>** To examine the extent to which these BIM capabilities in quantity surveying practice have an impact on project performance.	**<u>Objective 3</u>** To establish the relationship between BIM capabilities in quantity surveying practice and project performance.

Figure 1.1: Summaryof Approached Methods

1.6 Significance of the Research

BIM adoption has been gaining increased support by the industrial bodies and regulators in Malaysia. As urged by former director-general of Public Works Department (PWD), Datuk Seri Dr Judin Abdul Karim (2010) and former Work Minister of Malaysia, Datuk Shamin Abu Mansor (2012) in their speeches, it is essential to consider the application of BIM in practice as the application will be beneficial for the Malaysian construction industry in future. The implementation of BIM is certain to become increasingly important as it offers abundant benefits to the construction industry. Hence, more researches on the area of BIM application are needed as they will be beneficial for the construction industry.

This research had undertaken the effort to study the application of BIM in quantity surveying practice due to the limited research found in this area, as highlighted in previous section, thus creating the need to conduct a study. It broadens the area of BIM research in the construction industry by identifying the list of BIM capabilities in quantity surveying practice. It contributes to the knowledge on how BIM capabilities can improve the performance of QS by adopting BIM at the early stage. Nagalingam et al. (2013) stressed that it is vital to understand BIM in quantity surveying practice; hence capabilities of BIM in quantity surveying practice are indispensable to highlight for better understanding. As addressed by Ho (2012), QSs who are slow to adopt BIM will lag behind compared to other professions which would affect their professionalism and services provided. Thus, this research is able to increase awareness among QSs through an understanding of the BIM capabilities in their practice. It then encourages QSs to benefit from the use of BIM for performance enhancement and to move away from the traditional, inefficient and old working methods.

Moreover, many previous studies have shown the impact of BIM application on project performance. Nonetheless, this research looked into BIM capabilities in quantity surveying practice and their relationship with project performance, as there is lack of study. Thus, it contributes to the gap on how BIM capabilities in quantity surveying practice can influence project performance. By establishing the relationships between BIM capabilities and project performance in a framework, it assists the QSs to assess the project improvement that can be delivered through the use of BIM in their practice. The relationship framework contributes to the body of knowledge on project performance in the construction industry. Understanding how BIM capabilities affect project performance can be a deciding factor for QSs to get involved in it. It is to show that the application of BIM in quantity surveying practice does matter in the quest for performance improvement on construction projects. Hence, this research had been essential in drawing the attention among QSs on the urgency to cope with BIM knowledge to achieve greater project performance outcomes.

Furthermore, this research creates alert to the government, the software vendors, and the professional bodies on the BIM benefits and increase awareness among QSs by highlighting the list of BIM capabilities identified and the relationship framework developed in this research. Moreover, it can be used for quantity surveying organizations for promoting BIM capabilities and to deliver the relationship between BIM capabilities in quantity surveying practice and project performance. The adoption of BIM among QSs has been low due to lack of awareness and understanding. With regard to this, it is necessary to increase the awareness among QSs. These parties play a pivotal role in promoting the capabilities of BIM in quantity surveying practice. As the application of BIM is increasingly widespread, QSs will need to adapt accordingly to provide more sophisticated cost management services by incorporating BIM in their practices.

1.7 Outline of Thesis Structure

This study has been structured to 8 chapters and below is the summary of each chapter in this study:

Chapter 1: Introduction

The first chapter is the background of the study. It comprises of introduction, problem statements, aim and objectives, research methodology, significance of the research, and outline of thesis chapters.

Chapter 2: Building Information Modeling (BIM) Application in Construction Industry

This chapter provides an overall understanding on BIM application in the construction industry. This includes the definition of BIM, history, evolution, features and, its application in the project life cycle. The application of BIM in various selected countries is also explored.

Chapter 3: Building Information Modeling (BIM) Application in Quantity Surveying Practice

This chapter begins by discussing the roles and the performance of QSs in the construction industry. The chapter also explains how BIM application can benefit QSs as compared to traditional methods. A review of prior researches pertaining to BIM application in QSs related tasks is provided to form the study background. Next, the capabilities of BIM in quantity surveying were identified following RIBA Plan of Work 2013.

Chapter 4: Research Methodology and Design

This chapter describes how the study was designed and conducted to achieve the aim and the objectives of the research. It includes research design, strategy, data collection and analysis methods.

Chapter 5: Preliminary Interview Results

This chapter presents the results from the preliminary interview conducted with 8 QSs. A list of capabilities of BIM was finalized to be included in the quantitative questionnaire survey.

Chapter 6: Questionnaire Data Analyses

This chapter presents quantitative analyses collected from the questionnaire survey. The findings were presented and compared with previous literature findings.

Chapter 7: Interview Validation Results

This chapter presents the qualitative interview results with 15 QSs. The purpose is to validate the survey results that conducted from the previous stage.

Chapter 8: Conclusion and Recommendations

The last chapter summarizes the overall research findings and results based on the objectives. At the end, it provides the conclusion and recommendations for this research.

1.8 Summary of Chapter

This chapter introduces the background of the research. A brief introduction of BIM, how it has developed into an essential tool in the construction industry, and its relevance to the quantity surveying profession are presented. The need to conduct a study on BIM capabilities in quantity surveying practice during pre-construction stage and their relationships with project performance were also highlighted in this chapter. The chapter briefly explains the research methodology of the research and the significance of conducting this research. A summary of the thesis structure is also presented to offer an overall view of the whole research.

CHAPTER 2

BUILDING INFORMATION MODELING APPLICATION IN CONSTRUCTION INDUSTRY

2.1 Introduction

The purpose of this chapter is to develop an understanding of the BIM application in the construction industry. This chapter begins with an overview of the nature of construction industry and how application of BIM brings benefits to the construction industry. Next, the background information related to BIM with specific focus to definition, history, evolution, and features are presented. This is followed by discussion on BIM applications in the project life cycle, mainly design, construction, and maintenance stages. At the end of the chapter, the development of BIM implementation in various selected countries around the world is captured to offer a better global perspective on BIM.

2.2 The Construction Industry and BIM Application

The construction industry is unique in terms of its characteristics of fragmented nature (Isikdag et al., 2007). It is believed that fragmentation within the industry itself has inhibited improvement in its performance (Bouchlaghem et al., 2004; Aouad et al., 2003). Many evidences have pointed out that the fragmentation in the construction industry is the root cause of many problems that occur in a construction project. According to Marshall-Ponting and Aouad (2005), the fragmented nature of the construction industry has reduced the performance in the industry such as project delays, cost overrun, information wastage, repetition and replicated works. Meanwhile, Anumba and Evbuomwan (1997) highlighted that fragmentation in the construction industry has created adversarial culture and information with data generated at one stage that could not be automatically available for re-use at later stage which results in poor flow of information. Moreover, poor coordination between project parties (Lee and Sexton, 2007; Succar, 2009), difficulties in promoting collaborative (Marshall-Ponting and Aouad, 2005) and ineffective communication (Lee and Sexton, 2007; Marshall-Ponting and Aouad, 2005) are problems that arise from fragmentation nature of the construction industry. Hence, the fragmentation nature has created numerous problems in the construction industry which leads to unsatisfactory project productivity and performance.

Furthermore, Sommerville et al. (2004) indicated that the construction industry is regarded as a highly inefficient industry that relies on traditional means of communications which is based on the traditions of paper. The medium of communication among project participants is two-dimensional (2D) drawings and these drawings are not integrated, thus usually pose conflicts and misinterpretation. Moreover, large volumes of information from multi-disciplinary disciplines result in difficulty to manage and to exchange information across disciplines. These methods are inefficient, labor intensive, and greatly susceptibility to error. Hence, it has decreased in documentation quality and significant losses are accrued in the construction industry due to lack of interoperability between the various disciplines (Macdonald and Mills, 2011). With regard to this, project performance is affected.

Moreover, much has been written about the inefficiencies of the construction industry that are associated with fragmentation and traditional way of communication, presented by Smith (2010) and Panaitescu (2014). The errors and problems attributed to this practice have led to financial losses and wastes in the construction industry. Based on the publication of National Institute of Standards and Technology (NIST) entitled *Cost Analysis of Inadequate Interoperability in U.S. Capital Facilities Industry*, continued use of paper-based business practices, lack of standardization in documentation, and inconsistent technology adoption among stakeholders were the key reasons for this massive loss of financial resources (Gallaher et al, 2004). This study reported that lack of software interoperability has cost the industry $15.8 billion annually. Besides, it is noticeable that the construction industry is under pressure for performance improvement that is caused by the characteristics of fragmentation. Therefore, it is imperative to rectify and to overcome fragmentation and inefficient practices in the construction industry.

Therefore, it is believed that the adaptation of new technology enhancements is considered as an essential mechanism to improve the construction performance by eliminating industry fragmentation. Mihindu and Arayici (2008) stressed that adaptation of building information modeling (BIM) technology has been inevitable. As articulated by several scholars (Jordani, 2008; Bernstein and Pittman, 2004; Shen and Chua, 2011; Davidson, 2009), BIM is perceived as the catalyst to eliminate industry fragmentation and inefficiencies. McCuen (2008a) also mentioned that BIM acts as a mean to provide the construction industry with an opportunity to improve business processes in the design, construction, operations and maintenance of a facility.

The concept of BIM is to construct a building virtually in a model prior to building it on site. It is possible to stimulate and to analyze potential impacts, identify possible mistakes and errors, and most importantly, make adjustments before the building is constructed. This approach avoids serious impacts to the project as most of the problems and issues have been identified and resolved earlier. As explained by Haron (2013), most of the relevant aspects can be considered and highlighted before instructions for construction are issued when a project is planned and built virtually in the model. Furthermore, instead of sharing information through paper based documents, BIM utilizes a single shared repository that contains all project information that could be accessed by all project participants. Therefore, BIM is viewed as the solution for improving and rectifying the inefficiencies in the traditional business processes of the construction industry, as outlined by McCuen (2008a).

In addition, much has been written about the benefits of BIM application. Stanford University's Center for Integrated Facilities Engineering (CIFE) reported BIM provided a 40% reduction of unbudgeted changes; cost estimation accuracy within 3% as compared to traditional estimates; 80% time reduction in cost estimate generation; contract savings up to 10% through clash detections; and reduced project completion time by up to 7% (cited in CRC Construction Innovation, 2007). Meanwhile, Eastman et al. (2008) documented the benefits of BIM application into four categories of project process: pre-construction, design, construction and fabrication, and post-construction. Thus, BIM has the capability to save cost, reduce time, and improve the quality of work or in other words, significant improvements can be attained in terms of time, cost, quality, and efficiency in the construction projects. Therefore, it is indispensable for the construction industry to get immersed into the BIM application.

2.3 Building Information Modeling (BIM)

The background of BIM that covered definition, history, evolution, and features are explained in details in following section.

2.3.1 Definition

It is crucial to differentiate and to understand the definition of Building Information Modeling and Building Information Model. Wong et al. (2009) stated that the terms "Building Information Modeling" and "Building Information Model" are used interchangeably, but to be precise, there is a difference between these two terms. The former is classified as a process, while the latter is a product.

Davidson (2009) pointed out that BIM may be variously viewed as a type of software (tool), a technology and related deployment processes. In the context of tool, BIM is an innovative tool for managing information of a project throughout the life cycle of the project. It can be defined as a tool that supports either existing or new construction project delivery processes. Based on a report by the National Institute of Building Science (NIBS, 2008), the prominent premise of BIM allows different stakeholders at different project phases to collaborate together in a common platform to insert, extract, update or modify the information stored in the model. BIM has provided a platform to project participants for collaboration to better coordinate information and improve communication. All information pertaining to buildings such as design, costing, specification, construction, and maintenance are stored in a single database.

Besides, in the context of BIM as a process, the concept is supported by Schwegler (2001), Lee et al. (2006), and Azhar et al. (2012). These authors defined BIM as a virtual process of using computer generated model to simulate planning, design, construction, and operation of a facility. Building information in different project phases is created and managed in an interoperable way by allowing project participants to share, integrate, and assess building information in the model more accurately and efficiently than traditional processes. BIM is a process that drives a new project delivery method which requires close relationships among its project participants and fosters open exchange of electronic information. It requires early involvement of all project stakeholders in the process. Hence, the traditional project delivery systems are no longer suitable in BIM-based projects. Figure 2.1 illustrates the differences between the traditional and the BIM processes.

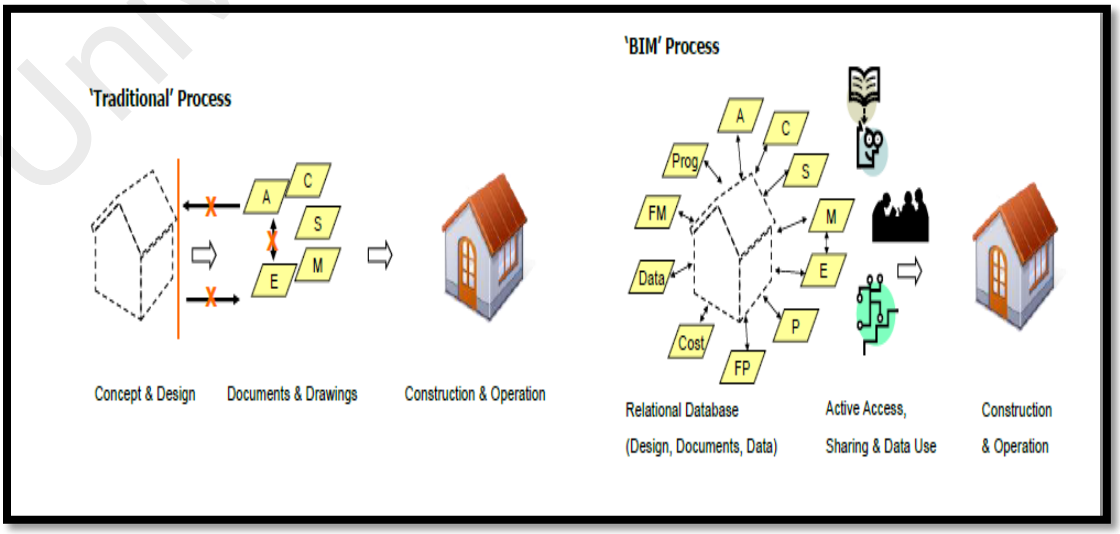

Figure 2.1: Differences between Traditional and BIM Process (Azhar, 2012)

On the other hand, from perspective of technology, Gu and London (2010) and Gu et al. (2008) defined BIM as a technology approach that all building information throughout the project life cycle are stored, managed, shared, accessed, and updated by project participants in the form of a data repository. It is considered as model-based technology that is linked to a database of project information in a consistent, structured, and accessible way. The BIM technology is hailed from object-oriented parametric modeling technique (Azhar et al., 2008a) which determines BIM as a technology. This parametric is referred as change propagation, whereby a change made in any representation is propagated across the model. Figure 2.2 depicts the visual representation of BIM concept.

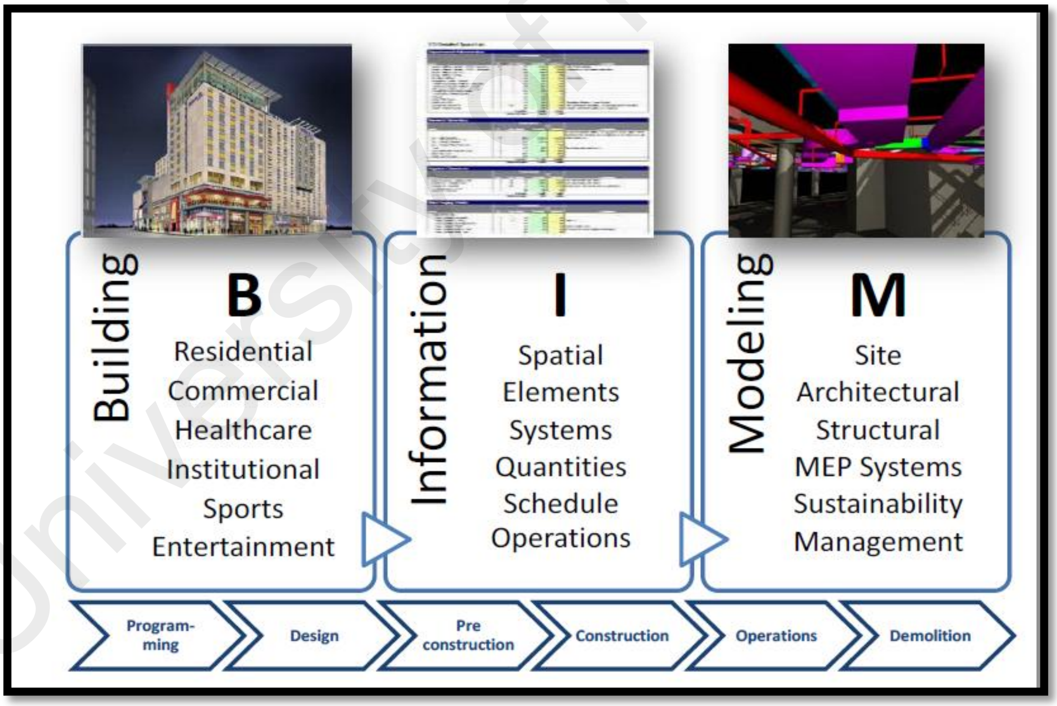

Figure 2.2: A Visual Representation of BIM Concept (Azhar, 2012)

In short, BIM has been defined separately by different authors in three categories; as a tool, process, and technology. Eastman et al. (2008) have provided a definition that encompasses all these three categories. Eastman et al. (2008, pp. 467) defined BIM as *"tools, processes, and technologies that are facilitated by digital and machine-readable documentation about a building, its performance, its planning, its construction, and later, its operation*." In their context, BIM is an associated set of processes of using modeling technology to produce, manage, and share information in a model with the use of BIM related tools. It is a process of project simulation through a 3D model and link information of project life cycle associated to it. Hence, BIM is described as a tool, a technology, and a new way of working method, which is aimed to improve delivery of the facility.

Meanwhile, the National Building Information Model Standard (NBIMS) (2007, pp 21) defined a building information model as *"a digital representation of physical and functional characteristics of a facility. As such, it serves as a shared knowledge resource for information about a facility, forming a reliable basis for decisions during its life-cycle from inception onward."* Hence, building information model is the result of the modeling activity, representing the physical and functional characteristics of a building and containing all the information pertaining to the building that can be used for decision making throughout the project life cycle. Therefore, the resulting model is a data rich 3D parametric virtual model that contains precise geometry and relevant data needed to support the design, procurement, fabrication, construction, and maintenance activities of a building (Eastman et al, 2008). With these features, the model can be used to demonstrate the entire life cycle of the building (Bazjanac, 2006) which facilitates cooperation between different project parties in the project.

Nevertheless, despite all definition, BIM is not just a tool or software to be installed in the workstation. Instead, it is a combination of software and process. Jayasena and

Weddikkara (2012) defined it as an information technology (IT) solution for integration of software applications and IT tools to design and to construct a building in a common collaboration platform. BIM application does not only use 3D intelligent models but also requires significant changes in the project delivery processes and workflow (Hardin, 2009). It is noted by Davidson (2009) that BIM requires a new working method and a whole paradigm shift. The construction industry is required to have a paradigm shift from 2D-based documentation and delivery processes to a digital prototype and collaborative workflow. Besides, work processes and practices of all project parties will radically change with the adoption of BIM.

2.3.2 History of BIM

BIM is a successor to computer aided design (CAD) (e.g. AutoCAD) which started in the 1980s. In the early 1980s, architects began to use personal computer-based CAD rather than drafting method in their practice. Instead of manually drafting on drawing boards, construction documents and shop drawings were plotted from computers (Autodesk, 2002). Drawing files were exchanged and shared with project participants rather than physical underlay drawings. These types of files do not only store graphics, but also conveyed information about the building. Hence, the use of CAD files has evolved towards communicating meaningful information about a building.

However, object-oriented CAD has slowly come to its path in the construction industry in the early 1990s. One of the reasons for the increase in this adoption is because traditionally manual practices rely substantially on human input, which inevitably causes errors or missing information that leads to extra waste. There is absence of inherent coordination between drawings, conflicts checking, and changes in coordination for traditional manual practices. Meanwhile, object-oriented CAD supports the display of building in 3D digitally. Data objects such as doors, windows, and walls, stored in graphical and non-graphical data that carry rich information.

In addition, BIM gets in place when construction participants start to take advantage of the intelligence that is embedded in the model. In a BIM-based workflow, building information is stored and managed in a database that facilitates easy sharing of information. This sharing of project information enables new workflow that allows project participants to capture, insert, extract, and manage data in a single data repository. By storing and managing information in this way, changes in the data that often occur can be logically propagated and managed by BIM rather than relying on disparate versions or copies.

2.3.3 Evolution of BIM from CAD

Figure 2.3 is the BIM Maturity Diagram prepared by Mervyn Richards and Mark Bew in 2008. It shows the evolution from the traditional CAD to the introduction of an integrated and interoperable BIM. Moreover, it captures different levels of sophistication or maturity that range from Level 0 to Level 3 in the use of BIM. Using advanced technology can provide tremendous benefits, but the initial step would be a departure from traditional ways of working. Moving to object CAD technology from CAD-based technology can be an incremental change, but shifting to parametric building modeling technology for BIM requires a new way of working (Autodesk, 2003).

2.3.3.1 Level 0 - Unmanaged Computer Aided Design (CAD)

At this level, the construction industry adopted a document-based way of working by exchanging information either via paper or electronic. When a document is produced, by hand or computer, it is presented in a 2D format with paper or in a computer as an unstructured stream of text or graphic entities which is difficult to be reused or checked (Nisbet and Dinesen, 2010). The outputs of 2D drawings are still presented on paper or PDF files.

The CAD applications were adopted to represent 2D geometry via graphical elements, such as lines, arcs, symbols, etc. (Alufohai, 2012). For instance, walls are merely represented as parallel lines. The lines do not carry any intelligence about the elements they represent. It is classified as "level 0" style of working because there is absence of information sharing and collaborative working.

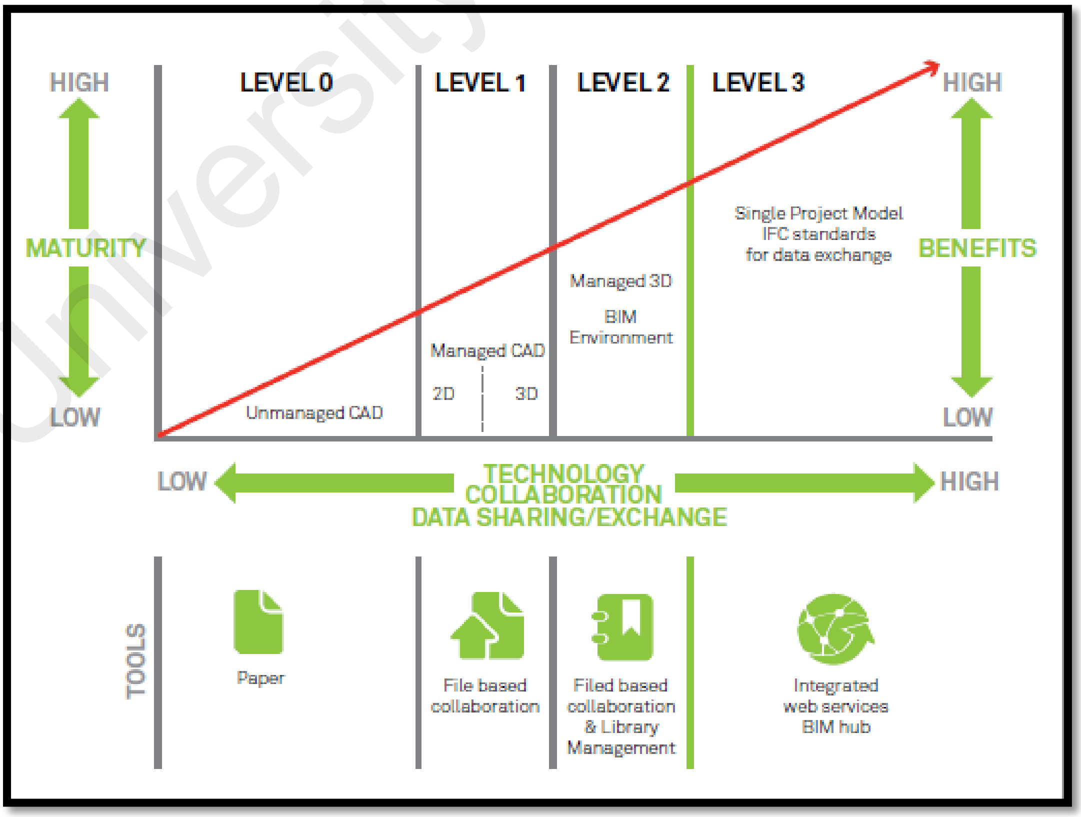

Figure 2.3: BIM Maturity Levels based on Richards and Bew (Connaughton, 2012)

2.3.3.2 Level 1 – 2D and 3D

At "level 1", CAD is managed in 2D or 3D format. 2D format is still using but more complex information such as the relationships between elements could not be represented. 2D CAD drawings have been slowly replaced by tools that could create 3D views of a design. Drafting is often in 3D with greater use of common standards once the construction players start to structure and share information. However, 3D CAD mainly focuses on creating geometry supporting visualization. In this level, data are managed standalone and cannot be shared collaboratively among project members. Collaboration and integration are absent in this level.

2.3.3.3 Level 2 – BIM

When the industry has already begun to exploit shared and structured information, this scenario leads to steady rise to "level 2" on this upward curve of industry improvement. This level constitutes a managed 3D environment in separate discipline BIM tools with relevant data attached. Integration is accomplished on the basis of proprietary interfaces, 4D program data, and 5D cost elements (Kalzip, 2012; Elliott, 2012). However, the full potential of the data have not been realized at this level. This is due to the fact that different software vendors have their own proprietary systems as they use different rules for the definition of object families, so their systems are not interoperable (Nisbet and Dinesen, 2010). The single model does not allow collaboration information as the systems are not interoperated.

2.3.3.4 Level 3 – Integrated BIM (IFC)

At this highest level, it is a completely open process. Data are integrated by web services compliant with emerging Industry Foundation Classes (IFCs) standards which are managed by a single collaborative model server (Kalzip, 2012; Elliott, 2012). IFC is a file format developed by the International Alliance for Interoperability (IAI) that supports the exchange and the use of data across technological platforms (Dawood and lqbal, 2010).

IFCs provide a set of rules and protocols that determine how the data represent the building in the model are defined, and the agreed specification of classes of components that enables the development of a common language for construction (Lee and Sexton, 2007). Therefore, it is known as integrated BIM with IFC standard which ease the flow of information, promote collaborative use of information, and overcome the interoperability problem. In this way, rich, useful, and structured information can be shared between project participants in a standard method without loss of accuracy to ensure efficiency and consistency. It allows BIM data to be operated at its full potential for different project stages.

2.4 Features of BIM

CAD and BIM applications are two successive techniques that are deployed to redress certain inadequacies in manual drafting and design methods (Olatunji et al, 2010b). However, CAD drafting is limited to 2D or 3D drawings which are based on geometric data only. Wong et al. (2010) stated that BIM is an alternative to the traditional, paper-based, 2D or 3D CAD-based. It is known as data-rich, object-oriented, intelligent, and parametric digital representation of the facility. Thus, project participants are allowed to insert, extract, update, and modify data and information that can be used to make decisions and to improve the process of delivering the building (AGC, 2005). There are certain features and capabilities promised in BIM, which are different from CAD. Understanding the concept of these parametric objects is a key to comprehend what a building information model is and how it differs from traditional 2D design. Figure 2.4 summaries the features of BIM.

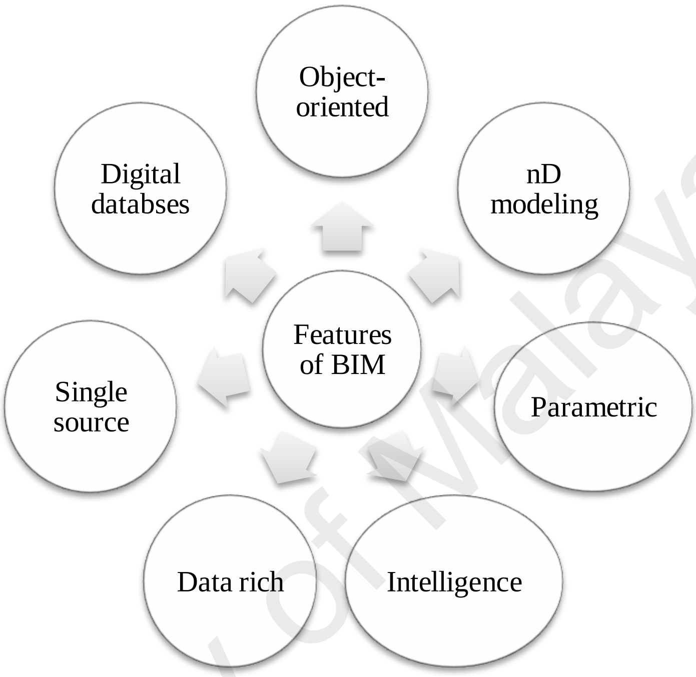

Figure 2.4: Features of BIM

2.4.1 Object-oriented

BIM creates an object-oriented database that is made up of intelligent objects, for example, walls, doors, and windows, which are capable of storing both quantitative and qualitative information about the project (Haron et al., 2009; Davidson, 2009). BIM is defined as object-oriented in nature as it contains specific characteristics, properties, and rules. The rules and characteristics embedded in objects are allowed for adjustment to the objects automatically when a change is made to the model as the information in the BIM is interconnected. Traditionally, a designer would draw a line to depict the position of a wall or door which can only be interpreted by certain people. However, with BIM, information structures of the design are presented as objects (walls, columns, windows, doors, etc.) with attributes and relationships between the building elements (Babič et al., 2010).

2.4.2 nD Modeling

Multi-dimensionality is one of the well-known features of BIM. The objects of the model can be in different states in different phases of the lifecycle in order to represent the 'N' dimensional information about the building (Isikdag et al., 2007). Lee et al. (2003, p.37) defined nD model as *"an extension of the building information model, which incorporates multi-aspects of design information required at each stage of the lifecycle of a building facility."* Thus, BIM is not just limited to 3D geometric, but further dimensions include "time" (4D) and "cost" (5D) factors. Table 2.1 tabulates the nD modeling of BIM.

Table 2.1: nD modelling

2D	3D	4D	5D
Two dimension with width and length information on flat plan	Three dimension with width, length and height information that can be used for visualization	Incorporate time aspect for model based project sequencing	Incorporate cost aspect for model based cost estimating

4D model is formed by incorporating construction activities represented in time schedule that are linked to a 3D design model to develop a real-time graphical simulation of construction progress. The time dimension consists of scheduling and sequencing, which are beneficial for a contractor to evaluate project workflow for planning to improve productivity. Meanwhile, 5D model is created by integrating the project cost to the BIM model. Automatic analysis of costing and quantities can be extracted from the BIM model which enables instant generation of cost budgets.

2.4.3 Parametric

One of the main and important features of BIM is parametric, which makes building information more reliable and coordinated. Davidson (2009) reinforced this view and stated that parametric modeling sets BIM apart from traditional 2D drafting software as BIM works with coordinated and computable data. Zeng and Tan (2007) supported this statement by stating that BIM is based on intelligent parametric modeling technology that replaces traditional computer aided architectural design.

The term "parametric" describes a process by which adjacent element or assembly is automatically adjusted when one element is modified in order to maintain a previously established relationship (Stine, 2011). Parametric modeling uses parameters (numbers or characteristics) to determine the behavior of a graphical entity and to define relationships between model components (Autodesk, 2007). Parametric modeling combines a data model (geometry and data) with a behavioral model (change management) that gives meaning to the data through relationships (Autodesk, 2003). Due to the relationships between model components, parametric change engine will determine which other related elements that need to be updated and changed when the user modifies an element in the model.

Furthermore, Sackrison (2008) stated that as changes are made to the model, these functional relationships and all other information related to the building project are automatically updated. The parametric model understands all the features and the interactive rules of the components. Meanwhile, Autodesk (2007b) indicated that the changes never start with the entire building model; it always starts with a few elements explicitly touched by the user and continues with selective propagation of changes that minimizes the number of elements to be updated. It eliminates manually updated changes which are error-prone and tedious. Moreover, whether views (such as plans, sections, and elevations) or sheets (such as component categories, door, and window list), they all remain related to all the views of the model (Zeng and Tan, 2007). Hence, it enhances coordination and maintains consistency of the information whenever there is a change in the model as everything is interconnected.

2.4.4 Intelligence

Moreover, it is noticeable that BIM is “intelligent” due to the relationships that are built into the model. Components within the model know how to interact with one another when changes are made. All information related to the building, including its physical and functional characteristics, project life cycle information, graphical and non-graphical information, appears in a series of “smart” objects (Azhar et al, 2008a). Zeng and Tan (2007) defined that a designer can maintain the smartness of the initial design; for example, a designer can design a door in a wall with its distance to the window at 3 feet. When the design is changed, the system automatically updates the information pertaining to the door, the wall, and the window. Hence, the model is “smart’ by managing the attributes and the relationships between the building components.

2.4.5 Data Rich

Graphical and non-graphical data such as drawings, specifications, and schedules are included in the model. Besides, information such as geometry, spatial relationships, geographic information, quantities and properties of building elements, cost estimates, material inventories, and project schedule (Azhar et al, 2008a) are all available in the model. Hence, BIM is called a rich model because all objects in it have properties and relationships, and this information can be used for data mining to develop simulations or calculations using the model data (CRC Construction Innovation, 2007). All the data included in the model satisfy the needs of all the project stages. Autodesk (2011) observed that early access to the rich information that is contained in the models helps project participants to gain more insight of the project and to exchange ideas. Project-related decisions can be made earlier, rapidly, and effectively.

2.4.6 Single Source

BIM provides a single, logical, and consistent source for all building information (Howell and Batcheler, 2005). All the required data and information throughout design, procurement, construction, operation, and maintenance of a building will be stored and available in one accessible location. The wealth of information, such as aggregate size, materials, purpose, specifications, manufacturer, and price, are available in a single model (Crespo and Ruschel, 2007), which is appropriate for managing information in a central shared location. It makes the information available for use and reuse at every point in the project.

BIM also serves as a centralized shared knowledge resource for project participants (Smith, 2014). It provides a single repository of information base that can be accessed by all project participants. Changes to each item are made in only one place, and so, each project participant sees the same information in the repository (Lee and Sexton, 2007). This feature ensures consistency, accuracy, and accessibility of data. As mentioned by Rowlinson et al. (2010), this ensures and maintains a consistent data format that reduces confusions, errors, and misinterpretations that are experienced by different project participants.

2.4.7 Digital Databases

BIM is also defined as a new method of creating, sharing, exchanging, and managing information throughout the entire building lifecycle (Isikgag et al, 2007). All the information is created and stored in a database instead in a format, such as drawing file or spreadsheet. It will be available for use and reuse at a later stage of the project. The building information is presented on a presentation format that is suitable for a particular user to edit and to review. Although the type of presentation format is distinct for different project participants, all views are in a same information model. Once changes are made by one of the project participants in their presentation format, BIM assures that changes made in any of these views are reflected in all other presentations (Autodesk, 2002) through digital databases. A change to any part is automatically coordinated in this database through the project.

2.5 BIM Deliverables

BIM is an approach to three major phases in the building lifecycle, which are design, construction, and management. McCuen (2008b) stated that BIM utilizes a standardized machine-readable information model for each facility to improve design, construction, operation, and maintenance processes. The model has been proven to be comprehensive and durable to manage building design and project data throughout all phases of the project lifecycle from conception, through design and construction, to operations and maintenance (Wong et al., 2010). Figure 2.5 shows the summarized mind map of potential BIM deliverables organized based on phases of project life cycle.

2.5.1 Design Phase

During the design phase, visualization is the main feature of BIM that enables architects, engineers and contractors to visualize what is to be built in a simulated environment. Hence, it improves the ability of construction players to understand what is being presented. Any potential issues and uncertainties related to design, construction or operational can be identified and detected earlier in the virtual environment. Mistakes can be identified and addressed early in virtual environment before the actual construction of a project, which do not cause serious consequences on the project (Haron et al., 2009). In this context, all the relevant aspects of the project can be considered and planned before the actual construction takes place to avoid abortive work and to reduce construction waste.

Furthermore, BIM is able to improve the accuracy of cost estimates. Material quantities are automatically quantified and extracted to reduce errors and save time. Manning and Messner (2008) identified that sections, perspectives, plan views, and quantity takeoff could quickly (in many cases automatically) be updated to effectively ascertain potential costs. Changes are detected and updated automatically when they are made in the model which ensures accuracy and consistency. A popular use of BIM is for clash and conflict detection. All major systems can be visually checked in BIM for interferences (Azhar et al, 2008b). Any design conflict and clashes can be identified and resolved early to avoid change orders which often cause delay and extra costs.

In the context of site planning and analysis, BIM allows construction participants to review site access in multiple perspectives, transportation routing, and also analyze different alternatives and options simultaneously. A wide range of analyses and checking can be performed, such as design, which can be improved by exploring heating, lighting, and comfort. Moreover, fire and smoke simulations can be identified as well. Besides, some of the greatest applications of BIM are energy and thermal analyses for sustainability purposes. Design changes can swiftly be made and the analysis for rerun, so that the design achieves optimum efficiency (Nisbet and Dinesen, 2010). BIM also allows a facility to be analyzed and determined both for its energy consumption and its other impacts on carbon generation throughout its life cycle.

2.5.2 Construction Phase

During construction phase, BIM plays an important role in planning, scheduling, and sequencing of construction phase. Construction schedule can be developed in BIM, which facilitate planning, monitoring, and visualization of the construction progress. It is difficult to view correctly the work planning at construction site, especially for large and complex projects. As compared to traditional planning methods by using Gantt chart, the actual construction sequence can be visualized systematically with time and cost implications attached which ease planning and monitoring.

Besides, BIM allows for the consideration of alternative approaches to sequencing, site logistic, site access, site planning and layout, and crane and material placement (Haron et al., 2009). Contractors can coordinate the site more efficiently to develop traffic layouts and identify potential hazards at the construction site which can aid in preparing a more realistic site safety plan. Eastman et al. (2008) further explains that this graphic simulation provides considerable insight into how the building will be constructed day-by-day, and reveals source of potential problems and opportunities for possible improvements, which conform to the case studies conducted by Huang et al. (2007), and Koo and Fischer (2000). Moreover, it helps for material ordering, fabrication, and delivery schedules for all building components (Azhar et al, 2008b) to avoid wastage and to remove any potential unproductive activities.

Moreover, constructability is crucial to ensure synchronous of the design and construction planning. Based on a study conducted by Ting et al. (2007), 4D modeling enables its users to visualize the constructability of the proposed construction approach. Any construction issue or problem can be identified and avoided before going to the construction site. Risky construction methods can be identified and designed before it is too late and costly. As asserted by deVries and Harink (2007), BIM is used as an enquiry tool that could solve problems at the early stages in a production process.

2.5.3 Management Phase

Building information model contains complete information about a building from planning until construction. This information can be leveraged for use by facility managers during operation and management stages. Research suggests that 86% of the lifecycle cost of a facility occurs after construction is completed and approximately $10 billion is annually lost in the US due to inadequate information access and interoperability issues during operations and maintenance phases (Newton, 2004). Therefore, the use of BIM at this phase can significantly help to prevent these loses.

In the management phase of the building lifecycle, BIM makes available concurrent information, such as the building spaces, systems, and components on the use or performance of the building; its occupants and contents; the life of the building over time; and the financial aspects of the building (Autodesk, 2003). BIM can be used to access, track, update, and maintain this information to improve the effectiveness of operations throughout the lifecycle of the building. As stated by Jordani (2011), the facility managers can obtain information on product, warranties, life cycle of the product, maintenance checks, replacement cost, installation and repair procedures.

Besides, BIM provides owners and facility manager digital record of information in relation to architectural, structural, mechanical, engineering and plumbing elements of the building. By using information in a BIM record model for asset maintenance, facility managers can evaluate the cost implications of changing or upgrading building assets. Besides, facility manager can produce accurate quantity takeoff of current company assets for financial reporting and estimating the future costs of upgrades or replacements.

Furthermore, using a BIM model for space management will provide area information for space and occupancy which enables the facility team to analyze the existing use of space, evaluate proposed changes, and effectively plan for future needs. On the other hand, building systems simulation and management can be used for tracking performance data from the building systems and for comparing these values to design model predictions. It in turn enables facility managers to ensure that the building is operated based on specified design and sustainable standards, and also identifies opportunities to modify operations for system performance improvement. By extracting information from the BIM model, energy consumption and life cycle cost calculations can be validated via energy modeling, whole building commissioning requirements and Leadership in Energy and Environmental Design (LEED) rating system. Besides, it is believed that consistent access to this type of information will improve cost management in maintaining of a facility.

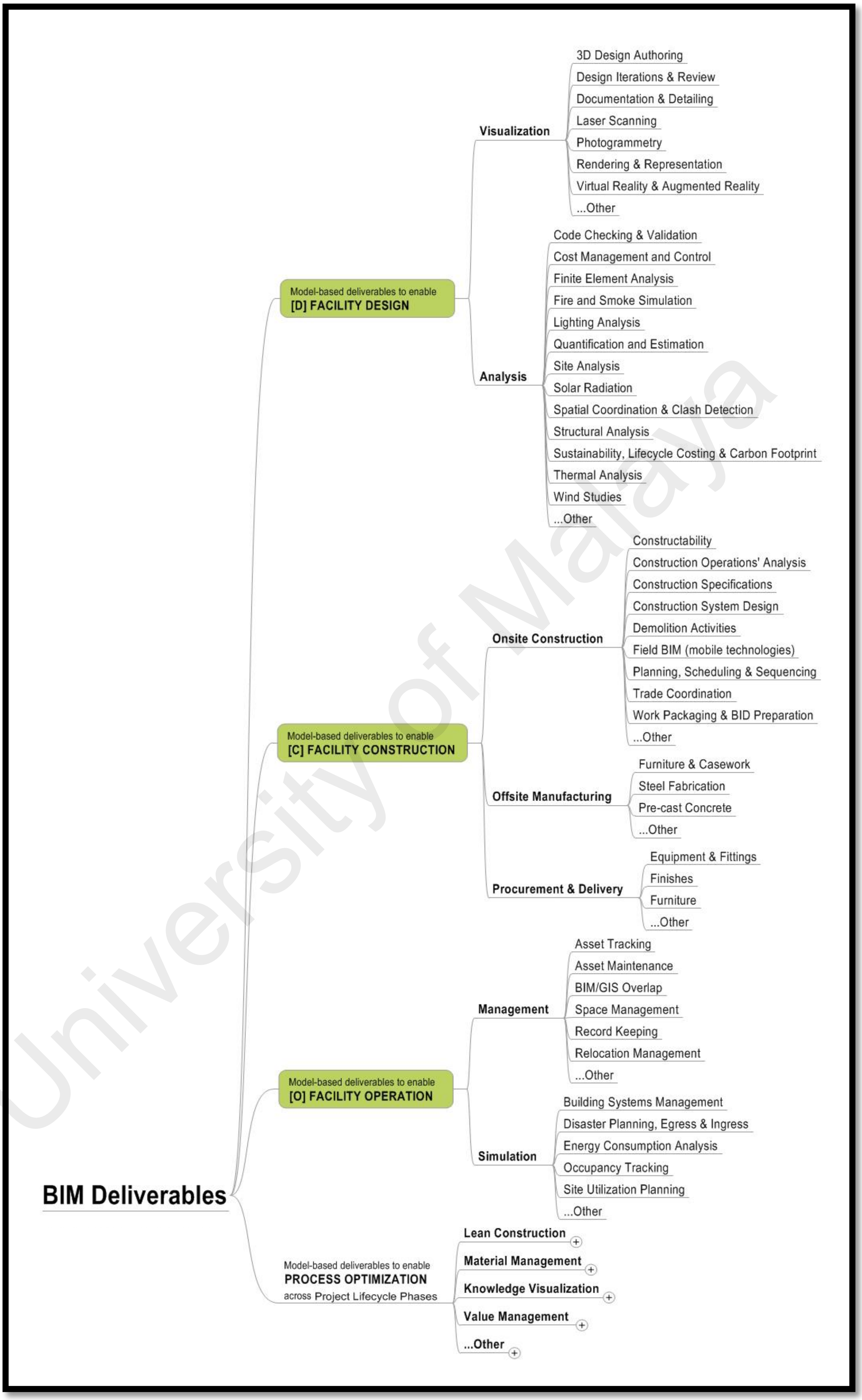

Figure 2.5: A Summary of Model-Based Deliverables (Succar, 2011)

2.6 BIM Application in Multiple Countries

It is noticeable that the growth and developments of BIM have been observed to vary among many different countries around the world. Various initiatives and efforts have been taken to implement BIM in a country. It is crucial to be aware and stay informed about technological developments to attain better global perspective of BIM application. BIM initiatives from the USA, UK, Finland, Norway, Denmark, Singapore, and Malaysia are briefly reviewed in this section.

The USA is a large country that uses BIM as an emerging technology to assist in conceiving, designing, constructing, and operating buildings and also produces a great deal of BIM technology (Wong et al., 2010). In the USA, General Services Administration (GSA) is the main public client who plays an important role in construction and operation of all federal facilities. In order to achieve the objectives of its BIM program, GSA has taken several initiatives. In 2003, a National 3D-4D-BIM program was launched to encourage the use of 3D and 4D technologies over the drawing-based 2D technologies through GSA website. Besides, GSA provides support, such as expert support and assessment for ongoing capital projects to incorporate 3D, 4D, and BIM technologies, and also assesses the industry readiness and technology maturity (Wong et al., 2010). In the design stage, GSA has taken a few initiatives. First, GSA has mandated the use of BIM in the design stage for new buildings designed through the Public Buildings Services (PBS) (Hardy, 2006). Next, GSA has collaborated with BIM software developers to produce a new GSA BIM Guide that assists designers to develop the final concept designs for PBS and to meet GSA's spatial program.

Meanwhile, in the UK, the government has actually mandated the use of BIM. Announced by the Government's Chief Construction Adviser, Paul Morrel, in May 2011, BIM will become a key part of the procurement of the UK public project by 2016. Lack of compatible systems, standards, protocols, and the differing requirements of clients and lead designers have hindered the adoption of BIM. Therefore, the UK Cabinet Office published a "Government Construction Strategy" that documented an entire section on "Building Information Modeling". This strategy not only had a dramatic impact on the UK industry, but also offered the potential to influence BIM implementation on a wider global scale as other countries have also taking note on this strategy (Smith, 2014). Besides, the government, which is supported by the Architectural, Engineering and Construction (AEC) BIM Committee, has developed a few standards that are aimed to provide practical protocols and procedures to AEC firms in the UK for transitioning from CAD to BIM (Khemlani, 2012). Besides, the UK government focuses on developing standards that enable all members of the supply chain to work collaboratively through BIM (Khemlani, 2012).

In addition, the Scandinavian region (Finland, Norway, and Denmark) is considered as the most active in BIM implementation (Wong et al, 2009; Khemalni, 2012). These regions are among the earliest to adopt the model-based design (Wong et al., 2010). They also push for interoperability and open standard in AEC technology embodied primarily by the IFC. The wide adoption is due to the long snowy winters in these countries that make prefabrication in buildings very important, which in turn is greatly facilitated by the data rich and the model-based BIM technology (Khemlani, 2012).

In Finland, the Senate Properties is the public owner who gives great commitment by leading the way on running pilot projects by using BIM and IFC towards wider BIM adoption. The Senate Properties has mandated the use of this model to meet the IFC standard in its project starting from October 2007 (Senate Properties, 2009). All design software packages are checked against the current version of IFC. They have also set up a detailed modeling guideline to convey the modeling data requirements for the project participants at each stage of the design. The guidelines are in Finnish language and cover a number of guidelines on product modeling in detail. They cover general principles of product modeling in construction projects, architectural design, structural design, and building services design (Senate Properties, 2009).

On the other hand, in Norway, the public construction and property management representative, Statsbygg, plays an important role in promoting BIM usage, and requires the use of BIM in all public projects. In fact, Statsbygg aimed to utilize BIM in all phases to a complete extent for projects by the year 2010 (Statsbygg, 2007). BIM manual was developed as Norway's BIM guidelines based on the experience from the Statsbygg's HIBO project that was accomplished by using BIM. The BIM manual is synchronized with the Norwegian standard NS8353 CAD manual and the NBIMS standard from the USA (Wong et al., 2010).

In Denmark, three public owners have initiated BIM application, such as The Palaces and Properties Agency, The Danish University, the Property Agency and Defense Construction Service. They have specified modeling standards and guidelines to adopt BIM in their projects. Wong et al. (2009) claimed that although the government projects in Denmark do not represent a large part of the total property area, their impact on the market created by the IFC requirement is big. A package of 3D CAD guidelines was developed under the Digital Construction Program initiated by the Danish Enterprise and Construction Authority. The guidelines are concerned on both setting up and fulfilling requirements in file and database-based CAD/BIM applications (Wong et al., 2010). This program requires the BIM model to contain exchanged information by using the IFC format for all projects above 5.5 million Euros (Smith, 2014). Moreover, a number of guidelines related to BIM requirements have been developed within this program for BIM adoption.

In Asia, Singapore is one of the earliest countries that have realized the potential of BIM and have implemented BIM at the public sector (Wong et al, 2009; Khemlani, 2012). The Building and Construction Authority (BCA) is the main organization that governs the construction industry in Singapore. BCA has a BIM roadmap that pushes the Singaporean construction industry to use BIM widely by 2015. The roadmap contains strategies and initiatives to facilitate the transition among businesses and professionals from using conventional 2D building plans to 3D models. On the other hand, the Construction and Real Estate Network (CORENET) program is an initiative launched by the Ministry of National Development to drive transformation in the industry through the use of information technology.

CORENET provides information services, including e-information system such as e-NPQS and e-Catalog, integrated submission system such as e-submission and integrated plan checking system. The CORENET e-PlanCheck defines Singapore's Automated Code Checking System, and several authorities in Singapore have participated in the e-submission system which requires BIM and IFC to be used (Wong et al, 2009). The

CORENET e-PlanCheck system allows project designers and engineers to check their designs for regulatory compliance through an internet gateway. Checking non-compliances through this system has been aimed to reduce design errors and ambiguities, minimize the risk of professional liability, and improve overall performance in the design stage.

In Malaysia, the uptake is still relatively new and in infancy stage due to lack of understanding of BIM in terms of its definition, technology, process, and new roles (Haron et al., 2012) compared to other developed countries. However, the adoption is taking place rapidly recently. The Construction Industry Development Board (CIDB) Malaysia has outlined BIM as one of the emerging technologies to be deployed in the construction industry in order to have a systematic management of projects, reduce materials, time, and resources wastage and improve the national productivity (CIDB Malaysia, 2013). The key mover in the BIM adoption and the promotion is government agencies, such as PWD, that undertake the leadership role in BIM implementation in realizing the need for industry players to move together cohesively and build the best practices for virtual design and construction (Tan, 2012b).

Meanwhile, CIDB has taken several efforts to enhance BIM application by providing awareness programs and workshops for the industry. Besides, the National Steering Committee of BIM was established in July 2013 and it consists of relevant government agencies, professional bodies, private sectors, and academia, which aim to facilitate the adoption and the implementation of BIM in Malaysia (CIDB Malaysia, 2013). This committee assists and provides strategic directions to the industry on BIM application by formulating BIM standard manual and guideline as reference for construction players to ensure standardization.

All over the world, a lot of efforts have been driven by numerous governments worldwide to speed up the adoption of BIM. A number of initiatives have been carried out to engage and to inform project parties about the potential productivity gains from BIM application. Besides, the public sector also plays a critical role in leading the industry towards BIM adoption. Support from the public sector can be regarded as the driving force for BIM implementation and it creates a uniform environment for wide acceptance of BIM (Wong et al, 2009).Governments in various countries have taken different initiatives to enhance BIM application in their own countries. On the other hand, active involvement of the private sector in BIM initiative helps to create new business process, partnerships, and collaborations. Moreover, it would influence strong commercial incentives for developing new software and in increasing the capabilities of existing software and hardware used for BIM (Wong et al, 2009). Regardless of their roles in BIM development, strong support, involvement, and collaboration from both public and private sectors would contribute great efforts in promoting and providing support for BIM implementation and development.

2.7 Summary of Chapter

This chapter provides an overview of the nature of construction industry by highlighting that BIM is the remedy tool to rectify the fragmented and conservative characteristics of the construction industry. After reviewing the definition, history, evolution, and features of BIM, there are certain features and capabilities promised in BIM, which are different from CAD. This chapter summarizes that BIM has been adopted widely at design, construction, and maintenance stages. Besides, the literature review shows that BIM application has transformed the way buildings are designed, constructed, and maintained through project life cycle, which can improve project delivery. Findings from the literature also have indicated that BIM initiatives are taking place in different countries to facilitate the adoption of BIM.

CHAPTER 3

BUILDING INFORMATION MODELING (BIM) APPLICATION IN QUANTITY SURVEYING PRACTICE

3.1 Introduction

The aim of this chapter is to list the BIM capabilities in quantity surveying practice during the pre-construction stage following the RIBA Plan of Work 2013. Given that the initial objective of the research had been to identify the capabilities of BIM in quantity surveying, this chapter presents an extensive review of literature pertaining to the BIM capabilities in quantity surveying practice.

The chapter begins with the definition of quantity surveyor (QS), their roles, contribution, and performance in the construction industry. Next, the chapter addresses the inefficiencies of QS in performing their tasks by using traditional methods and how BIM can help to improve the efficiency and performance. A review of the previous studies related to BIM application in QS related tasks was conducted as well in order to identify the study gap. Furthermore, the capabilities of BIM in quantity surveying are discussed by referring to RIBA Plan of Work 2013. With that, a summary of the identified capabilities of BIM in quantity surveying practice is generated.

3.2 The Roles and Services of Quantity Surveyors (QSs)

There are various factors that affect the success of a construction project, but Cheung et al. (2004) mentioned that the ability of key project members, such as QS, was one of the factors that required the effort of QS to perform the project tasks. Quantity surveying profession is a key discipline in the construction industry. The QSs play a vital part throughout the construction process by working closely with other members of the project team such as the architects, engineers, contractors, project owner, and the like.

QSs have been called by many names, such as cost consultant, cost managers, cost engineers, building economists, and construction accountants. Different authors have used different names in their studies (RICS, 1991; Seeley, 1997; Seeley and Winfield, 1999; AACE, 2000; Kelly and Male, 2006; Oke et al., 2010) and in Malaysia as well (Ali and Toh, 2008; Lim et al., 2002; Darmawan, 2000; Mohd Nor and Egbu, 2010; Lee and Lim, 2009; Tan and Yeoh, 2012). It has been noted that the most common name for this profession in Malaysia is "*quantity surveyor*". According to Aje and Awodele (2006, p.64), QS is *"a professional trained, qualified, and experienced in dealing with problems relating to construction cost, management and communication in the construction industry"*.

QSs possess the competency, the skills, and the knowledge to provide proper cost management of the construction project by forecasting, analyzing, planning, and controlling cost. Hence, he/she is the expert in managing the cost of projects to achieve value for the clients' money. QSs could be engaged by client as a consultant or as contractor's QSs. In this study, the targeted QSs were consultants engaged by clients as they play a major role in providing and managing cost for projects.

The services provided by QSs are vast throughout the entire life span of a project from project inception to completion. Willis et al. (1994) have described in broad the roles of QSs, such as providing preliminary cost advice, feasibility studies, cost planning and controlling, life cycle costing and value analysis, advice procurement and tendering procedures, contract documentation, tenders evaluation, cash-flow forecasting, financial statement and interim payments preparation, final accounting, and settlement of contractual disputes. Specifically, the services provided by QSs are generally divided into two stages, which are pre- and post-construction stages of projects.

During the pre-construction stage, quantity surveying services include the preparation of preliminary estimates and feasibility studies, cost plans and schedules, and bills of quantities. Building measurement and bills of quantities preparation are core services that underpin the quantity surveying practice (Olatunji et al., 2010b). Besides, QSs also compile documentation for construction contracts, and prepare and analyze construction contract tenders. On the other hands, during post-construction stage, Harun and Abduallah (2006), and Jagun (2006) highlighted services provided by QSs include: general contractual advice, contract administration, settling capital allowance calculations, risk management settlement, and provide alternative dispute resolution services. Conclusively, QSs perform different roles in the pre- and post- construction stages.

Nonetheless, pre-construction is known as an important stage as many decisions related to design and cost are made at this early stage. Poor design and cost advice at this early stage will affect the later construction stage, which often causes many problems, such as redesign, change order, rework that leads to cost, time overrun, and client dissatisfaction. In fact, many problems that occur in the construction stage are a result of the actions carried out during the pre-construction stage (Silva, 2001). Al-Reshaid et al. (2005) pointed out that project delays and cost overruns are the two problems that occur at the construction stage due to oversight and improper planning during the pre-construction stage. Gibson and Hamiltion (1994) also criticized that a badly performed pre-project stage in the construction industry will result in poor project performances, such as cost overruns and time delay at the later project stage.

However, Al-Reshaid et al. (2005) highlighted that these problems can be mitigated provided proper attention is paid to the pre-construction stage of the project. These problems can be identified and predicted during the pre-construction stage before they actually occur on construction sites. As stressed by Cheung et al. (2012), the ability of decisions to affect performance is higher at pre-construction stages as the cost of design changes is higher in the later stages. Hence, well planning and establishment of design and costing at early stage are imperative in order to reduce the risk of negative impact at the later stage.

Apparently, they have significant influences on the project performances during construction stage, which urge the need for more efforts towards early decision making at the early stage. This has been affirmed by Dumont et al. (1997) and Cho et al. (1999) that planning efforts conducted during early stages of a project are crucial as they have greater effect on project success compared to efforts undertaken on the later stages. The more effort is spent at the beginning, the more smoothly the project will progress (Arditi and Gunaydin, 1997; Silva, 2001). Therefore, this research focused on identifying BIM capabilities at pre-construction stage in quantity surveying practice. It had been suggested that this would enable QSs to carry out their professional planning and monitoring during early stage for better performance of the project.

3.3 Traditional QS Practices and BIM Practices

Traditionally, QSs performed their tasks manually or with the help of measuring tools. They rely on 2D-based documents, such as floor plans, elevation, section, and other documents. Several authors such as Abdelmohsen et al. (2011), and Aibinu and Venkatesh (2012) further explained QSs relied on manual quantity takeoff using 2D drawings from designers, on screen takeoff from PDFs or CAD drawings, or excel spreadsheets. This approach is error prone (Sabol, 2008; Aibinu and Venkatesh, 2012) as a great deal of human interpretation is needed (Monteiro and Pocas Martins, 2013). Thus, these methods introduce the potential for human error and inaccuracies in costing.

Furthermore, several scholars have highlighted the inefficient methods adopted by the QSs, which in turn affect the project outcomes. RICS (2009) asserted that the cost planning process has been found to be inconsistent and inaccurate which results in poor cost management service to the construction industry. Moreover, Forgues et al. (2012) commented the traditional estimating practice is highly fragmented, resource intensive, and it is an ineffective process due to poor cost estimating that is often realized at the end of project phase. Poor cost estimating methods by QSs do not only affect the project performance, but also client dissatisfaction. Poon (2003) stated that these pitfalls on cost performance could be very damaging towards client interests. Meanwhile, Fortune (2006) pointed out that clients are dissatisfied by the output of services provided by the QSs. Hence, it has been observed that the limitations of traditional practice are evident in the extensive time spent, poor quality, and inaccurate estimate which can affect the project performance and lead to client dissatisfaction.

As building works are getting more complex and clients require for more fast-track project delivery, an urgent need for an efficient practice by QSs has arisen. The construction industry has a pressing need for accurate and efficient cost management techniques throughout the construction process. Hence, it is crucial for QSs to move away from old methods to respond promptly, accurately, and confidently to all challenges. It is imperative that QSs adopt better and efficient tools to save time and to enhance cost accuracy.

Therefore, in order to keep pace with the competitive industry, professionals need to bring new technology into play. The quantity surveying profession should continue to change and grow by enhancing their knowledge in order to meet the ever changing conditions of the construction industry, as stressed by Brandon (1990). Adaption to the changing circumstances has become critical to the QSs in order to remain within their leading role as cost experts. Besides, industry’s demands that changed to be more cost-effective, schedule-efficient, and better quality projects have led to BIM application in quantity surveying practice. BIM is the innovative technology that has been revolutionized the construction industry. It is believed that by using BIM in quantity surveying practice, the QSs are taking their role to the next level by utilizing models to provide detailed and accurate estimates and cost plans (Mitchell, 2012).

Furthermore, BIM is gradually replacing 2D or 3D CAD as it provides major improvements on the limitations of 2D. The difference between BIM and CAD is that the latter is only able to represent 2D geometry via graphical elements, such as lines, arcs, and symbols (Nagalingam et al., 2013; Alufohai, 2012), which is unable to represent more complex information, such as the relationship between the elements. The lines in CAD do not carry any intelligence about the elements they represent. For instance, wall element in CAD is represented by two lines, however in BIM; wall is created with its own properties, such as height, weight, thickness, surface area, bearing or non load bearing, fire rating, materials, and other information. Kumar and Mukherjee (2009) explained that there is no linkage between the data created by CAD as they are created separately and do not carry any intelligent connection between the documents, whereas, BIM is known as an intelligence and an integrated database that stores information of the entire building. It specifies the relationships between various building elements that allow all components to be constantly responsive to changes and automatically regenerate when changes occur.

In quantity surveying practice, BIM offers significant benefits compared to traditional drawing-based and manual taking off process based on 2D drawings. BIM generates quantities, takeoff, and counts automatically from the model that will cut down the time and costs required for QSs to prepare an estimate. The need for tedious manual takeoff is eliminated, human errors can be avoided, and hence, it provides a faster way to analyze cost data and prepare cost estimates. One of the advantages of

BIM over CAD is the ability to deal with design change efficiently due to parametric change feature that coordinates changes and maintains consistency whenever changes happen.

When changes occur, it requires manually editing and updating for all drawing views which is daunting and tedious. The manual process requires a great deal of time and energy to revise the quantities to accommodate the design changes. The QSs would have to cautiously check what have been changed, added or deleted on the drawings. This process is time-consuming and leads to serious consequences if the changes are not detected. However, BIM allows change in one drawing view to be represented consistently in all other drawing views. Thus, it allows the QSs to easily identify changes in drawing and automatically update the quantities when the design is changed. Changes can be readily accommodated and information stays consistent with the design throughout the project.

In addition, the benefits of BIM application in achieving better cost and time performance have been proved by several scholars. A case study conducted by Eastman et al. (2008) proved that by using BIM for estimating, 92% of time reduction was achieved to produce the estimate with only a 1% variance between the manual and the BIM-based processes. Meanwhile, Stanford University conducted a research and found that with the usage of BIM, 40% elimination of non-budgeted changes, improved accuracy of cost estimation within 3%, 80% reduction in time to create cost estimates, a 10% saving of project value by identifying clashes before construction, and a 7% reduction in project time were achieved (Quek, 2012). By adopting BIM, it has the potential to remove the laborious tasks performed by the QSs, which can improve their performances and project outcomes.

BIM application is gaining momentum in cost management aspect and it is essential for QSs to embrace the BIM application in their practice. Thurairajah and Goucher (2012) advocated that it is paramount for QSs to fully understand how they can work effectively with BIM, and increase awareness and knowledge of the usability of BIM to avoid falling behind other construction professionals. Quek (2012) also urged that QSs should adopt BIM earlier to avoid from being lagged behind compared to other professions in the industry by proving real value early in the project design stage. Thus, as urged by many authors, it is critical for the QSs to start moving to modeling practices for better project performance.

3.4 Previous Studies of BIM Application in Quantity Surveying Related Tasks

Numerous previous studies had been conducted to investigate the BIM application in cost management aspect or quantity surveying related tasks by focusing in different scopes, as illustrated in Table 3.1. Most of these studies (refer to Table 3.1) discussed the concept of BIM in cost management aspects, such as potential, benefits, barriers and challenges of BIM adoption in quantity surveying practice. Besides, impacts and effects of BIM application on the roles of QSs were covered also. Comparison studies between BIM application and traditional methods in quantity surveying practice had been reviewed. Studies of BIM application in cost management aspects related to life cycle costing, IFC standard, and education were also explored by several authors. A few studies did develop standard, frameworks and models for BIM application in cost estimating process. However, there are very limited studies on 5D BIM, especially on how BIM can help QSs in a project, as pointed out by Wang et al. (2014). A preliminary review of the literatures indicated a gap in research related to BIM application with regard to QSs specifically focusing on the capabilities of BIM application in the quantity surveying profession. Moreover, no study has looked into how BIM capabilities in quantity surveying practice may affect project performance.

Table 3.1: Precedent Studies on BIM Application in Quantity Surveying Related Tasks

No.	Author(s)	Year	Title of study	Focus of the study
A) The potential, benefits, barriers, strategies, impacts and challenges of using BIM for QSs				
1	Alufohai	2012	Adoption of building information modeling and Nigeria's QUEST for project cost management	The actual and potential roles of BIM in achieving better budgeting and cost management were examined in this paper, which focused in Nigerian public construction projects.
2	Kraus et al.	2007	Challenges in estimating costs using building information modeling	The authors discussed the application of BIM, the benefits of its application, and the challenges in estimating cost by using BIM.
3	Quek	2012	Strategies and frameworks for adopting building information modeling for quantity surveyors	This paper looked at current BIM adoption in Malaysia and the context abroad. Issues in BIM usage, benefits of its application, broad frameworks of foreign BIM codes, and standards were also reviewed.
4	Autodesk	2007a	BIM and cost estimating	This white paper by Autodesk explored how the reliable information within a model can be used for cost estimating by outlining the approaches and discussing the benefits.

Table 3.1: Precedent Studies on BIM Application in Quantity Surveying Related Tasks (cont')

No.	Author(s)	Year	Title of study	Focus of the study
5	Matipa et al.	2008	How a quantity surveyor can ease cost management at the design stage using a building product model	The aim of this study was to show results from a case study of deploying a building product model on a commercial project with the purpose to ease cost management duties of the QSs.
6	Mitchell	2012	5D BIM: creating cost certainty and better buildings	This paper discussed 5D BIM application for QSs by setting out the opportunities that arise from 5D.
7	Thurairajah and Goucher	2012	Usability and impact of BIM on estimation practices: cost consultant's perspective	This study focused on the usability and the impact of BIM for cost consultants through an in-depth literature review, developed conceptual framework, and questionnaires.
8	Thurairajah and Goucher	2013	Advantages and challenges of using BIM: a cost consultant's perspective	This study focused on the advantages, challenges, impacts and usability of BIM application among cost consultants via literature review, questionnaire surveys, and interviews.
9	McCuen	2008a	Scheduling, estimating, and BIM: a profitable combination	The case study presented in this paper looked into scheduling and cost functions in the model development by concluding that 4D and 5D applications were beneficial to project team and owner.
10	Kim et al.	2009	Automated building information modeling system for building interior to improve productivity of BIM-based quantity take off	The research proposed an automated modeling method that modeled a building interior automatically and tested it at a typical condominium building project. The authors found that the productivity of BIM-based quantity takeoff and estimation process could be improved by the system.

Table 3.1: Precedent Studies on BIM Application in Quantity Surveying Related Tasks (cont')

No.	Author(s)	Year	Title of study	Focus of the study
11	Sabol	2008	Challenges in cost estimating with building information modeling	This paper comprehensively discussed cost estimating by using BIM in the aspects of information exchange and challenges.
12	Gee	2010	The influence of building information modeling on the quantity surveying profession	This research investigated the qualities and the influence of BIM on the quantity surveying profession, by discussing the opportunities, barriers, and changes in order to incorporate BIM successfully into the quantity surveying profession.
13	Stanley and Thurnel	2014	The benefits of, and barriers to, implementation of 5D for quantity surveying in New Zealand	This paper presented the benefits and barriers of 5D BIM application by QSs in Auckland through interviews. It intended to prove a snapshot of the current BIM application in quantity surveying practice.
14	Yin and Kun	2013	Construction project cost management based on BIM technology	The authors proposed strategies to improve cost management by using BIM information integration system.
15	Smith	2014	BIM and the 5D project cost manager	This paper examined the opportunities and the challenges of cost professions to be integrally involved and to embrace 5D BIM applications in order to become 5D project cost manager.
16	Kala	2010	Using an integrated 5D and location-based planning system in a large hospital construction project	This paper presented a case study of hospital project by using 5D systems combined with location-based planning. The author concluded that the 5D system provided better results for constructability and scheduling.

Table 3.1: Precedent Studies on BIM Application in Quantity Surveying Related Tasks (cont')

No.	Author(s)	Year	Title of study	Focus of the study
B) BIM adoption level of QSs				
17	Sattineni and Bradford	2011	Estimating with BIM: a survey of US construction companies	A survey was conducted among construction practitioners to determine the extent to which estimating processes were automated in the construction industry.
18	Tan	2011	Level of awareness towards building information modeling among quantity surveyors in Malaysia	This research determined the level of awareness among QSs in Malaysia towards BIM technology via questionnaire surveys.
19	Zhou et al.	2012	Small and medium enterprises (SME) readiness of BIM: a case study of a quantity surveying organization	This paper analyzed the readiness of SME quantity surveying organizations in BIM adoption. The benefits, barriers, and challenges of SME organizations were presented.
20	Aibinu and Venkatesh	2014	Status of BIM adoption and the BIM experience of cost consultants in Australia	By adopting web-based survey and interviews, this research looked into the experience of quantity surveying firms in using BIM in Australia. The progress of the QSs in using BIM features was also discussed in this research.
C) Comparison of BIM and traditional working methods in cost management aspect				
21	Olatunji and Sher	2010	A comparative analysis of 2D computer aided estimating and BIM estimating procedures	This paper compared the impacts of BIM on cost estimating procedures to traditional 2D estimating method. BIM was able to improve the limitations of 2D in cost estimating.
22	Jiang	2011	Developments in cost estimating and scheduling in BIM technology	This study showed that BIM application enhanced the traditional scheduling and cost estimating methods by conducting a case study at three-story training facility.
23	Alder	2006	Comparing time and accuracy of building information modeling to on-screen takeoff for a quantity takeoff of a conceptual estimate	This study compared quantity takeoffs by using BIM and on screen takeoff for a small commercial building in time and accuracy aspects.

Table 3.1: Precedent Studies on BIM Application in Quantity Surveying Related Tasks (cont')

No.	Author(s)	Year	Title of study	Focus of the study
24	Kulasekara et al.	2013	Comparative effectiveness of quantity surveying in a building information modeling implementation	The influences of BIM on practices of QSs were explored in this study. Moreover, the authors compared the effectiveness of BIM tools against conventional quantity surveying methods.
25	Shen and Issa	2010	Quantitative evaluation of the BIM-assisted construction detailed cost estimates	This study focused on developing a quantified evaluation method to measure the impact of BIM assisted detailed estimating tools in generating detailed cost estimates. The authors conducted an experiment to compare the performance of BIM and traditional method for cost estimating.
26	Forgues et al.	2012	Rethinking the cost estimating process through 5D BIM: a case study	This paper provided a comparative study of BIM-based estimating software, and discussed the technological and organizational challenges of implementing BIM-based estimating within a construction firm.
27	Witicovski and Scheer	2012	Some improvements for BIM based cost estimation	This study reviewed traditional and BIM-based cost estimating practices. Six Brazilian case studies were used to discuss drawbacks, difficulties, and advantages of using BIM, which resulted in proposed improvement in the quantity surveying tasks.
28	Olatunji et al.	2010a	The impact of building information modeling on construction cost estimation	This study explored the impact of BIM on construction cost estimation by comparing auto-measured BIM models with existing standards and estimation procedures.

Table 3.1: Precedent Studies on BIM Application in Quantity Surveying Related Tasks (cont')

No.	Author(s)	Year	Title of study	Focus of the study
D) BIM in quantity surveying education				
29	Sylverster and Dietrich	2010	Evaluation of building information modeling estimating methods in construction education	This study was conducted to increase the understanding of the ability of BIM in estimating procedures for integration within construction education in order to improve understanding among students on the estimating process.
30	Gier	2008	What impact does using building information modeling have on estimating to construction management students	This study examined the influence of construction visualization tools and BIM on the estimating skills of construction management students by examining their completion time and accuracy on a construction estimating quantity takeoff assignment.
E) BIM application in project life cycle				
31	Popov et al.	2006	Complex usage of 4D information modeling concept for building design, estimation, scheduling and determination of effective variant	This paper explained the use of BIM in the project, starting from planning, designing, estimating, and construction stages. The authors concluded that BIM is a means to manage a project effectively.
32	Eastman et al.	2008	BIM Handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors	This book provided a comprehensive review and analysis of the state of the art of BIM application. The authors provided an in-depth understanding of BIM implementation in different project phases including cost estimating stage.
F) BIM application and QSs roles				
33	Nagalingam et al.	2013	Building information modeling and future quantity surveyor's practice in Sri Lankan construction industry	The research explored the potential expansion of QSs' roles and responsibilities in a sustainable BIM-based project delivery in Sri Lanka.
34	Olatunji et al.	2010b	Building information modeling and quantity surveying practice	This study explored the relationship between the roles of QSs and BIM system in the construction industry.

Table 3.1: Precedent Studies on BIM Application in Quantity Surveying Related Tasks (cont')

No.	Author(s)	Year	Title of study	Focus of the study
35	Matipa et al.	2010	Assessing the impact of new rules of cost planning on building information model schema pertinent to quantity surveying practice	This research explored the impact of the new rules of measurement on the building information model schema pertinent to the quantity surveying practice.
36	Hannon	2007	Estimators' functional role change with BIM	This paper explored the changes in an estimator's functional roles as BIM application requires additional skills and knowledge for success utilization.
G) BIM process related to cost management aspect				
37	McCuen	2009	The quantification process and standards for BIM	This article discussed the process and the standard of BIM application for cost engineers.
38	Meerveld et al.	2009	Reflections on estimating - the effects of project complexity and the use of BIM on the estimating process	This research explored the effect of project complexity and the use of BIM in the estimating process by conducting three case studies (parking structure projects).
39	Popov et al.	2010	The use of a virtual building design and construction model for developing an effective project concept in 5D environment	The authors analyzed the theoretical principles and the practical innovative applications of BM, computer-aided evaluation and construction process simulation techniques based on the concept of Virtual Project Development.
40	Monteiro and Pocas Martins	2013	A survey on modeling guidelines for quantity take off oriented BIM-based design	This research presented a case study to survey BIM input/output dynamics for quantity takeoff, and examined model behavior when constrained by existing specifications for quantity takeoff and detailing modeling guidelines.

Table 3.1: Precedent Studies on BIM Application in Quantity Surveying Related Tasks (cont')

No.	Author(s)	Year	Title of study	Focus of the study
H) Develop model/framework/ standard/guidelines of BIM application related to cost management aspects				
41	Cheung et al.	2012	Early stage multi-level cost estimation for schematic BIM models	This paper detailed the cost estimation module that enabled quick and intuitive exploration of early stage design in 3D environment by proposing an intuitive method to incorporate cost (and multi-level) estimation into the early stage of design produced by Sketch-up.
42	Elbeltagi et al.	2014	BIM-based cost estimation/ monitoring for building construction	In view of the importance for monitoring construction project, this research developed a model that integrated BIM visualization, project cost estimates and cost monitoring/control technique. It offered the project participants a framework to view and evaluate construction progress with respect to cost.
43	Lee et al.	2014	BIM and ontology-based approach for building cost estimation	This research proposed an ontological approach for cost estimators to automate the process of searching for the most appropriate work items. This research proved that the proposed ontologies can be utilized in the practice after conducting a case study.
44	Kwon et al.	2011	Introduction of BIM quality standard for quantity take off	This study suggested the ways of securing BIM quality for correct quantity takeoff and also established modeling guidelines for extracting correct quantity takeoff from BIM data.
45	Lawrence et al.	2014	Create flexible mappings between building information models and cost information	This research proposed a generic approach by using mappings to create and to maintain cost estimate by relating the cost information between BIM objects and cost data. This approach was validated via case studies and interviews.

Table 3.1: Precedent Studies on BIM Application in Quantity Surveying Related Tasks (cont')

No.	Author(s)	Year	Title of study	Focus of the study
46	Kim et al.	2012	A hybrid conceptual cost estimating model for large building projects	This research developed a hybrid conceptual cost estimating model for a large building construction project. The proposed model was validated by eight case studies that improved the accuracy of the estimation and also the confidence of the estimators in the conceptual estimates.
47	Lin	2013	Innovative generation in cost management through BIM environment	This study focused of 5D BIM application in quantity surveying practice by establishing a framework of 5D cost management. The research evaluated the degree of feasibility and efficiency of using 5D BIM for cash flow forecast preparation.
48	Samphaongoen	2010	A visual approach to construction cost estimating	This study presented a methodology that used parametric software and visualization technologies for cost estimating process. Besides, the author introduced a database technology to store labor, equipment, and material cost data in order to streamline the estimation process.
49	Ma et al.	2011	Application and extension of the IFC standard in construction cost estimating for tendering in China	This research identified the problems of using the IFC standard and then investigated the methods of applying the IFC standard to the construction cost estimating for tendering. The research established an information requirement model which included seven aspects of information entities in the IFC standard that can be applied to the development of construction cost estimating software.

Table 3.1: Precedent Studies on BIM Application in Quantity Surveying Related Tasks (cont')

No.	Author(s)	Year	Title of study	Focus of the study
I) BIM and IFC standard related to cost management aspects				
50	Staub-French et al.	2003	A genetic feature-driven activity-based cost estimation process	The authors focused on developing an IFC-based cost estimating system, whereby the results of IFC files were used, and then automatically applied corresponding prices for cost estimation.
51	Yabuki et al.	2005	A management system for cut and fill earthworks based on 4D CAD and earned value management system	The authors applied the IFC standard in the cost estimating of earthwork and accomplished the cost estimating function by using 4D model.
52	Abdelmohsen et al.	2011	Automated cost analysis of concept design BIM models	This paper developed an approach for automated cost analysis and reported the results by using 3D models in the form of IFC data for US courthouse.
J) BIM application in life cycle costing				
53	Fu et al.	2007	The development of an IFC based life cycle costing prototype tool for building construction and maintenance	This research developed a tool for life cycle costing based on application of IFC as an interoperable building information model. This tool helped to reduce tedious manual work and improved the efficiency of life cycle costing to achieve better decisions.
54	Kehily et al.	2013	Linking effective whole life cycle cost data requirements to parametric building information models using BIM technologies	This paper discussed the capabilities of BIM in the area of whole life cycle costing by focusing the data requirements in performing life cycle cost calculations and estimations. The authors examined the extent to which data could be attached to parametric BIM in order to perform faster and accurate analysis by the cost professionals.

Table 3.1: Precedent Studies on BIM Application in Quantity Surveying Related Tasks (cont')

No.	Author(s)	Year	Title of study	Focus of the study
55	Fu et al.	2004	IFC implementation in life cycle costing	The authors developed a system for life cycle cost assessment by automatically extracting cost estimating data from the IFC files, and then transferring the data to a pre-existing component of the life cycle cost assessment.
56	Nour et al.	2012	A BIM based energy and life cycle cost analysis/ optimization approach	This research focused on the building energy component of building life cycle cost parameter by using BIM. The authors adopted BIM based solution to select suitable building components among the alternatives in order to formulate a building configuration with minimum life cycle costs and also energy consumption.
K) Others				
57	Marzouk and Hisham	2014	Implementing earned value management using bridge information modeling	This research focused on applying BIM technology on bridges which was named as bridge information modeling. The authors presented bridge-specific application that could perform its function automatically in order to perform cost estimates and measure performance.
58	Wang et al.	2014	An innovative method for project control in Liquefied Natural Gas project through 5D CAD: A case study	This research explored 5D CAD in facilitating project cost control and scheduled control for Liquefied Natural Gas industry. Focus group and interview studies were carried out and the results obtained were used as information for the functionalities that a 5D CAD model should contain.
59	LINDSTRÖ M	2013	Model-based quantity take off in production	This research focused on an application of model-based quantity takeoff in the production area.

Furthermore, literatures have highlighted that the use of BIM as a means to enhance project performance has been widely acknowledged. Many previous studies have investigated the impact of BIM application on project performance (Suermann and Issa, 2007; Griffis et al., 1995; Koo and Fischer, 2000; Eisenmann and Park, 2012; Parvan, 2012; Sacks and Barak, 2008; Sun and Zhou, 2010; Yang et al., 2007). These studies have identified that positive project performances can be achieved by adopting BIM in the construction industry. Based on previous researches, limited attempts have been made to explore the relationships between BIM capabilities in quantity surveying practice and project performance by focusing on quantity surveying area.

Moreover, specific analyses on the relationships between BIM capabilities in quantity surveying practice and project performance are relatively rare. In fact, very little consensus exists as to how BIM application in quantity surveying during pre-construction stage can influence project performance. Therefore, the relationships between the capabilities of BIM in quantity surveying practice and project performance have remained unclear as there is no comprehensive study on it. The lack of information regarding BIM capabilities in quantity surveying practice along with uncertain impact of this application on project performance has resulted in reluctance among QSs to implement BIM and yet to embrace the full capacity of BIM. Accordingly, this study placed a considerable emphasis on quantity surveying practice. This research had been intended to fill this gap by studying the relationships between BIM capabilities in quantity surveying practice and project performance which consecutively led to the development of the relationship framework.

Furthermore, BIM has been adopted rapidly in the construction industry for the purpose to reduce time and cost, besides improving quality (Ku and Taiebot, 2011; Fallon and Mark, 2007) for better project performance. Chains of evidence from the literatures on the benefit of BIM application indicate that the implementation of BIM improves project performance in terms of time, cost, and quality (Woo, 2006; Quek, 2012; Migilinskas et al., 2006; Popov et al., 2006). Besides, it has been noted that time, cost, and quality are the three main project objectives that are concerned by clients (Popov et al., 2008; Bowen et al., 2012; Meng and Gallagher, 2012). However, many construction projects have suffered from poor performances such as delay in time, cost overrun, and poor quality before BIM application (Sun and Meng, 2009; Meng, 2012).

Al-Reshaid et al. (2005), and Gibson and Hamiltion (1994) provided a similar insight that poor time and cost performance have been due to bad planning by project consultants during pre-construction stage. Mitchell (2012) outlined that it is paramount to provide a series of cost estimate at the early project stage for early decision as it has great influence on the project outcomes and BIM can assist QSs in achieving those outcomes. Therefore, putting in more effort during the pre-construction stage by considering BIM capabilities in quantity surveying practice, project teams, and QSs can better identify and predict risk and uncertainty at the early stage before it influences the later project stage in time, cost, and quality aspects. It is hence, the purpose of this study had been to identify the BIM capabilities during pre-construction in quantity surveying practice in relation to project performance in time, cost, and quality aspects.

3.5 Definition of BIM Capabilities

Oxford dictionaries (2013) have defined capability as "the power or ability to do something". It often refers as ability, competency, and capacity. The term *capability* was defined by Stoel and Muhanna (2009, p. 181) as *"a special resource, encompassing a firm's capacity to coordinate and deploy other resources to effect a desired end".* It means the firm's ability to use resources in order to achieve the firm's goals. Many existing literature has defined information technology (IT) capability, while there is limited relevant literature that defines BIM capability. Moreover, there is limited definition regarding the capability of BIM in quantity surveying practice. In the IT context, Stoel and Muhnna (2009, p.182) defined IT capability as *"a complex bundles of IT-related resources, skills and knowledge, exercised through business processes, that enable firms to coordinate activities and make use of the IT assets to provide desired results".* It refers to the ability of an organization by adopting IT to achieve their organization goals. However, most of the existing literatures defined IT capability from two perspectives: 1) managerial capabilities (Sambamurthy and Zmud, 1992; Ross et al., 1996; Bharadwaj, 2000; Tippins and Sohi, 2003; Zeng and Huang, 2003; Zhang, 2005), and 2) technological skills (Teo and King, 1997; Sabherwal and Kirs, 1994; Sabherwal, 1999; Byrd and Turner, 2000). With regard to this, IT capabilities can be referred as the ability of an organization to achieve business objectives through IT implementations; on the other hand, it can also be attributed to the IT function within an organization.

In this study, BIM capability had been viewed as technological skills that refer to the ability that BIM can provide. The most suitable and relevant definition of BIM capability is defined by Succar (2012, pp. 124) as *"the ability to perform a task or deliver a BIM service/product".* Hence, this study synthesized these views and defined BIM capabilities as the ability of BIM provided in quantity surveying practice in order to enhance QSs' job performance through BIM implementation. In this context, it is generally taken to mean the strength or the competency related to BIM that is applied in quantity surveying practice.

3.6 Identifying BIM Capabilities in Quantity Surveying Practice

In order to identity the capabilities of BIM in quantity surveying practice during pre-construction stage, RIBA Plan of Work was chosen as a template in this study due to its widespread use in the construction industry (Kirkham, 2013; Sundar, 2012). Besides, a few scholars have referred to the RIBA Plan of Work as reference in conducting their researches in Malaysia (Rashid et al., 2014; Abu Bakar et al., 2012). It is a well-organized, a coordinated and a structured approach which clearly defines the work stages in each project and as a guideline to allocate the role and the responsibility of a particular consultant at every work stage. The plan of work breaks down the process of designing and managing building into a set of simple work stages that is easy to understand. It divides the development of construction projects into several stages which provide guidance and procedures of the activities that take place during each stage.

The RIBA Plan of Work 2013 has been the latest plan of work that was developed by RIBA to ensure alignment with the best practice across all specialists within integrated project teams tailored to the current needs. The new plan of work overlaps the existing

11 stages (Stage A-L) to the new 8 stages (Stage 0-7) (Figure 3.1). The work stages have been defined in numerical rather than alphabetical. New stage 0 is an optional stage that strategically appraises and defines projects before detailed briefs are created. Stages A and B have been merged into one stage (Stage 1) and it is named as preparation stage that as it is related to preparing activities and to establish brief. Stage 2 maps the former stage C as early stages of design development while Stage 3 matches broadly to the former stage D and part of stage E with slight differences as the developed design is co-ordinated with cost information by the end of the stage. Stage E is changed to stage 4 as the technical design stage which comprises of residual technical work of the core design team members, whereby at the end of this stage, all design work will be accomplished. The design works should be completed at the end of this stage. Stages F to H have been eliminated, but it is covered by a separately procurement task bar. Meanwhile, Stage 5 maps the former stage J and K as construction stage. Stage 6 maps former stage L as handover and close out stage. Stage 7 is a new stage which includes post-occupancy evaluation and review of project performance.

Although it appears radically different, the work stages and task descriptions in the new RIBA plan of work 2013 are similar to the former A-L stages in many ways. For the purpose of identifying capabilities of BIM in quantity surveying practice, it is necessary to map the pre-construction stage in RIBA plan of work to define the work stage description and the tasks of QSs. With the RIBA plan of work as reference, it helps to increase understanding of each stage, and thus, capabilities at each stage can be easily identified in a clearer manner. Hence, this study identified the capabilities of BIM for QSs, particularly by referring to the RIBA plan of work 2013. As the scope of this study had focused pre-construction stage, stages 1 until 4 had been applicable and are discussed further in the next section.

	Original RIBA Plan of Work			RIBA Plan of Work 2013	
				0	Strategic Definition
Preparation	A	Appraisal		1	Preparation & Brief
	B	Design Brief			
Design	C	Concept		2	Concept Design
	D	Design Development		3	Developed Design
	E	Technical Design		4	Technical Design
Pre-construction	F	F1	Production Information		
		F2			
	G	Tender Documentation			
	H	Tender Action			
Construction	J	Mobilisation		5	Construction
	K	Construction to Practical Completion			
Use	L	L1	Post Practical Completion	6	Handover and Close Out
		L2			
		L2			
				7	In Use

Figure 3.1:RIBA Plan of Work 2013 against Original RIBA Plan of Work (RIBA, 2013)

In addition, BIM is an evolving concept that follows the level of detail (LOD). LOD is defined as the progression of a BIM element from the lowest level of approximation to the highest level of representation (Bedrick, 2008). Each level is designed for specific need at every stage of the process. The level of approximation ranges from conceptual (LOD 100), approximate geometry (LOD 200), precise geometry (LOD 300), fabrication (LOD 400) and as-built (LOD 500). The costing development for a project is seen as a continuous and an evolving process when the amount of information is increased as the project progresses. As a project design is developed, cost estimation is prepared by increasing the degree of information provided. By using these definitions, the quality of the estimate is based on the quantities derived from the LOD provided by the 3D model depending on the project stage. Besides, by increasing the LOD as design evolves, estimates will become more detailed with fewer unknown elements and assumptions are made. Nevertheless, this study, LOD 100 to LOD 300 had been applicable as they corresponded to the pre-construction stage.

The identified capabilities were labelled with tags C1, C2, C3, etc. After reviewing the literatures, the capabilities of BIM in quantity surveying practice were summarized as in the followings and each capability is discussed in detail in the next section.

1. Cost appraisal can be prepared quickly at feasibility stage (C1).
2. Preliminary cost plan can be prepared by extracting quantities directly from the model (C2).
3. Easily update cost plan more details as design is developed (C3).
4. Easily generate accurate cost estimate for various design alternatives (C4).
5. Design changes are reflected consistently in all drawings views (C5).
6. Cost implication of design changes can be generated easily without manually re-measurement (C6).
7. Clash detection reduces design errors and cost estimates revisions (C7).
8. Cost checking can be performed quickly to ensure all items are captured (C8).
9. Improved visualization for better understanding of design (C9).
10. Automatically quantification for BQ preparation (C10).
11. Intelligent information management allows data to be stored in a central coordinated model (C11).

3.6.1 Stage 1: Preparation

Stage 1 is an initial stage in a project that relate to carrying out the preparation activities and briefing tasks in tandem. The details work stage description and BIM capabilities at Stage 1 are elaborated in the following sub-section.

3.6.1.1 Work Stage Description

At the beginning of a project, client spells out the project objectives and develops initial project brief. At this stage, client will want to establish cost limit for the project. Therefore, QS undertakes studies into the feasibility of construction projects by preparing cost appraisal to determine the initial building cost. QS provides cost advice to the client after assessing the project technically, functionally, and financially. This assists the client in determining and assessing the viability and the feasibility of undertaking the project prior to design. Early assessment of cost allows the client to decide undertaking the project by establishing initial tentative budget. To sum up, this stage is to consider and to confirm that the client's budget is feasible to proceed.

However, information available is limited at this early stage as it consists of simple sketches and other relevant information. It requires a number of assumptions as to the nature and the characteristic of the project. QSs have to draw upon accumulated experience and based on available design and cost data. For instance, QSs have to use cost intelligence from past experiences and actual cost data to compare the initial estimate with other similar completed projects.

This stage has been recognized as a crucial decisive stage because a number of critical designs and decisions are made (Smith and Jaggar, 2007) to fulfill client's requirements and needs. Olatunji et al. (2010a) highlighted that one of the most important causes of cost overruns in construction projects is the discrepancies between initial estimates and actual project costs. Hence, the result of the estimate at this stage has the largest impact on the final building cost.

3.6.1.2 BIM Capability

At the early stage, project cost needs to be performed quickly within a limited time period by using limited information and also reasonably accurate for formulation of an initial budget (Gunduz et al., 2011; Sonmez, 2004). However, project information is always limited at the early phase which causes many uncertainties and difficulties to produce the initial cost appraisal within a limited time period.

By using BIM at this stage, Chang and Shih (2013) explained that the information in the model during this stage consists of site context, topography, surroundings roads, and building massing. DLS (2011) pointed out that information at this level only indicates areas, height, volume, location, and orientation which allow estimating to be done by using cost per unit floor area. In spite of that, project cost at this feasibility stage can be calculated instantly by using BIM *(C1)* based on the available information in the model (Roginski, 2011).

Besides, LOD 100 in BIM is known as the initial concept estimate (Mitchell, 2012) which allows QSs to determine the initial cost of a project faster and accurately. Therefore, cost geometry can be extracted by using BIM from the earliest design to generate a basic costing that defines the project scope at an elemental level and establishes a realistic budget (Exactal Technologies, 2010). This cost appraisal forms part of the feasibility study allowing client to determine the feasibility of the project. By providing cost appraisal within a shorter period of time, the client is able to make more informed decisions which result in higher quality construction that meets cost and time constraints.

3.6.2 Stage 2: Concept Design

Stage 2 is a project stage whereby the initial concept design is produced in line with the requirements of the initial project brief. The details work stage description and BIM capabilities at Stage 2 are elaborated in the following sub-section.

3.6.2.1 Work Stage Description

After establishing the likely cost bracket or range at the feasibility stage, the design team starts to develop the design in more detail at this stage. Although there is an increase in the amount of design information, there is still insufficient data for reliable cost targets to be prepared in detailed (Smith and Jaggar, 2007). Hence, the lump sum amount of cost limit will evolve in the form of group element costs rather than individual element costs. QS begins the process of producing the first structured cost plan, namely outline cost plan or preliminary cost plan, which aims to confirm the budget set at the feasibility stage (Smith and Jaggar, 2007). The cost plan is presented in a group element format by showing cost allocation to the major parts of the project. The objective of this cost plan is to present the cost distribution to the various group elements that make up a project to gain a balance in cost allocation among the elements.

At this stage, various outlined proposals for design are available for QSs for evaluation and comparison in cost aspect. Each alternative outlined proposals are evaluated to identify the best means of satisfying the requirements of the client. QSs carry out analytical studies for a number of design solutions by considering the client's requirements and the cost limit set by the client. If there is a discrepancy between the outlined cost plan and the cost limit, clients and the design team will have to make decision as to whether adjust the allowances or to accept the outlined cost plan that is more realistic than the first estimate prepared during the feasibility stage (Smith and Jaggar, 2007). Once the client accepts the outlined cost plan, the design team will proceed to the next stage by producing scheme design.

3.6.2.2 BIM Capability

The task of QSs at this stage is to provide a more comprehensive cost estimate than feasibility study made at the previous level based on a better developed design and scope of work. The LOD in BIM is developed to LOD 200 as the design information is updated. LOD 200 allows QS to prepare a cost plan that is presented in an elemental format, which states the generic element as the detail specification is still unavailable at this stage. This capability enables QSs to extract geometric data contained in the model to generate preliminary cost estimates *(C2)* (Cheung et al., 2012; McCuen, 2008a;

Nagalingam et al., 2013). The output of this stage is that the initial cost plan becomes the basis for improving and updating estimates during project stages whenever the model information is changed and updated (Mitchell, 2012).

Moreover, at this stage, BIM is able to speed up cost plan preparation for a number of design solutions for various design proposals *(C4)*. This capability enables fast and accurate comparative evaluation of multiple design options at the early stage (Exactal Technologies, 2010; Mihindu and Arayici, 2008; Mitchell, 2012; Popov et al., 2010; Nagalingam et al., 2013). It allows QSs to explore and evaluate the cost of alternative options spontaneously by taking into account on the building type, shape, and size (Cheung et al., 2012; Coates et al., 2010). Based on the reliable information from the model, QS is able to provide preliminary cost estimates of two design alternatives in one day (Fallon and Mark, 2007) as compared to traditional method that provides significant time saving over traditional method (Exactal Technologies, 2010). As highlighted by Akintoye and Fitzgerald (2000), QSs were under pressure to produce error-free and near-perfect cost information within a limited time during the earlier stage of project. Hence, BIM can overcome this limitation of manual practice as QSs are able to complete a series of estimates for various designs at the early phase that enables comparison to be made quickly.

Furthermore, cost evaluation for different design alternatives allows clients to choose the optimal design that would meet their requirements. It increases clients' satisfaction as they are able to obtain early cost feedback on the design alternatives (Pennanen et al., 2011) and improved understanding of the likely cost influences of design decisions (Deutsch, 2011). Hence, it allows real-time and quick response to design options and encourages the pursuit of more efficient and sustainable designs for better building. Mihindu and Arayici (2008) agreed that optimum lifecycle costs with more sustainable product development process can be achieved through comparison of various design alternatives by using BIM. Besides, costly constructions items can be identified at an early stage so that the clients could plan appropriate contingency against these or suggest an alternative for more efficient design solutions.

3.6.3 Stage 3: Developed Design

During stage 3, concept design is developed further and a number of iterations of the design may be required. Cost information at the stage shall align to the developed design. The details work stage description and BIM capabilities at Stage 3 are elaborated in the following sub-section.

3.6.3.1 Work Stage Description

During this stage, the design team begins to firm up their design proposals. Elemental cost target has to be established. Major activities at this stage are to obtain all planning approvals, progress to full design by producing detailed sketch plans, including elevations and sections, and formulate cost plan and specification. Design progresses and more detailed information become available which enable more accurate measurements to each element. Here, QS conducts further cost studies and estimates to prepare developed design cost plans that are presented in an elemental cost format, stating the specific construction materials, finishes, specification with elemental unit rates, and quantities (Mitchell, 2012). Detailed cost plan is produced to show a more realistic breakdown of the elements. It is the detailed breakdown of the cost limit into cost target by showing how much money is distributed on each detailed functional element of the building (Smith and Jaggar, 2007), which can be used for cost controlling as the design is developed. If budget is exceeded, the cost plan should be accompanied by recommendations on potential savings and changes, if necessary (Smith and Jaggar, 2007).

3.6.3.2 BIM Capability

As the design is developed in more detail, QSs are required to update the cost plan into a more detailed breakdown. LOD 300 in BIM is defined by Mitchell (2012) as a developed design model that allows QSs to prepare developed detail design cost plans that are presented on a sub-elemental basis, stating the specific construction elements, finishes, and specification. The cost assumptions generated in the previous stage are transferred to this level of cost model by using more accurate measurements (actual geometric data in the 3D model) and hence the cost estimate becomes more accurate (Cheung et al., 2012). Besides, the cost database in BIM comprises of a few entries which allow elemental cost plan to be prepared automatically and more detailed through a built-in automation facility in the model estimates (Cheung et al., 2012; Thurairajah and Goucher; 2013; Nagalingam et al., 2013). By linking the 3D model and the cost plan, detailed cost plans can be generated, and this enables QS to extract element quantities from the model to perform element cost estimation with more detailed breakdown estimates (Cheung et al., 2012). Quantities and rates can be calculated by using more detailed geometric information from the model. With regard to this, the cost plan becomes the basis for providing quick updated estimates whenever the design is changed due to the link (Mitchell, 2012; Sylvester and Dietrich, 2010). Hence, cost plan can be easily updated with more details as the design is developed *(C3)*.

At this stage, it has been noted that drawings, details, and specifications from designers are important sources of information for QSs to perform detailed cost estimation. Traditionally, QS works closely with design team to obtain drawings and design information in order to perform detailed cost estimation. Huge efforts are required from the design team to provide the QS with complete and accurate drawing types such as plans, elevations, sections, details, and schedules. However, QS faces difficulty in obtaining this information timely and accurately from design team which affects the progress of the project. This is because information exchange between project stakeholders is executed by sending paper-based documents to each other.

In addition, Sommerville et al. (2004) pointed out that construction industry is a highly inefficient industry that relies heavily on traditional means of communication which causes an obstacle in information sharing. Hence, coordination and communication among project team members becomes complex which leads to increased risk of errors and miscommunication. Hence, BIM has the potential to eradicate this inefficiency by handling numerous and different information in a single database. Intelligent information management *(C11)* is one of the capabilities of BIM through a repository of information database in a model (Cheung et al. 2012; Olatunji and Sher, 2010).

It allows the valuable data to be stored, shared, retrieved, and passed among project members with minimal efforts. Thurairajah and Goucher (2013) found that 77% of the surveyed cost consultants perceived BIM as an approach for easier sharing and obtaining of information compared to traditional practices throughout their research. All the information is derived directly from the model which allows QS to refer to correct and precise information at anytime for cost estimation. In addition, Popov et al. (2010) pointed out that project team members could effectively share information in the model by eliminating a few pitfalls, such as data redundancy, re-entering data, data loss, miscommunication, and translation errors. It eases information exchange between team members as everyone refers to a single data rich building model that contains a wealth of information. The easy access to information offered by BIM allows better exchange and sharing of ideas that reduce information break down.

Furthermore, one of the objectives at this stage is to integrate detailed design decisions from all designers into a unified scheme. Design accuracy and consistency among various design disciplines are crucial for obtaining planning approvals. BIM has the capability to integrate and to merge multiple models, such as architectural, structural, engineering, mechanical, and plumbing, to better understand the constructability of the building by identifying clashes and analyzing for interference. This capability is known as clash detection *(C7)* and it is a key benefit of BIM for QSs (Thurairajah and Goucher, 2013; Stanley and Thurnel, 2014). Meanwhile, Coates et al. (2010) claimed that clash detection can be undertaken to rectify the traditional problem of construction documentation which is clash between various disciplines. 50% of the respondents agreed that clash detection between designs would lead to fewer cost estimate revisions in early project stages, as discovered by Thurairajah and Goucher

(2013). This capability reduces costs and eliminates reworks by identifying design conflicts at the early stage (Condit, 2006). Hence, it reduces errors and discrepancies in design that often occur in traditional methods, which lessens the work of QSs to prepare revise costing.

Moreover, frequently changing the design and the scope occurs regularly throughout the design process. It is a major cause of cost overrun as project cost correlates to the building design. If changes or design revisions are undetected, it can lead to major impacts on the project cost. BIM has the capability to specify the relationship between various building elements in a digital database. Linking is connected among the elements that have relationship. Autodesk (2011) explained that relationships are automatically built into the model which results in components within the model know how to respond and interact with each other. Due to this capability, as design changes are made to the model, affected elements that are interrelated by the linkage will instantly adapt themselves to the new design (Sylvester and Dietrich, 2010). Hence, design changes are reflected consistently in all drawing views *(C5)* is one of the capability in BIM. Design changes are automatically depicted in the model and are also propagated throughout all drawing views (Chang and Shih, 2013). All floor plans, sections, and elevations will be accurate and consistent. Hence, drawing revisions are automatically updated and identified (Exactal Technologies, 2010) into a computerized model rather than plane format drawings (Mihindu and Arayici, 2008). It will always represent the latest iteration of the design which avoids the risk of using obsolete drawings. In addition, Sarshar et al. (2004) agreed that automated updating eliminated the risk of working with old version data. Manual methods of handling, storing, and maintaining paper-based information such as drawings and documents are difficult, time consuming, and costly due to frequent updates and revisions when design changes.

Besides, updating building quantity manually corresponding to design changes is a major challenge, as pointed out by Lawrence et al. (2014). BIM capability, which directly links model to cost database, offers the opportunity for cost management improvement. Dynamic links are generated and are created with the model assemblies (architectural, structural, civil, mechanical, engineering, and plumbing), elemental areas, and rate library which establish connection and relationship among these elements (Staub-French and Fisher, 2000; Mitchell, 2012; Meerveld et al., 2009). With this linking, changes in design result in changing to dimensions which can automatically update quantities and regenerate the associated estimate (Exactal Technologies, 2010; Papadopoulos, 2013). The quantities of the elements affected are automatically updated and the cost estimates are automatically recalculated when changes happen. It allows for the consistency of cost data and the adaptation to the design iterations whenever the design changes (Abdelmohsen et al., 2011). Thus, cost implication pertaining to changes in design can be generated automatically without the need to recalculate *(C6)* (Malone, 2013; Popov et al., 2010; Thurairajah and Goucher, 2013; Kala et al., 2010: Jiang, 2011).

Furthermore, BIM has the capability to access the implications of changes by reflecting them in the unit quantities and cost per unit quantities respectively. The process will never begin from quantity takeoff again. It provides a real-time iterative design model which allows everyone in the project team to see the consequences of a design change on costing which has not previously been accomplished within the traditional method (Cheung et al., 2012). Without intelligent BIM model to establish the relationship between model elements and cost information, QSs are required to track all changes manually and to determine when and also how to adjust the cost information when design changes occur (Staub-French and Fisher, 2000). It is time consuming to identify what is changed, what is new, what has been omitted, or which specifications are different from the previous design. Lawrence et al. (2014) highlighted that a lot of manual works are required to look for changes when the revised designs are issued without any indication of what has been changed. This often results in overlooking of missed out items due to the difficulty faced in recognizing the changes. However, with BIM, cost implication of design changes can be obtained quickly.

3.6.4 Stage 4: Technical Design

At stage 4, all the design work will be accomplished and ready for tender. Hence, there are two major tasks at stage 4 which are cost checking against cost plan to ensure that the design is in order and bills of quantities preparation after cost checking. In this study, for the sake better comprehension, the work at stage 4 is separated and discussed into two sections, which are stages of cost checking and bills of quantities preparation.

3.6.4.1 Work Stage Description: Cost Checking

In this stage, when a cost plan has been established, working drawings and detailed specifications are produced by designers which involve detailed consideration of detailed design of all parts of the building. Thus, brief should not be modified and changed from this point onwards. All necessary documents are ready for submission to obtain planning approval from the statutory authorities as failure to do so will cause delay and serious impacts to the project. Hence, this is a critical stage in the life cycle of the project. The main task performed by QSs is cost checking and monitoring on the various targets that have been established in the detailed cost plan (Smith and Jaggar, 2007). The detailed design of each element will be cost checked by QSs, and if necessary, remedial action should be taken. Besides, cost checking consists of comparing estimated cost of the elements in the detailed design with cost target of the element from the previous stage. Moreover, the checking process is paramount to ensure that all the design elements are captured in the costing. It is to avoid missed out elements before construction begins.

3.6.4.2 BIM Capability

Cost checking and monitoring are important tasks at this stage to ensure that every design elements is captured in costing. Through manual method, it increases time and energy of performing checking and monitoring. Besides, items can be easily overlooked or miscalculated in a large complex project. For instance, if reinforcement bars are missed out in calculation for a floor, it will cause serious impact on the project cost. This serious mistake has often caused QSs in trouble. However, visual on screen checking in the model for completeness *(C8)* ensures that all items are measured and priced (Exactal Technologies, 2010). Besides, BIM has a 3D viewer function (Sylvester and Dietrich, 2010) which allows cost checking to be done quickly at endless number of times, and in a complexity of combinations. The traditional practice does not allow one to do so due to limited time constraint for checking as it is laboriously intensive and cumbersome. Hence, BIM has the capability to cut down the effort of cost checking against design elements which eliminate the risk of missed out elements.

3.6.4.3 Work Stage Description: Bills of Quantities (BQ) Preparation

After completing cost checking in the previous stage, the detailed design will need to be converted into information that is required for tender documentation. As highlighted by Smith and Jaggar (2007), the main purpose is to ensure the completed design is within the cost limit and the forecast tender sum. Two main tasks performed by the QSs at this stage are detailed cost checking for each element by using preliminary detailed drawings and taking appropriate remedial action if there is discrepancy in costing between cost target and the cost limit. Once these elements have been confirmed, working drawings and detailed specifications will be prepared by the designer after considering the detailed design of all parts of the building. The presence of detailed drawings and specifications allows the QSs to prepare accurate measurement and estimation. QSs will prepare accurate descriptions of the material, measures approximate quantities based on working drawings, and price these quantities by estimating for forecasting the total cost of the project. This in turn will generate BQ for tendering and selection of a suitable contractor to carry out the construction work. A final pre-tender estimate based on this tender documentation can be produced by pricing the final bills of quantities. This will serve as a means of comparison between the price breakdown from the successful tenderer and the progress payments made during the construction stage.

3.6.4.4 BIM Capability

BQ preparation has remained an important service of the quantity surveying profession at this stage for tendering purpose. While at post-construction stage, BQ is used for variation valuation, valuations for interim certificates, and final accounting (Seeley, 1997). Although BQ preparation is an important task in the construction process, it is a tedious and a time consuming task which requires re-measurement for any design iteration. The most tedious component during BQ preparation is quantity takeoff. Quantity takeoff is measuring quantities from design drawings that are needed for pricing by breaking down the project into units of work in order to evaluate the cost and the time needed. Although they are mere minor parts of the cost management process, they take up a lot of the QSs' time, focus, and attention. This is due to the process that involves identifying items and their interrelationships on the drawings and specifications, finding dimensions, and lastly, calculating the quantities, lengths, areas, and volumes of the identified items (Shen and Issa, 2010). Many hours are spent on each estimate, accounting for and measuring each item needed to complete the project, and in evaluating their associated costs (Alder, 2006). The quantity takeoff process for cost estimating still remains a manual process, rather than employing the BIM automation tool (McCuen, 2009; RLB, 2011).

In addition, Popov et al. (2008) suggested that 5D BIM model can be used to reduce time for the calculation of quantities to eliminate uncertainties, errors, and inaccuracies that occur due to manual calculation. Therefore, the automation of quantity takeoff *(C10)* for BQ preparation is one of the capabilities in BIM (Eastman et al., 2008; Popov et al, 2010, Malone, 2013; RLB, 2011, Deutsch, 2011; Staub-French and Fischer, 2000; Papadopoulos, 2013; Meerveld et al., 2009; Davidson et al., 2009; Aouad and Lee, 2007; Tiwari et al., 2009; Monteiro and Pocas Martins, 2013; Nagalingam et al., 2013; Gee, 2010; Kulasekara et al., 2013; Lee et al., 2014; Olatunji and Sher, 2010) that help to simplify the task of QS by removing routine and drudgery that come with this task.

By using BIM, the takeoffs, counts, and measurements can be generated directly from the underlying model.

It arises from the capability of BIM to understand and to recognize the relationship of each element to automatically extract the element properties and their associated quantities. Rather than measuring quantities on plans and elevations manually, the model automatically analyses and identifies all building materials and their components (Kuo and Eastman, 2009), and extracts quantities directly from it, based on the attributes of objects. Hannon (2007) has addressed this point by stating QS is able to extract or map the quantities from the model to perform estimating as the quantities are contained in the model. The one-click tool enables QSs to get an estimate effortlessly by saving their time from calculating the quantities and selecting work standards because these can be done by BIM automatically (Popov et al., 2004). Such work via traditional method could take days to complete, but now, only in hours.

This capability offers a great deal of benefits to the QSs. 77% of cost consultants agreed that this capability would increase the accuracy of cost estimates, as revealed by Thurairajah and Goucher (2013) in their research. Tulke et al. (2008) also asserted that automated measurement increases the speed of estimating and improves the accuracy of quantities. It also allows QSs to provide better and faster cost advises, as claimed by McCuen (2008a) and Exactal Technologies (2010). This capability helps to improve QSs' job performance by eliminating tedious traditional takeoff methods and by reducing human error. Furthermore, by reducing time of doing taking off manually, QSs can spend more time and apply knowledge to higher value estimating activities such as allocating appropriate rates and risks. Mitchell (2012) pointed out that instead of spending 90% of the time calculating quantities, QSs can spend most of the time to generate savings and efficiencies. Therefore, this capability facilitates QSs in producing quality quantification. BQ can be produced automatically and linked to databases where information regarding labor, material, and other costs information are stored.

Furthermore, interpretation of design drawings is important during quantity takeoff for BQ preparation. However, Witicovski and Scheer (2012) highlighted the largest problem in estimating is the incorrect visualization of the project information. If it is not fully visualized and understood, it can be interpreted wrongly in the contract documents and may consequently create problems during the construction stage. There are some limitations of drawings. They require multiple views, such as plan, section, and elevation, to depict a 3D object in detail. They are stored as lines, arcs, and text that are only interpretable by some people, but they cannot be interpreted by computers (Eastman et al., 2008). Hence, it requires correct interpretation and understanding of the drawings from the users. BIM have addressed the limitations of 2D drawings that lack of the rich 3D context (Froese et al., 1999; Staub-French and Fisher, 2003).

Visualization has been recognized as an effective tool in getting better understanding of a design in a project especially complex relationships and complex system (Eastman, 2008; Card, 1999; Kamat, 2001; McKinney and Fisher, 1998; Haque and Mishra, 2007; Thurairajah and Goucher, 2013; Stanley and Thurnell, 2014; Olatunji and Sher, 2010) *(C9)*. This capability can reinforce an understanding of the design that is not particularly evident in 2D drawings (Kala et al. 2010). Papadopoulos (2013) stated that BIM facilitates QSs to understand the project design by improving visualization. This capability enhances the understanding among QSs on the design especially complex design and structure. Besides, Olatunji et al. (2010a) pointed out that visualization facilitates more accurate judgment for construction realities as QSs are able to visualize and rotate design in different views and perspectives. Inaccurate drawing interpretation during measurement will also be eliminated, as pointed out by Thurairajah and Goucher (2012). Hence, QSs will be able to provide accurate costing advice to client as they have adequate understanding and correct interpretation of the design.

3.7 BIM Capability in Quantity Surveying Practice: A Conceptual Framework

BIM offers a new way of documenting, designing, constructing, and managing the building lifecycle processes. Many realistic advantages can be realized by the utilization of BIM in quantity surveying practice such as integration, synchronization, accuracy, consistency, and coordination. Integrating BIM model with costing database will create a linkage that makes changes captured in the model are updated in costing instantly. Design is synchronized with costing in the project as changes in design will be automatically updated in costing. Cost accuracy is ensured due to automatic update of design. Thus, consistency can be achieved due to uniformity between drawings, specifications, and costing. Clash detection capability is able to detect design conflict and interference checking at the early stage to ensure coordination among design which will reduce cost estimation revision. This results in a better and an efficient way for building team to work, with time and cost saved, enhanced quality, and better buildings.

Hence, the first objective of this research is to identify the BIM capabilities in quantity surveying practice which underpin the overall research process. After comprehensive reading was conducted, a summary of the BIM capabilities in quantity surveying practice following the RIBA Plan of Work 2013 is illustrated in Table 3.2. Overall, the literature review process arrived at 11 BIM capabilities identified as associated with project performance. A conceptual framework was constructed to connect the 11 capabilities and project performance, as displayed in Figure 3.2. The “relationship” is the outcome of the research which needs to be established in order to determine if BIM capabilities, especially in quantity surveying practice are related to project performance in time, cost, and quality aspects. Thus, it is noteworthy that clear understanding of BIM capabilities is a key factor for QSs to obtain competitive advantage in the construction industry. Given this conceptual framework, the relationship between these 11 capabilities and project performance had been investigated. The framework provides a clear direction for the research, as well as a means for organizing the collection and analyses of data, which were further developed in the next stage of the research.

3.8 Summary of Chapter

QSs have been known as cost experts who provide cost management services for clients. Traditionally, they adopt inefficient methods to perform their tasks that may affect the project performance. However, with the adoption of BIM, there is potential to rectify the shortcoming caused by the traditional approach which improves the performance of QSs. Besides, it had been discovered that there has been lack of research approaches in BIM capabilities as far as quantity surveying practice is concerned after literature review was carried out. By using RIBA Plan of Work 2013 as reference, 11 capabilities were identified in the quantity surveying practice. As a result, a conceptual framework was developed which represents the theoretical way of framing the research from the beginning. This allows for suitable research designs and methods to be considered and developed in the next chapter.

Table 3.2: Summary of the BIM Capabilities in Quantity Surveying Practice Following RIBA Plan of Work 2013

RIBA Work Stages (former)		RIBA Work Stages 2013 (latest)		Description of tasks	Tasks of a quantity surveyor	Capability of BIM
A	**Inception**	**1**	**Preparation**	- Set up project team. - Identify client's requirements. - Establish cost limit/ budget.	- Conduct feasibility study and determine budget - Prepare cost appraisal (preliminary costs advise) based on preliminary information to enable client to decide whether to proceed.	1. LOD 100: initial concept estimate by the model Cost appraisal can be prepared quickly at the feasibility stage for client to evaluate the feasibility of the project (Mitchell, 2012; Roginski, 2011; Exactal Technologies, 2010).
B	**Feasibility**					
C	**Outline Proposals**	**2**	**Concept Design**	-Distribute the cost limit to various project elements. - Prepare analytical studies of a number of design proposals based on schematic drawings.	- Prepare cost plan (outline or preliminary cost plan) in a group element format. - Evaluate and compare cost of various design proposals	1. LOD 200 estimate by model Preliminary cost plan: estimated cost based on measurement of generic element by extracting quantity directly from model (Cheung et al., 2012; McCuen, 2008a; Mitchell; 2012; Nagalingam et al., 2013). 2. Easily generate accurate cost estimate of a number of design solution for various proposals for comparison and evaluation. (Mitchell, 2012; Mihindu and Arayici, 2008; Cheung et al., 2012; Exactal Technologies, 2010; Popov et al., 2010; Nagalingam et al., 2013; Coates et al., 2010).
D	**Scheme Design**	**3**	**Developed Design**	- Further develop design and cost. - Ensure overall design is the most effective. - Establish realistic elemental cost.	- Prepare elemental cost plan and update progressively as more information becomes available. - Establish sub-elemental cost targets	1. LOD 300 estimate by model Automatic update preliminary cost plan from the previous stage to detailed cost plan as design is developed by linking the model to cost database (Thurairajah and Goucher, 2013; Cheung et al., 2012; Nagalingam et al., 2013; Mitchell, 2012; Sylvester and Dietrich, 2010). 2. Easy access to information and drawings in a central coordinated data rich model (Cheung et al., 2012; Popov et al., 2010; Thurairajah and Goucher, 2013; Olatunji and Sher, 2010).

Table 3.2: Summary of the BIM Capabilities in Quantity Surveying Practice Following RIBA Plan of Work 2013 (cont'd)

RIBA Work Stages (former)		RIBA Work Stages 2013 (latest)		Description of tasks	Tasks of a quantity surveyor	Capability of BIM
						3. Design changes are reflected consistently in all drawings views (plan, elevation, and section) due to relationships that are generated by model among design elements to ensure latest iteration of the design (Sylvester and Dietrich, 2010; Chang and Shih, 2013; Exactal Technologies, 2010). 4. Cost implication regarding the changes in design can be generated automatically, without the need to re-measure and recalculate due to linking capability of design model and cost database (Malone, 2013, Thurairajah and Goucher, 2013; Popov et al., 2010; Exactal Technologies, 2010; Papadopoulos, 2013; Abdelmohsen et al., 2011; Kala et al., 2010; Jiang, 2011). 5. Clash detection between various types of design reduces errors in design and cuts down cost estimate revisions (Thurairajah and Goucher, 2013; Stanley and Thurnel, 2014; Coaster et al, 2010; Condit,2006).
E	**Detailed Design**	4	**Technical Design**	- Completion of the final layout drawings. - Ensure detailed design is contained within the final budget. - Design is frozen. - Complete all documentation of the agreed (frozen) design. - Design team prepare drawings and associated documents (schedules and specification)	- The detailed design of each element should be cost checked against cost plan. - Cost checking and monitoring are carried out. -Final cost checks of design against cost plan are done and remedial action is taken to keep within the budget and to maintain the client's requirements. - BQ preparation.	1. BIM allows cost checking to be done quickly and endless number of times by visual on screen checking to ensure that all design items are captured and measured (Sylvester and Dietrich, 2010; Exactal Technologies, 2010). 2. Improved visualization (Card, 1999; Kamat, 2001; McKinney and Fisher, 1998; Haque and Mishara, 2007; Thurairajah and Goucher, 2013; Stanley and Thurnell, 2014; Papadopoulos, 2013; Olatunji and Sher, 2010; Eastman, 2008). 3. Automatically quantification by model (Popov et al., 2010, Malone, 2013; RLB, 2011, Desutsch, 2011; Staub-French and Fischer, 2000; Papadopoulos, 2013; Meerveld et al., 2009; Davidson et al., 2009; Aouad and Lee, 2007; Tiwari et al., 2009; Monteiro and Pocas Martins, 2013; Nagalingam et al., 2013; Gee, 2010; Lee at al., 2014; Kulasekara et al., 2013; Olatunji and Sher, 2010; Eastman, 2008).
F	**Production Information**					

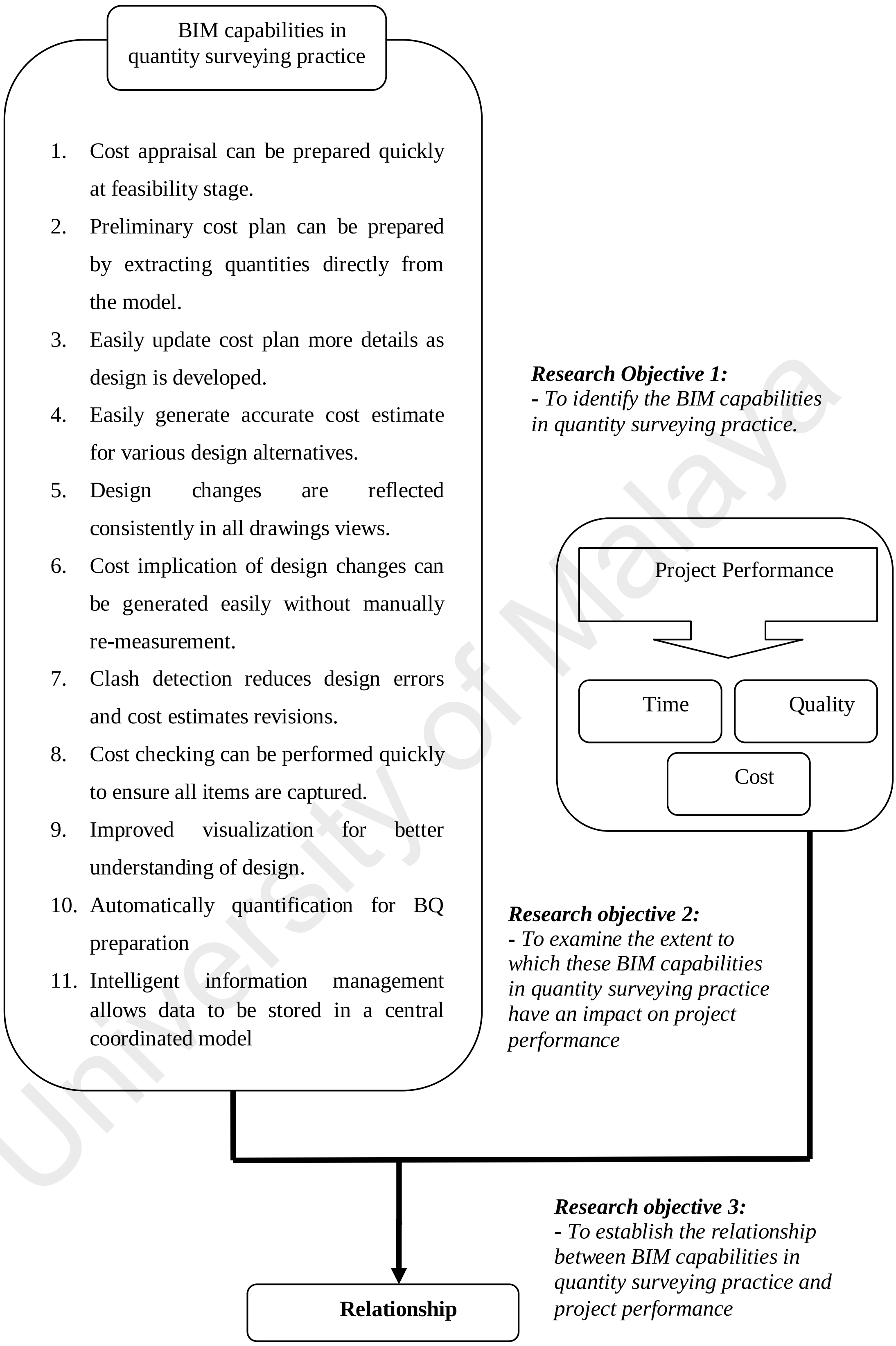

Figure 3.2: Conceptual Framework of BIM Capabilities in Quantity Surveying Practice and Project Performance

CHAPTER 4

RESEARCH METHODOLOGY AND DESIGN

4.1 Introduction

This chapter discusses the selection of appropriate research methodology that was adopted in the research. The rational on the choice of research methodology is discussed. The research designs that suit to achieve the aim and objectives of the research are addressed for data collection and analyses.

4.2 Research Design

Creswell (2007) defined research design as procedures for collecting, analyzing, interpreting, and reporting data in any research studies, while Yin (2009) stated it is a logical sequence that connects research questions and conclusion through data collection, analysis, and interpretation. Thus, research design is a systematic and detailed outline of how to address the research problem effectively and it constitutes of a blueprint for the collection, analysis, and reporting data. There are three types of research designs that are widely discussed in the social science research: quantitative, qualitative and mixed method. It is crucial to understand the characteristics of each research design as they provide direction for selecting the appropriate design that is suitable in conducting the research.

Quantitative research is a means to collect factual data and to apply scientific techniques in order to obtain measurement in the form of quantified data (Fellows and Liu, 2003). It aims for testing the objectives and theories by examining the relationship between the variables using statistical procedures (Creswell, 2009). Meanwhile, qualitative research employs the use of non-numerical data, which intends to observe social reality as experienced by the respondents. It seeks to explore and to understand the meaning of individuals or group that ascribe to a social or human problem (Creswell, 2009). Qualitative research is an empirical research where the data is not in number or statistics form, but in the form of word. With that, qualitative research is more subjective and may induce bias, while quantitative research can be examined in an unbiased manner as it generates numerical data rather than words. Hence, this is the major distinction between quantitative and qualitative researches. Another difference, as explained by Creswell (2009) is that quantitative data are thin and shallow, but they can be generalized and produce findings that are prescriptive in nature, while qualitative data are thick, deep, and holistic, which produce findings that are descriptive in nature.

Another research method is the mixed method, which combine both quantitative and qualitative data collection methods. The mixed method of quantitative and qualitative data collection is popular in social science researches because these different methods can compensate for each other's weakness and enhance one another's strengths (Creswell, 2005), thus it can increase the validity and the reliability of the research findings. Besides, Sarantakos (2005) further explained that a variety of information can be obtained on the same issue and the strengths of each method can be used to overcome the deficiencies of the other. Olsen (2004) pointed out that conflict over quantitative and qualitative research methods concluded that more than one research method may and should probably be adopted in order to fulfill a research aim. Using both methods can provide better understanding from multi-dimensional view of the subject that is being studied and yield better outcomes. The researchers can improve the accuracy of their judgments by collecting different kinds of data on the same phenomenon (Jick, 1979).

4.3 The Selection of a Research Design

Research design is paramount as it provides a guideline for researchers to collect and analyze data of a study. Appropriate research design will help to achieve the research objectives. Decision of the choice of research design and strategy depends on the nature of research subject, aims and research questions (Creswell, 2009; Tashakkori and Teddlie, 2003; Bryman and Bell, 2007). Besides, it is important for researchers to identify and decide the suitable research design by taking into consideration the purpose of the research.

In this instance, the nature of the research, aim and objectives had been to examine and establish the relationships between capabilities of BIM in quantity surveying practice (independent variables) and project performance (dependent variables). Previous studies adopted mixed method of quantitative and qualitative to explore the relationships between the independent and dependent variables (Dissanayaka and Kumaraswamy, 1999; Lam and Wong, 2009; Toor and Ogunlana, 2010; Meng, 2012; Jha and Iyer, 2007). Findings derived from a study using the quantitative research strategy can be enhanced by using qualitative study or otherwise. Bryman and Bell (2007) explained that the qualitative method can facilitate the understanding and the interpretation of the relationship between the variables from a quantitative study. Therefore, a mixed method design involves collection, analyses, and mixing of both quantitative and qualitative data, which can yield better outcomes and provide better understanding of research problems.

In addition, many scholars (Patton, 2002; Fellows and Liu, 2003; Olsen, 2004; Creswell, 2009) have concurred that mixed method is able to improve the quality and the validity of social science researches. However, it is noted that the choice of research method must be used appropriately, depending on varying situations. Thus, it is vital to consider how to mix the quantitative and qualitative methods. One must consider the purpose of the research, the questions investigated, and the resources available. It is therefore, offers a blueprint that enables researchers to identify the appropriate mixing method, and subsequently, the design of the research.

4.4 Designing the Research

Generally, there are three types of mixed method designs: triangulation, explanatory, and exploratory (Creswell, 2007; Creswell, 2005). All three types of mixed method designs have distinct characteristics, purposes, strengths and weaknesses that distinguish a design from the other two. Creswell (2005) highlighted six key characteristics of mixed method designs that need to be considered and incorporated for selecting appropriate designs. The six key characteristics are *rational of the design, quantitative and qualitative forms of data, priority, sequence, data analysis matched to* *a design, and diagram of the procedures*. Each of these six key characteristics is discussed in the following to identify the suitable mixed method design for this research.

The rational of design refers to the reason and the justification of mixing both quantitative and qualitative data. Triangulation design is adopted when the researchers intend to directly compare and contrast quantitative results with qualitative results (Creswell, 2007) to obtain different but complementary findings at the same time. On the other hand, the explanatory design is used when qualitative data help to further explain initial quantitative results (Creswell et al., 2003), whereas, the purpose of exploratory design is that exploration is needed for exploring a phenomenon. Creswell (2007) suggested that this type of research is suitable to use when measures or instruments are unavailable, the variables are unknown, or there is absence of guiding framework. After considering the purpose of the research design, it is paramount to identify the suitable type of quantitative and qualitative forms of data for data collection. The quantitative form of data can be referred to questionnaire survey and experiments, while the qualitative form of data consists of interviews and case study.

Furthermore, a researcher should consider the priority and the sequence of data collection for both methods, as it has major influence on the decision for the type of mixed method design chosen. Priority or weight refers to whether a researcher places more emphasis on one type of data than the other types of data (Creswell, 2005). The researcher needs to decide if both quantitative and qualitative methods have equal priority or only one method has a greater priority than the other. In triangulation design, both quantitative and qualitative methods are given equal weight. Both methods play an equally important role in addressing the research problem. As for explanatory design, quantitative method has a greater emphasis whereas in exploratory design, qualitative method has a greater emphasis than the quantitative method.

Sequence of data collection can be divided into concurrent or sequential approaches. The triangulation design is one-phase design in which researchers collect quantitative and qualitative data concurrently at the same time. It is a single phase of the research study, whereby quantitative and qualitative data are collected, analyzed, and interpreted at the same time. On the other hand, when quantitative and qualitative data are collected in two distinct phases, this type of research approach is known as sequential. Meanwhile, explanatory design is a two-phase design in which the researchers collect quantitative data prior to qualitative data, whereas, exploratory design is a two-phase design whereby the researchers collect qualitative data prior to quantitative data.

Next, the researcher should consider how to analyze the data collected from quantitative and qualitative researches. In triangulation design, the researcher can merge the two data sets during interpretation and analysis. As for explanatory and exploratory designs, Creswell (2005) suggested that researcher can analyze quantitative data separately from analysis of qualitative data for sequential data collection, and then connect the two data for discussion. Lastly, a diagram is essential to depict the procedures of data collection for an overview. Table 4.1 summarizes the major differences of these three types of research designs.

Table 4.1: The Major Differences of Research Design Types

Design Type	Purpose	Sequence	Priority	Analysis	Notation
Triangulation	Compare and contrast quantitative results with qualitative results	Concurrent: Collect quantitative and qualitative data at the same time	Equal priority	Merge the two data during interpretation	QUAN + QUAL
Explanatory	Further explained, follow-up explanations	Sequential: Collect quantitative followed by qualitative	Emphasis on Quantitative	Connect data between two phases	QUAN → qual
Exploratory	Measures or instruments are not available, the variables are unknown, or there is absent of guiding framework.	Sequential: Collect qualitative followed by quantitative	Emphasis on Qualitative	Connect data between two phases	QUAL → quan

By understanding and comparing these three designs of mixed method approach and considering the six key characteristic, it was found that explanatory had been appropriate for this research compared to exploratory and triangulation in order to achieve the research aim and objectives. The explanatory mixed method design comprises of sequentially two distinct data collection procedures, whereby the researcher began with collecting quantitative data, and then followed by collecting qualitative data to help explain or elaborate the quantitative results obtained in the first phase. The researcher placed priority on quantitative data collection and analysis compared to qualitative data.

The rational for this approach is that quantitative data and results provide a general picture of the research problem and results from qualitative data are needed to refine and explain the general picture (Creswell, 2005). Besides, qualitative data serve as a follow-up role to help refine or elaborate the results by exploring participants' views in depth. This method is suitable when the researchers want to follow up a quantitative study with a qualitative study to obtain more detailed specific information than can be gained from the results of statistical tests (Creswell, 2005; Creswell, 2007; Creswell, 2009). Hence, this research adopted the explanatory mixed method designs.

The present study began with the quantitative approach to examine the relationships between BIM capabilities and project performance through questionnaire survey. As pointed out by Creswell (2009), quantitative data collection is a means for testing objective theories by finding the relationship among variables. This approach was adopted as the aim of the research was to assess the relationships between BIM capabilities and project performance in the construction industry. Subsequently, the qualitative study was used to validate the findings of the quantitative study and to establish the relationships between BIM capabilities and project performance. Interview was found to be appropriate to verify the results of the questionnaire. As highlighted by Leedy and Ormrod (2005), personal interviews are suitable to serve as follow up purpose to examine the interviewees' opinions. Hence, semi-structured interview was conducted to discuss the relationships that were identified through questionnaire survey for validation purpose. Lastly, Figure 4.1 illustrated the process of collecting both quantitative and qualitative data in sequential approach for this research. After identifying the suitable research approach for this study, the detailed procedure of collecting quantitative and qualitative data is discussed in the next section.

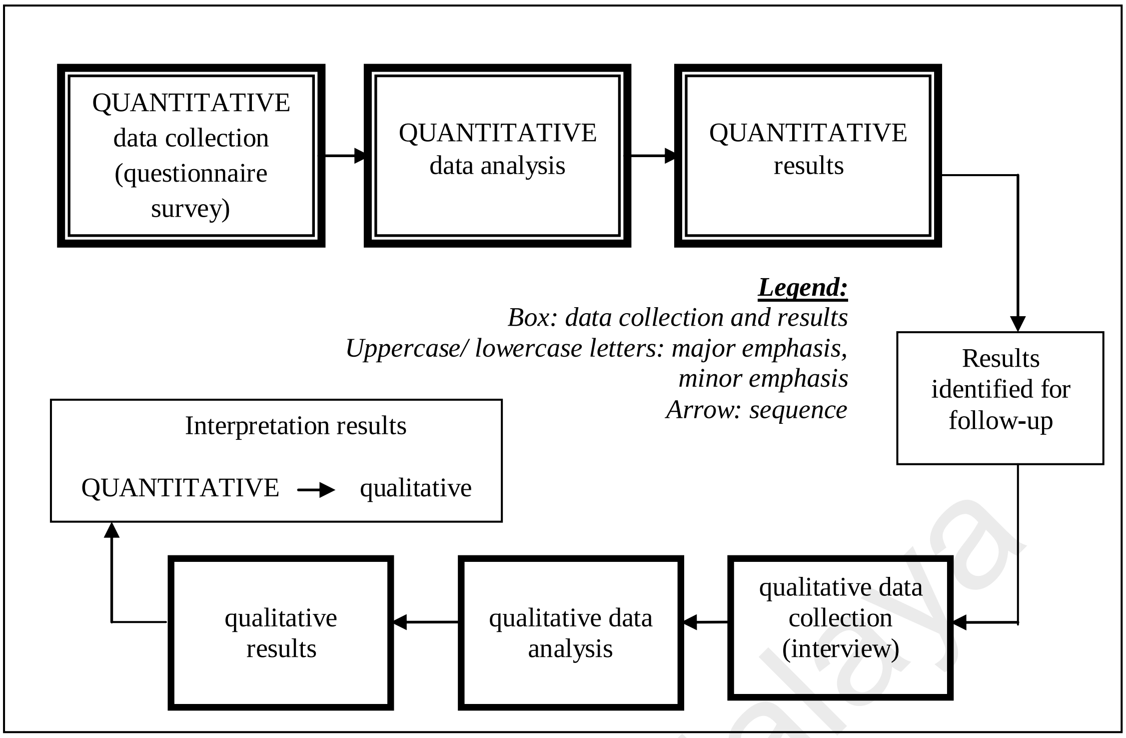

Figure 4.1: Explanatory Mixed Methods Designs for This Research

4.5 Phased Approach Taken by This Research

A research design was developed to guide the researcher on how to collect and analyze data for this study. As outlined in Figure 4.2, a sequential four-phased research approach was designed for quantitative and qualitative data collection and interpretation. The procedures taken in every phase of the research served as a means to inform the subsequent phases. Relevant procedures were conducted in every phase of the research, together with justification and resulting outcomes for every phase explained in this section. It is important to have a research design to guide the implementation of the research methods. Table 4.2 summarizes the whole process and the four key phases of the research.

Table 4.2: Four Phased Research Procedures

Phase	Procedures	Purposes	Outcomes
First phase (Literature review)	Review of prior research of BIM application in quantity surveying practice.	To establish the development of existing research in the area of BIM implementation in quantity surveying practice.	Identified the research gap. Limited study of BIM capability in quantity surveying practice during pre-construction stage and its relationship with project performance.
	Identification of capabilities of BIM in quantity surveying practice.	To identify a list of BIM capabilities in quantity surveying practice by using the RIBA Plan of Work 2013 as a guideline and various literatures relate to BIM application in QSs related tasks.	Identification of 11 capabilities of BIM in quantity surveying practice. Developed a conceptual framework.
Second phase (Preliminary interviews)	Semi-structured preliminary interviews with 8 QSs who used BIM in their practice.	To confirm the findings from phase one of the research, and allow for new capabilities to be presented in this phase. Confirmation of the capabilities is required to match the industry practice.	11 capabilities are discussed comprehensively by all interviewees. There are no other capabilities proposed by the interviewees.
	Use of content analysis to analyze interview data	Typical and popular method of analyzing qualitative interview data, especially for small amount of data.	8 capabilities were confirmed by all the interviewees. The other 3 capabilities were not confirmed by 1 of the interviewees. Overall, the capabilities identified were confirmed by the interviewees. For purpose of inclusivity, a total of 11 capabilities were carried forward to the next phase. ***Objective 1 is achieved.***

Table 4.2: Four Phased Research Procedures (continued)

Phase	Procedures	Purposes	Outcomes
Third Phase (Quantitative Questionnaire Survey)	Development of survey instrument. Sample determination.	Incorporate findings from phase two into development of survey instrument. Identify population and samples.	Developed a new survey instrument. Identified 131 quantity surveying firms that adopt BIM for practice.
	Pilot study	Conduct face validity, content validity, and pre-testing questionnaire to determine if the survey instrument had been relevant and represented the purpose of evaluation.	Refined the survey instrument.
	Wider data collection was obtained through self-completed questionnaires	Distribute questionnaires to quantity surveying firms that adopted BIM in their practice.	64 completed valid questionnaires were returned by the respondents.
	Data analyses using differential and inferential statistical methods (correlation and logistic regression)	Conduct rigorous and robust methods of analyses.	Correlation and regression results revealed that BIM capabilities had found associated significantly with project performance in time, cost, and quality aspects. ***Objective 2 is achieved.***
Fourth phase (Qualitative interviews)	Development of interview questions	Incorporate findings from phase three into development of interview instrument. Identify key interviewees.	Defined interview questions. Identified 15 QSs who adopted BIM for practice as interviewees.
	Semi-structured interview with 15 QSs	To validate the survey analysis findings from phase three of the research.	The quantitative results were discussed comprehensively by all interviewees based on their experience of using BIM in their practice and how it affected the project performance.
	Use of content analysis for interview analysis	Typical and popular method of analyzing qualitative interview data especially for small amount of data.	The quantitative results were confirmed and validated by the interviewees. Relationships were discovered between BIM capabilities in quantity surveying and project performance. ***Objective 3 is achieved.***

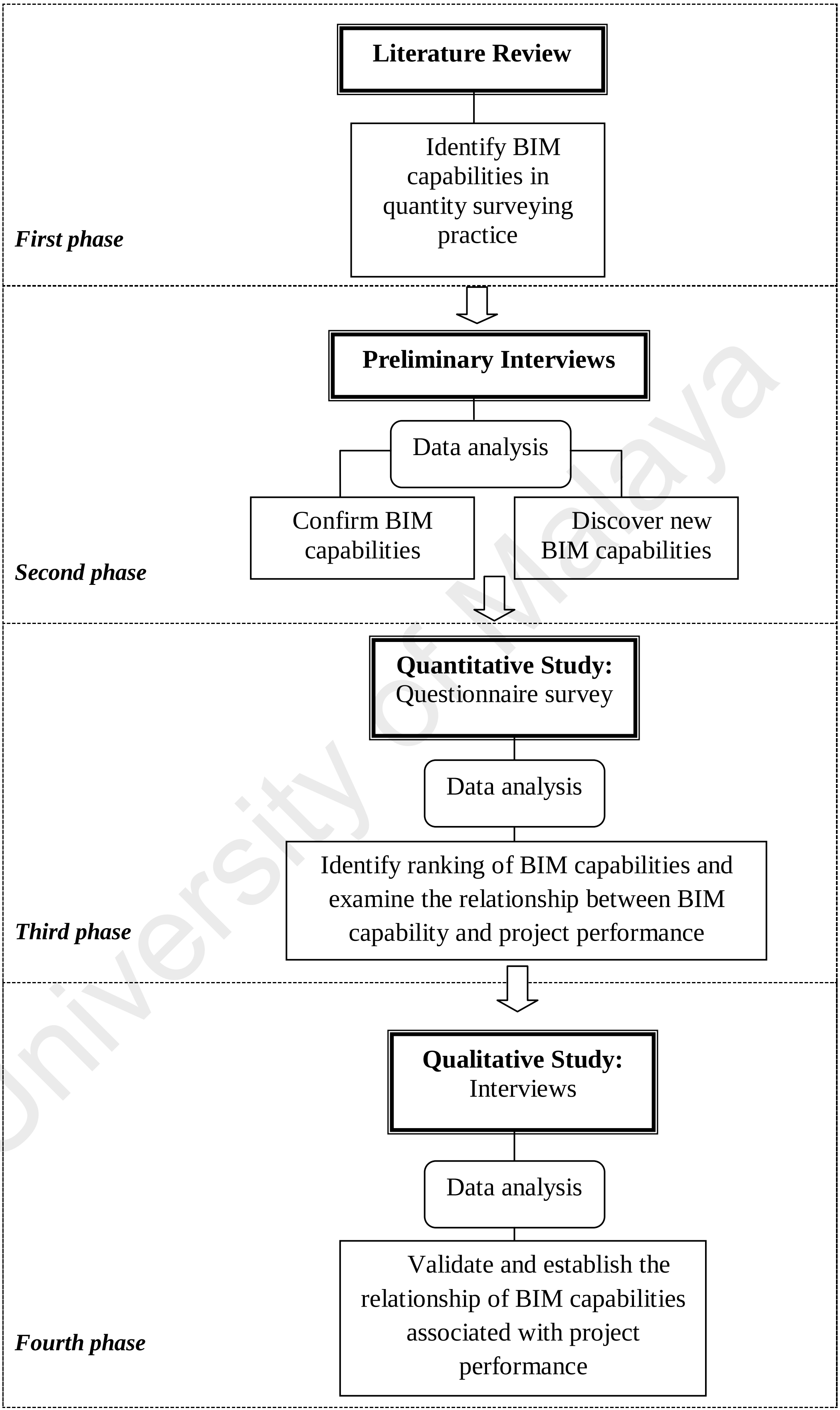

Figure 4.2: Four Sequential Phased Research Procedures

4.5.1 Phase 1: Literature Review

Literature review is a critical process to study the existing theories, concepts, and knowledge used in the study field. The first stage of the research was a broad literature review of BIM application in quantity surveying related tasks in order to identify the capabilities of BIM in quantity surveying practice. It attempted to achieve the first research objective; identifying the capabilities of BIM application in quantity surveying practice. Books, journals, articles, dissertations, conference papers and reports were reviewed in order to reveal the capabilities of BIM in quantity surveying practice. In order to obtain an overview of the tasks provided by QSs, RIBA plan of work 2013 was used as a template to identify the tasks provided by QSs at each work stage of the pre-construction stage. By having good understanding on the tasks and roles provided by QSs, it had been easier to identify the capabilities of BIM in quantity surveying practice at each work stage.

In addition, the critical review of literature identified a wide range of capabilities of BIM in quantity surveying practice that potentially could have an effect on project performance. In total, 11 BIM capabilities were identified to be associated with project performance. This stage formed the basis for the development of the capabilities for BIM application in quantity surveying practice, which may influence project performance. As a result, the findings from the literature review process resulted in a conceptual framework for BIM application in quantity surveying practice that conceptualized the links between the 11 BIM capabilities during pre-construction stage in quantity surveying practice and project performance. The researcher was guided by the conceptual framework in achieving the research aim and objectives. This is detailed in Section 3.7. Based on the conceptual framework established for this research, the next phase was sought to verify the capabilities of BIM in quantity surveying practice. Hence, the 11 capabilities were carried forward to the next phase for confirmation through interviews with QSs who adopted BIM in their practices.

4.5.2 Phase 2: Preliminary Interviews

This phase of the research utilized the findings from the literature reviews to confirm the identified BIM capabilities. Preliminary qualitative interview was chosen to develop an understanding of the BIM application in quantity surveying practice. This phase did not serve as a main data collection stage as it is a preliminary phase to explore the BIM capabilities in quantity surveying practice before rigorous research and comprehensive investigation. Cavana et al. (2001) suggested that qualitative studies, such as interviews can be adopted to gain familiarity with the phenomena and to generate further theories for empirical testing. It allows for rich data collection in terms of experience and perception of the interviewees. In fact, preliminary interview was employed by many researchers, such as Toor and Ogunlana (2010), and Haron (2013), as preliminary data collection to explore an issue before the main data collection.

The key aim of the preliminary interview was to verify the literature review findings and to confirm the capabilities discovered in order to reflect the concerns of the participants in the industry. It had been imperative to identify if these capabilities were viewed as relevant and critical for quantity surveying practice. The semi-structured interview session allowed interviewees to provide their opinions and views on the BIM capabilities in quantity surveying practice. Furthermore, this phase was also conducted to explore more capabilities of BIM in quantity surveying practice as there has been lack of research concerning BIM application in quantity surveying practice. The interviewees had the opportunity to propose other relevant BIM capabilities that could have been applicable in quantity surveying practice. This is a crucial procedure within the research as the identified BIM capabilities were very broad. They required further clarification and confirmation to be utilized for the next quantitative phase. Thus, using the interview method further confirmed and validated the BIM capabilities.

4.5.2.1 Interview process development

The interviews were semi-structured with a list of questions to address a particular topic and the interviewees were given a great deal of leeway in way of replying (Bryman and Bell, 2007). As suggested by Bryman (2004), this type of interview is suitable for an investigation of a fairly clear focus topic so that specific issues can be addressed. Section A of the questions had been on the background of the interviewees to ensure that they were suitable and were capable in answering the interview questions. Section B of the questions intended to verify the BIM capabilities that were identified through literatures. The views of the interviewees had been vital in explaining and in providing understanding on each capability of BIM in quantity surveying practice. Hence, a list of questions that contained all capabilities was used to guide the interviewees in providing their views and opinions that illustrated each capability. The complete set of interview questions is attached in Appendix A.

Furthermore, purposive sampling was employed, whereby the researcher intentionally selected the interviewees. Choosing participants in a qualitative study depends on whether they are "information rich" and relevant to the research questions (Bryman, 2004; Creswell, 2005). The target interviewees for the in-depth interviews were consultant QSs with good understanding of both BIM application and quantity surveying practice. BIM application is still not popular in quantity surveying practice, as highlighted in the literature. Hence, the criteria drawn ensured that the target interviewees possessed sufficient knowledge pertaining to BIM application and adequate experience in quantity surveying practice. 8 QSs with experiences in BIM application and quantity surveying practice were interviewed. The number of interviews depended on the saturation achieved (Glaser and Strauss, 1967; Bryman, 2004). Saturation was achieved after 8 interviews were conducted, as the interview process did not discover any new finding. The detailed profiles of the interviewees are given in Table 5.1, in Section 5.3.

The interviewees were contacted first via email or telephone to seek for agreement on participation in the interview. The purpose of the research and the interview were explained. It had been important to explain to the interviewees regarding the aim of the research and the purpose of the interview to gain their understanding. 8 interviews were conducted face-to-face with the interviewees in English after a meeting was arranged with each of them. This phase was conducted over a period of two months (April and May 2013) due to the time available for each interviewee.

Before the interviews began, words of greeting and appreciation were offered to the interviewees for allocating valuable time for the interview. After that, a brief and short introduction of the research was explained to the interviewees, the importance and the contribution of this interview to the research were highlighted. The interview began by exploring the detailed background of the interviewee (Section A). The interviewer discussed in detail the BIM capabilities (Section B) with the interviewee to obtain their views and opinions on each BIM capabilities that were found through literature reviews. Lastly, the interviewees were asked to provide their views and comments on BIM application in construction industry and quantity surveying practices. At the end of the interview, two of the interviewees requested for a copy of the interview transcript.

Every interview was digitally-recorded with consent of the interviewees before the interview began. Confidentiality was assured to the interviewees. The length of time for the interview varied and ranged from 40 minutes to one hour in duration. Audio recording was chosen to capture the content of the interviews for the later transcript stage. Besides, it was also to ensure that no information had missed out throughout the interview. Through audio recording, the interviewer could concentrate on the conversation with the interviewee to maintain the ongoing conversation. Hence, it took away the burden of note-taking during the conversation as not everything could be completely written down during interview.

4.5.2.2 Analysis of interview

Before the analysis process had begun, the audio-recorded interviews were transcribed. It was the process of transferring audio into written text. Transcribing interviews has advantages, such as correcting the natural limitations of memories, and allowing more details and repeating examination of what the interviewees said (Bryman, 2004). The transcribed interviews served as the primary sources of data and were analyzed using content analysis. As defined by Hsieh and Shannon (2005, p. 1278), qualitative content analysis is *"a research method for the subjective interpretation of the context of text data through the systematic classification process of coding and identifying themes or patterns".* It is known as a systematic process used to analyze the texts for compressing massive volumes of data via coding to examine themes and patterns in a particular text in order to explore the meaning.

The first step of content analysis was data preparation by transforming the data into written text, such as complete transcripts. Manual analysis was adopted as the size of the manuscripts was not large. Next, unit of analysis referred to the basic units of texts that were coded for analysis. They were labelled words, characters, sentences, or paragraphs in the transcript that could explain the phenomena or answer the research questions. The next step was developing coding scheme, whereby data were broken down into some manageable classification categories. The purpose of classification was to assist the search for patterns and themes within a particular text (Patton, 1990). The data collected were categorized based on the capabilities. Texts were sifted into relevant categories and similar meanings were aggregated together to obtain an overview. The last step involved making inferences of the themes identified and presenting meanings derived from the data. It was a critical step in the analysis process that involved examining the properties and the dimensions of the categories. At the end of the content analysis, the results were presented in the form of matrices, as suggested by Saunders et al. (2007). Matrices are tabular form with defined columns and rows which allow the researcher to display the findings systematically.

The results from this phase of the research was the verification of the capabilities identified at the first phase, together with an in-depth understanding of the capabilities of BIM application in quantity surveying practice perceived by the interviewees. Furthermore, this process allowed for the development of the survey instrument, as discussed in the following section.

4.5.3 Phase 3: Quantitative Questionnaire Survey

The third phase of the research was a survey with the aim to examine if these capabilities of BIM in quantity surveying practice had an influence on project performance. It permitted better understanding on the impact of BIM implementation during the pre-construction stage on project performance. The questionnaire survey was used as the main data collection as it enabled the researchers to examine and to explain the relationships between constructs in depth, in particular, cause-and-effect relationship (Saunders et al., 2007, Creswell, 2009). Therefore, it was the appropriate means of data collection to achieve the aim of the study.

4.5.3.1 Development of the survey instrument

Several scholars (Cavana et al., 2001; Bryman and Bell, 2007; Creswell, 2009) have discussed the important elements to design a good survey instrument. Following their recommendations, the questionnaire was designed for easy interpretation to achieve the research objectives. Closed questions were used and the respondents were required to tick the appropriate boxes. Closed questions offer advantages to both the respondents and researchers. It allows the respondents to make fast decisions to choose among a set of alternatives given by the researcher. On the other hand, it helps the researcher to code the information easily for subsequent data analysis.

The questionnaire consisted of four sections related to respondents' information, BIM capabilities, and project performance. A definition section was placed at the beginning of the questionnaire to clarify the respondents on certain terms. Section A represented general information, followed by section B that identified the respondent's organization in using modeling software and also compared the traditional methods with BIM application. Section C of the questionnaire measured the constructs in terms of their importance to project performance on a five-point Likert scale that varied from 1=not important to 5=extremely important. The last section required the respondents to assess the project performance by using BIM in time, cost, and quality aspects. Besides, the respondents were requested to provide information about time, cost, and quality of performance for the projects that employed BIM application. The questions were adopted and modified from previous studies that were related to project performance measures in time, cost, and quality aspects (Chan et al., 2001; Jha and Iyer, 2005; Jha and Iyer, 2006a; Jha and Iyer, 2006b; Jha and Iyer, 2007). A five-point scale was adopted to reflect the time, cost, and quality aspects of the performance.

In time aspect, the respondents were asked to compare the current project time (schedule status) to the estimated duration as adopted by previous studies (Wong, 2004; Dissanayaka and Kumaraswamy, 1999; Hong, 2011; Kog et al., 1999). Cost performance was rated by the respondents by comparing the current project cost to initial planned cost as adopted by previous studies (Dissanayaka and Kumaraswamy, 1999; Hong, 2011). Construction quality is a subjective assessment which is difficult to quantify (Chan et al, 2004). Therefore, it cannot be so easily quantified and measured compared to cost and time aspects. Quality can be defined as meeting the requirements and satisfaction of the clients, by how closely the project conforms to its requirements such as completion on time and within budget (Arditi and Gunaydin, 1997). In this study, quality was measured in terms of client satisfaction as widely adopted by previous studies (Adnan et al., 2000; Puspasari, 2005; Takim et al., 2003; Chinny et al., 2010; Rwelamila and Hall, 1995). This had been due to the fact that clients often experience dissatisfaction that are caused by cost overrun, project delays, inferior quality, and incompetent services provided by project teams (Contract Journal, 2004). Appendix B presents a blank copy of the questionnaire for the respondents.

4.5.3.2 Pre-testing of the questionnaire

Pre-testing of questionnaire surveys is important prior to distributing the final questionnaire to respondents. It is to ensure the design of questionnaire is appropriate and proper so that it will be able to achieve the research objectives. Pre-testing of the questionnaire includes content validity, face validity, and pilot study (Cavana et al., 2001; Creswell, 2005). Creswell (2009) further highlighted that pre-testing is important to establish the content validity of an instrument and to improve questions, scales and format.

Face validity is established after the questionnaire is developed. Bryman and Bell (2007) suggested that face validity can be established by asking people who are experienced or experts in a field to determine if the measures reflect the concept. Hence, the developed questionnaire was first reviewed by the research supervisory team in the area of IT. Face validity is important to ensure that the items in the questionnaire are clear and understandable to avoid wording ambiguity and confusion in each question. Besides, it is also to check if the items really measure the concepts. Upon conducting face validity, some questions were rephrased to increase clarity. Once the questionnaire was refined, it was ready for pre-testing with potential respondents to establish an initial reliability assessment.

The purpose of content validity is to ensure that the instrument adequately measures the concept (Cavana et al, 2001; Neuman, 2012). It aims to minimize any potential error associated with an instrument. The researcher can test the content validity by seeking the opinion of experts to ensure the adequacy of items to measure the concepts (Cavana et al., 2001; Saunders et al., 2007). In this study, 2 academicians in the field and 4 QSs were sought to validate the content of instrument. Feedback regarding the relevance, accuracy, sequencing, phrasing, and layout of the questionnaire was sought. The questionnaire was refined after the feedback especially the technical terms, sequence of items, format, and arrangement were retrieved to strengthen its validity and clarity.

Before the industry-wide survey, a pilot survey was carried out. The purpose of conducting a pilot study is to ensure that the respondents have no problems on understanding the questions or completing the survey. It is also to ensure that the survey questions operate well and the instrument as a whole functions effectively (Bryman and Bell, 2007). The self-administered questionnaires were pre-tested with 10 QSs in a pilot study. Amendments were made accordingly based on respondents' comments and suggestions. After conducting face validity, content validity, and pilot study, the final instrument was developed.

4.5.3.3 Sampling determination

The procedure for drawing a research sample involved five main steps as suggested by Churchill and Iacobucci (2004) and Wilson (2006): defined a target population; identify the sampling frame; select a sampling method; determine the sample size; and collect the data from sample. These steps are discussed in detail in the following paragraphs.

This research distributed questionnaire surveys to quantity surveying organizations in Malaysia. The target respondents were based on quantity surveying organizations registered with the Board of Quantity Surveyors Malaysia (BQSM). The list of the quantity surveying organizations was obtained from the BQSM. There was a total of 318 quantity surveying organizations registered under the BQSM. Probability sampling is random sample selection so that each unit in the population has an equal chance of being selected (Bryman and Bell, 2007). It is noteworthy that not all the quantity surveying organizations adopted BIM for practice. Probability sampling was not suitable, and hence, the current study employed non-probability sampling. Purposive sampling was adopted to identify samples easier. Purposive sampling can be adopted when the sample possesses desirable information and conforms to criteria determined by the researcher (Cavana et al., 2001). Therefore, quantity surveying organizations that adopted BIM in their practice were selected.

In order to reduce bias, the researcher made initial contact (pre-survey contact) with all quantity surveying organizations in Malaysia to identify the organizations that adopted BIM for practice. Besides, the researcher also made contact to BIM vendors to obtain a list of quantity surveying organization that adopted BIM in their practice.

Through telephone calls, the target respondents (unit of analysis) were determined. The target respondents were QSs with BIM knowledge in the organization. Therefore, QSs who were involved in projects that used BIM were contacted to advise them to expect a questionnaire. This was to ensure that the questionnaires were distributed to organizations that adopted BIM for practice and enabled the researcher to ensure that the target respondents were capable in answering the questions in the questionnaire. This improved the reliability of responses as the questionnaires were distributed to the right respondents. Table 4.3 tabulates the sample size observed. Out of 318, 131 quantity surveying organizations were selected.

Table 4.3: Sampling Distribution

Target	Population	Sample
Malaysia quantity surveying organization	318	131

4.5.3.4 Distributing questionnaires

The final version of the questionnaire was printed out with a cover letter and posted with pre-paid return envelopes to quantity surveying organizations that agreed to dispatch questionnaire by post. Nevertheless, a majority of the quantity surveying organizations requested the questionnaire to be sent via e-mail. The questionnaires were distributed to 131 quantity surveying organizations. Data collection was self-administered, emailed, and the researcher visited, distributed, and collected the questionnaires by hand. After two weeks of distributing the questionnaires, a phone call or a reminder email was sent out to the respondents who failed to return the questionnaire after reaching the deadline given. After a month, follow-up calls and emails were sent out to remind the respondents gently. The field of the study was carried out between October and December 2013.

4.5.3.5 Data analysis

Data generated from the questionnaire were analyzed by using Statistical Package for the Social Science (SPSS). Frequency distribution and descriptive analysis such as mean and standard deviation were performed first. Next, reliability test was carried out by using Cronbach's alpha (α) to identify the degree of reliability in terms of internal consistency. Then, relative importance index was used to rank the BIM capabilities based on their importance. Correlation test was conducted to examine the BIM capabilities that were associated with project time, cost, and quality performance. Logistic regression was adopted to identify the BIM capabilities that affected the project performance to examine the relationship in more detail. These analyses are discussed further in the following section.

The results obtained from the questionnaire survey and analysis are discussed and compared with past research and theory. The results of the research could either support the previous findings or reject them with new achieved results. Moreover, the results obtained may recommend methods to modify or to enhance the existing theory to increase its applicability.

a) Frequency distribution

Frequency distribution is the number of times for each score on a single variable (Leech et al., 2011). It is obtained for all the nominal variables, especially for demographic variables. The frequencies can be visually displayed as bar charts and pie charts.

b) Descriptive statistics

Descriptive statistics such as means and standard deviation are obtained to measure the data. It is used to describe the characteristics of a variable (Chua, 2012; Saunders et al., 2007). Mean is known as a measure of average to represent a set of values in the distribution. The mean is computed by summing up all the scores and dividing the number of scores, as shown in the following:

$$\text{Mean} = \frac{\text{Total score}}{\text{Number of scores}} = \frac{\sum X}{N}$$

Meanwhile, standard deviation explains the dispersion of scores in a distribution. Generally, it indicates the deviation of each score from the mean of all the scores. The formula of standard deviation is as in the following:

$$\text{Standard devitation}, \sigma = \sqrt{\frac{\sum(\mathrm{x} - \bar{\mathrm{x}})^2}{\mathrm{N} - 1}}$$

Where, x = observations; x-bar = mean; and N = total number of observations

c) Reliability test

Reliability is one of the important aspects in a research. The purpose is to check the internal consistency and stability of the instrument (Cavana et al., 2001; Sekaran and Bougie, 2009). It is meant to test the consistency of respondents' answers to all the items in a measure (Cavana et al., 2001). Reliability test was carried out by using Cronbach's alpha (α) to indicate how well the items in a set were positively correlated to one another. SPSS was used to conduct this analysis and it provided statistics called Cronbach's alpha coefficient. The higher the coefficients, the better the measuring instrument. According to Malhotra (2003) and Leech et al. (2011), Cronbach's alpha of 0.60 and above indicates good reliability.

d) Ranking of BIM capabilities

In order to rank the capabilities of BIM according to their importance, relative importance index (RII) was applied for this purpose. RII method has been adopted by many researchers (Chan and Kumaraswamy, 1997; Kometa et al., 1994; Aibinu and Jagboro, 2002; Jha and Iyer, 2005; Sambasivan and Yau, 2007) in earlier studies to rank the variables. Hence, similar method was adopted to analyze the data. The five-point scale 1-5 was transformed to relative importance indices for each of the 11 capabilities of BIM in quantity surveying practice by using the following equation.

The relative importance was evaluated using the following expression:

$$Relative\ Importance\ Index\ (RII) = \frac{\sum W}{A(N)} = \frac{5n1 + 4n2 + 3n3 + 2n4 + 1n5}{5N}$$

Where W is the weight given to each capabilities by the respondents and ranges from 1 to 5, A is the highest weight (i.e., 5 in this study), and N is the total number of respondents.

These indices were then used to determine the rank of each capability. The weight average for each capability was determined and ranks (R) were assigned to each capability representing the perception of the respondents. These rankings were used to compare the relative importance of the capabilities.

e) Correlation coefficient test

Correlation test was utilized to examine the BIM capabilities that were associated with project time, cost, and quality performance. The purpose of correlation test is to measure the association between two continuous variables. By conducting this test, the researcher is able to know how those variables are related to each other. The type of correlation test used depends on the type of measurement scale. Spearman's rho correlation is used when one or both of the variables are ordinal (Leech et al., 2010; Chua, 2012). As this study adopted ordinal data, this type of correlation method was deemed as the most appropriate method for correlation analysis. Moreover, there is support in the literature (Lam and Wong, 2009; Toor and Ogunlana, 2010; Ringim et al., 2012) for the use of correlation analysis in examining the association between variables. Thus, to examine the relationship between two variables, the BIM capabilities in quantity surveying practices and project performance were correlated using the Spearman correlation analysis.

A research hypothesis is generated to determine the relationship. The null hypothesis and alternative hypothesis are:

H_0 ($p > .05$) - There is no significant correlation between BIM capabilities and project performance.

H_1 ($p < .05$) - At least one of the BIM capabilities has significant correlation with project performance.

In social sciences research, the significance level (p) is normally reported as 0.05 (Field, 2009). This significance value determines the significant relationship between the variables. For this research, there is a significant relationship between the BIM capabilities and project performance if the significance level is less than 0.05. However, if the significant level is greater than 0.05, the alternative hypothesis is rejected and report that there is no significant relationship between the BIM capabilities and project performance.

f) Logistic Regression

Regression method was adopted to investigate the effect of BIM capabilities on project performance. By adopting this method, the project performance can be predicted to further understand the relationship between capabilities and project performance. As this study investigated the effects and the impacts of using BIM capabilities in quantity surveying practice on project performance, hence, regression was adopted. Saunders et al. (2007) explained that regression is used to assess the strength of a cause-and-effect relationship between a dependent variable and one or more independent variables. With this method, which BIM capabilities influence the project performance had been discovered.

Linear regression and logistic regression are two popular methods that have been adopted widely in social science researches to investigate the effects of the independent variables on the dependent variables. As explained by Hair et al. (2009), logistic regression is appropriate when the dependent variable is a categorical (non-metric) variable and the independent variables are non-metric variables. In this study, both independent and dependent variables were in ordinal scale (non-metric variables).

Hence, logistic regression was found to be appropriate in this study. The ratio of sample size for the independent variables is an important consideration when regression is adopted. The minimum requirement is to have at least five times more sample size than the number of independent variables (Coakes and Ong, 2011; Hair et al., 2009). In this study, the sample size was 64 and the number of independent variable was 11. Hence, it satisfied the basic requirement to use logistic regression.

The application of logistic regression had been preferred due to a number of reasons. First, it does not require meeting the assumptions of multivariate normality, linearly related or of equal variance, which makes its application appropriate in many situations (Hair et al., 2009; Field, 2009; Leech et al., 2011; Wong, 2004; Tabachnick and Fidell, 2007). Multiple linear regressions require normality assumption which is difficult to achieve in practice, whereas logistic regression has been found to be very robust without strongly adhering to this assumption (Sharma, 1996). Second, it has straightforward statistical tests to incorporate metric and non-metric variables and nonlinear effects (Hair et al., 2009). It does not require linear relationship between the independent variables and the dependent variables as does multiple regression. Hence, it is more popular in application due to lack of assumptions required as multiple regression does.

Moreover, logistic regression analysis has been widely used by researchers in construction research for establishing the relationship between several independent variables and a dependent variable to predict the project performance (Diekmann et al., 1994; Wong, 2004; Alzahrani and Emsley, 2013). In addition, logistic and linear regressions differ, whereby the former is designed to predict the probability of an event occurring (Hair et al., 2009; Alzahrani and Emsely, 2013). Logistic regression estimates the likelihood that an event occurs and produces dichotomous outcome that is easily interpreted. It is known as binary logistic regression when the dependent variable is dichotomous and the independent variables are either categorical or continuous. It can indicate an outcome of a situation whether it will happen or otherwise. Thus, the probability of an event to occur can be measured via this method.

- Interpretation phase

In this study, 11 capabilities of BIM were referred as independent variables or predictors, and the project performance as dependent or explanatory variable.

The relationship was expressed in the form of

$$Logit\ (Y) = \ In\left[\frac{\pi}{1-\pi}\right] = \ \alpha + \ \beta_1 X_1 + \ \beta_2 X_2$$

Where,

Y = dependent variables

π = probability of the event

α = Intercept

β_1, β_2 = regression coefficients

X_1, X_2 = independent variables

Logistic regression model predicts the logit of Y from X. The logit is the natural logarithm (In) of odds of Y, and odds are ratios of probabilities (π) of Y happening to probabilities (1 - π) of Y not happening. This dichotomous probability was measured by 0 or 1. The dependent variables which were project performances, were re-coded to be dichotomous of good and poor performances from a 5-point scale. Performance was considered to be good if the performance rating was equal and greater than 3 (≥3) and poor if the score was less than 3 (<3). After that, the 5-point scale was re-coded into dichotomous variables, which were good (1) and poor (0) performances. Then, the probability of project performance was predicted (good or poor) based on BIM capabilities in quantity surveying practice. Moreover, the predictors that contributed significantly to the regression were identified.

- Reporting results

Several parts had to be included for logistic regression model evaluation to assess the overall model fit. In making an assessment of the overall fit of a logistic regression model, Park (2013) and Peng et al. (2002) suggested a few approaches: goodness-of-fit, statistical tests of individual predictors and predictive accuracy of the model as expressed in classification table. These evaluations were adopted and are explained in the following section.

Goodness-of-fit statistics was used to assess the fit of a logistic model against actual outcomes (Peng et al., 2002). In SPSS, Hosmer-Lemeshow test, also called the chi-square test is used to test for overall fit of model (Peng et al., 2002; Bewick et al., 2005). A non-significant value (p>.05) concludes that the model adequately fits the data, therefore, good overall model fit. The model does not adequately fit the data if the value is significant. In addition, Cox and Snell R^2 and Nagelkerke R^2 can be used to assess the goodness-of-fit for a model. They are used to indicate how useful the predictor variables are in predicting the criterion variables. Nagelkerke R^2 is generally and preferably used for explanation compared to Cox and Snell R^2 (Leech et al., 2011; Bewick et al., 2005).

As for statistical test of individual predictors, the value of coefficient β determines the direction of the relationship between X and the logit of Y. It provides the information about the contribution and the importance of each predictor variables to the criterion variable. A significant value ($p<.05$) indicates that the variable contributes to the predictive ability of the model.

Meanwhile, the classification table is used to evaluate the predictive accuracy of the logistic regression model (Peng and So, 2002; Wong, 2004). It provides an indication on how well the model is able to predict the correct category (good/bad performance). The predictive accuracy of the model can be found in a classification table by referring to the percentage correctly classified.

4.5.4 Phase 4: Qualitative Interview

At the last phase of the study, semi-structured interview was conducted with QSs who adopted BIM in their practices. In this study, the purpose of adopting this method was to validate the findings from the questionnaire to further examine how BIM capabilities influence project performance. This in turn, established the relationship between BIM capabilities and project performances. Songer and Molenar (1997) asserted that qualitative interview is used for validation purpose to provide clarity to the survey results. In addition, the interview helped to explain the relationship between BIM application in quantity surveying practice and project performance. Saunders et al. (2007) highlighted that semi-structured interview is used to understand the relationships between variables, such as those revealed from a descriptive study. Therefore, interview was executed to gather more detailed information from the interviewees in order to validate the results of the questionnaire survey. This allowed rich collection of data in terms of experience of BIM adoption to reflect the reality of the current situation. Moreover, the researcher had direct interaction with the interviewees in more depth to discuss the relationships between BIM capabilities and project performance.

4.5.4.1 Interview process development

Purposive sampling was employed as explained in section 4.5.2.1, whereby the researcher intentionally selected the interviewees based on the criteria if they are "information rich" and relevant to the research questions. The interviewees were selected to ensure the reliability of the responses as they met the following criteria:

a) Had working experience of at least 5 years in quantity surveying practice to ensure the interviewees have extensive experiences in performing QS tasks during pre-construction stage.
b) Experienced in using BIM for project.

The potential interviewees were contacted via email and telephone to request for their permission to take part in the interview session. In this study, 15 QSs were interviewed as a complement to the questionnaire survey. Saturation was achieved after 15 interviews were conducted, as the interviewing process did not discover any new information. This phase was conducted over a period of two months (April to June 2013) due to the availability of each interviewee. The detailed profiles of the interviewees are given in Table 7.1, in Section 7.3.

The interviews were conducted in English with QSs from each firm. The interviewees were asked a range of questions related to the capabilities associated with the implementation of BIM and the impacts of these BIM capabilities on project performances. The interviews enabled a deeper interrogation and understanding of the issues. Before the interview began, the researcher sought the consent from the interviewees to record the content of the interview. However, one of the interviewees refused to record the interview session. Hence, the researcher had to record down the information by hand and also at the same time carry out the interview. The length of time for the interview varied and ranged from 50 minutes to one hour in duration. The interview validation process was conducted over a period of two months (May and June 2013) due to the availability of each interviewee

4.5.4.2 Analysis of interview and interpretation

Data obtained from the interviews were analyzed by using content analysis as described in section 4.5.2.2. The process of qualitative analysis began with the development of data categories by classifying the data into categories. The purpose was to condense and to rearrange the data into more manageable form. Next, the unit of the data was attached to the relevant categories. The data were then presented in an organized and condensed manner by displaying them in matrices to identify emergent patterns. Lastly, the results were interpreted to draw conclusion.

The findings from this phase of the research validated the survey results at the previous phase to establish the relationship between BIM capabilities and project performance. The views and elaborations of interviewees are discussed and quoted. Interview results were then discussed and compared with the results from the questionnaire results for validation purpose.

4.6 Summary of Chapter

This chapter has reviewed the research methodology used in carrying out this study. The overall research procedures and analyses methods are explained. A four-phased research mixed method approach was designed and adopted, employing quantitative and qualitative methods. First, a detailed literature review was carried out to identify a set of 11 BIM capabilities in quantity surveying practice. It was followed by preliminary interviews to confirm the BIM capabilities identified from the existing literature. Following this, a set of questionnaires was designed to examine the relationship between BIM capabilities and project performance. Lastly, qualitative interviews were carried out to validate the questionnaires survey results.

CHAPTER 5

PRELIMINARY INTERVIEW RESULTS

5.1 Introduction

This chapter presents the results and the analysis of qualitative interviews as preliminary data collection for this research. The purpose of conducting preliminary interview was to validate the BIM capabilities that were found from the literature. This chapter begins with the profiles of interviewees to depict their background. Next, this chapter discusses in detail of each BIM capabilities in quantity surveying practice, and lastly a summary of the results is tabulated. The preliminary interview results provided important insights into how quantity surveyors (QSs) perceived each BIM capabilities in quantity surveying practice in order to confirm the literature findings. The results of the preliminary interview helped in developing the conceptual framework, as proposed in Chapter 3, and in carrying on to the third phase of the research.

5.2 Data Analysis Techniques

The research methodologies used, including interview sample and data collection process, are detailed in Section 4.5.2 of Chapter Four. Before the analysis process had begun, the audio-recorded interviews were transcribed. The transcribed interviews were analyzed using content analysis as explained in Section 4.5.2.2 of Chapter Four.

5.3 Results of Interview Responses

In order to verify the capabilities of BIM in quantity surveying practice, data were gathered through semi-structured interviews with 8 interviewees. The target interviewees were QSs who adopted BIM in their practices, as this study looked into the BIM application from the perspectives of QS. The detailed profiles of the interviewees are depicted in Table 5.1. Besides, to ensure anonymity and confidentiality of the interviewee results, each interviewee was assigned with an identification tag as presented in Table 5.1 to represent the details and the background of the interviewees.

Table 5.1: Interviewees' Profiles

Interviewees' tag	Position	Years of experiences in construction industry
Interviewee A	**Deputy Chairman** in quantity surveying consultancy company (private)	19
Interviewee B	**Director** in quantity surveying consultancy company (private)	27
Interviewee C	**QS** in quantity surveying consultancy company (private)	6
Interviewee D	**Senior QS** in quantity surveying consultancy company (private)	9
Interviewee E	**Senior QS** in quantity surveying consultancy company (private)	10
Interviewee F	**Director** in quantity surveying consultancy company (private)	32
Interviewee G	**Director** in quantity surveying consultancy company (private)	35
Interviewee H	**Senior QS** in quantity surveying consultancy company (private)	19

5.4 Key Findings of the Preliminary Interview

This section discusses in detail the BIM capabilities in quantity surveying practice that were confirmed from the preliminary interviews with QSs who were experienced in BIM application. Primarily, the interviews served the purpose of validating findings from the literature review and identifying key issues by obtaining views from the interviewees. The interviews also were intended to refine the conceptual framework underpinning this research by establishing a list of capabilities of BIM in quantity surveying practice. Consequently, the findings from this phase of research were used to help the development of the questionnaire survey to the next phase of the research. Table 5.2 summarizes the content analysis results of the interviews.

Table 5.2: Content Analysis Results of Preliminary Interview

Themes	Segments and Emerging Codes	Interviewee
C1: Cost appraisal can be prepared quickly at feasibility stage	faster and accurate	*A, B, C, D, E, F, G, H*
	LOD 100	*C*
	more analyses for client at early stage	*A, C*
	for client early decision making	*A, C*
	correct inputs is required from consultant	*A, G*
	rubbish in, rubbish out	*A, C, G, H*
C2: Preliminary cost plan can be prepared by extracting quantities directly from the model	quickly and accurately	*A, B, C, D, E, F, G, H*
	different LOD	*C*
	correct inputs is required from consultant	*A, C*
	rubbish in, rubbish out	*A, C, G, H*
C3: Easily update cost plan more details as designed is developed	easily updated	*A, B, C, D, E, F, G, H*
	manual method is time consuming	*C, D, E*
	less than an hour by using BIM	*C, D, E*

Table 5.2: Content Analysis Results of Preliminary Interview (continued)

Themes	Segments and Emerging Codes	Interviewee
C4: Easily generate accurate cost estimate for various design alternatives	more alternatives provided	*A, B, C, D, E, F, G, H*
	What-if analysis	*B*
	manual method is tedious	*E, F*
	cost advise for alternative	*A, C, G*
C5: Design changes are reflected consistently in all drawing views	minimize mistake due to obsolete drawings	*D, G*
	changes reflected consistently	*A, B, C, D, E, F, G, H*
	different file format problem	*A*
C6: Cost implication of design changes can be generated easily without manually re-measurement	show cost difference of design changes	*D, F*
	cost comparison	*D, F, G*
	one press of button	*C, G*
	no need re-measurement	*B, C, D, E, F*
C7: Clash detection reduces design errors and cost estimates revisions	detect errors	*D, E, G*
	merging different drawings	*D, E, G*
	eliminate mistake during later stage	*D, E, G*
	poor quality of all designs	*C*
C8: Cost checking can be performed quickly to ensure all items are capture	elements can be shaded	*F, H*
	ensure all elements included	*F, G, H*
	avoid missed out items	*A, B, C, E, G*
	minimize errors	*C, G*
	not every elements modeled into model	*A, C*
C9: Improve visualization for better understanding of design	understand design easier	*A, B, C, D, E, F, G, H*
	Visual on screen	*C, E*
	detect error easily	*C, E*
	avoid misinterpretation	*D, E, G, H*
C10: Automatically quantification for BQ preparation	very fast to get quantity	*A, B, C, D, E, F, G, H*
	less tedious compare to manual method	*B, H*
	save time	*A, C, D, E, G, H*
	accurate cost	*A, C, E, G, H*
	not every elements modeled into model	*A, C, G, H*
	rubbish in, rubbish out	*A, C, G*

Table 5.2: Content Analysis Results of Preliminary Interview (continued)

Themes	Segments and Emerging Codes	Interviewee
C11: Intelligent information management allows data to be stored in a central coordinated model	collaboration platform	*D*
	single model with information	*B, F*
	difficult to achieve	*A, H*
Other capabilities	an opportunity to diversify QS' roles	*C, F, G, H*
	4D modeling	*B, G*
	carbon foot print calculation	*A, G*
	Facilities management	*G*

5.4.1 Cost appraisal can be prepared quickly at feasibility stage (C1)

C1 was identified by all interviewees as a capability of BIM in quantity surveying practice. With LOD 100, QSs can prepare cost appraisal quickly by extracting quantities from the model. QSs are able to provide more analyses for client at the very beginning stages which lead client to make accurate decision. As quoted from interviewee C:

"…quantity can be extracted from the model very fast to generate cost appraisal…" (Interviewee C)

However, it was noted by both interviewees A and G that correct inputs and information by consultants into the model are essential for QSs to extract accurate quantities from the model for cost appraisal preparation.

5.4.2 Preliminary cost plan can be prepared by extracting quantities directly from the model (C2)

C2 was highlighted as a capability of BIM in quantity surveying practice by all interviewees. C1 is similar to C2 but it requires different LOD for quantities extracted from the model. Preliminary cost plan can be prepared within a shorter time by QSs with information contained in the model. Right and precise information in the model is essential for accurate quantity generation. Quoted from interviewee E:

"…QS can prepare cost plan faster after extracting quantity out from the model…" (Interviewee E)

5.4.3 Easily update cost plan more details as design is developed (C3)

All interviewees acknowledged C3 as a BIM capability in quantity surveying practice. Cost plan tends to change frequently in construction projects due to changes in design or client's requirements. Traditionally, QSs take times to update the cost plan whenever the design changes. However, with this BIM capability, cost plan can be updated easily when design is updated and developed as highlighted by interviewee C:

"…it can be done less than an hour with BIM…" (Interviewee C)

5.4.4 Easily generate accurate cost estimate for various design alternatives (C4)

C4 was regarded as a capability of BIM in quantity surveying practice, as perceived by all interviewees. With this capability, QSs can provide more cost alternatives for different designs. As mentioned by interviewee B:

"…what-if analysis…more cost alternatives for clients…" (Interviewee B)

It can be done by traditional way; however, it is time consuming and prone to errors. Clients are satisfied with more design alternatives provided as cost is one of their concerns. Hence, this capability allows QSs to provide client with accurate cost advice which subsequently increases clients' satisfaction. Interviewee E shared experiences of using this capability:

"…it takes a longer time if performed manually. BIM allows us to prepare cost estimate quickly for a few façade designs…" (Interviewee E)

5.4.5 Design changes are reflected consistently in all drawing views (C5)

C5 was viewed as a capability of BIM by a majority of the interviewees, except interviewee A. Design changes happen frequently in the construction projects. The real problem is drawing coordination. Traditionally, when there is a change, drawings plan, sections, elevations, schedules, and other related documents need to be updated manually in order to reflect the latest design. Interviewees highlighted that interrogation of the drawings and queries to correct design was a frequent problem in traditional 2D-paper based method. Mistakes and missed out updates still happen frequently. With this capability, it ensures latest iteration of the design and avoids QSs from using obsolete drawings for cost estimating. Interviewee G addressed that:

"…changes frequently happen…BIM is the best tool to rectify the impact of changes. It allows coordination to be done quickly if changes occur…" (Interviewee G)

Interviewee D explained:

"…It can minimize mistakes by using obsolete drawings and project parties are aware of the latest drawings…" (Interviewee D)

Nonetheless, interviewee A argued that this capability does not happen automatically as every project party uses different types of file formats, which hinder changes to be reflected consistently in all drawing views. Quoted from interviewee A:

"…every project parties use different type of file…inhibits changes reflected consistently…" (Interviewee A)

Overall, this capability was considered as an important capability of BIM in quantity surveying practice.

5.4.6 Cost implication of design changes can be generated easily without manually re-measurement (C6)

C6 was recognized by all interviewees as a capability of BIM in quantity surveying practice. As mentioned earlier, design changes frequently happen in a construction project. Client wishes to know the cost implication when design changes as it will influence their budget. Therefore, QSs have to prepare the cost implication within a shorter time for clients. Traditional practices typically do not have this capability of performing such tasks immediately. Meanwhile, BIM application has the capability for cost implication to be generated faster and accurately without the need to re-measure. Cost differences can be identified easily which allow client to see how the changes affect the total cost of a building. As quoted from both interviewees D and F:

"…it shoes the cost differences of design changes which allow QSs to make cost comparison…" (Interviewees D and F)

5.4.7 Clash detection reduces design errors and cost estimates revisions (C7)

C7 was viewed as a capability of BIM by a majority of the interviewees, except interviewee C. Clash detection allows QSs to detect the design errors earlier by merging different sets of drawings which can reduce variation orders and cost estimates revisions. Design coordination is important to ensure all elements are designed in order at the beginning stage so that QSs will be able to perform measurement and costing based on the accurate design drawings. The earlier a QS detects design clashes, the earlier the project team can rectify the design errors before comprehensive cost estimation and avoid the risk of variation order during a later stage. As explained by interviewee D:

"…by detecting errors at the early stage, it would eliminate mistakes at the later stage, which can reduce cost estimate revisions and variation orders during the construction stage…" (Interviewee D)

5.4.8 Cost checking can be performed quickly to ensure all items are captured (C8)

C8 was acknowledged by all interviewees as one of the BIM capabilities in quantity surveying practice. This capability was viewed as an important capability to ensure that all design elements are included in the costing. Cost checking is a crucial task performed by QSs to avoid missed out elements that were not captured in the costing. It reduces the risk of items being left out which has serious impact on costing. However, it is important to note that not all design elements are modeled. Therefore, QSs should be aware of this in BIM application. Quoted from interviewee F:

"…elements can be shaded to ensure that they have been captured in the model…" (Interviewee F)

5.4.9 Improve visualization for better understanding of design (C9)

C9 was essentially viewed to be important in quantity surveying practice as BIM capability. QSs tend to use longer time to study and to understand the design before performing measurement and providing costing. It requires QSs' imagination and interpretation. 3D visualization is the utmost capability of BIM to enhance QSs' understanding. It helps them to provide accurate costing for the design based on correct interpretation on the design. Interviewee D stated that:

"…QS can visualize the design on the model rather than based on imagination to avoid misinterpretation…" (Interviewee D)

5.4.10 Automatically quantification for BQ preparation (C10)

C10 was accentuated by all interviews as BIM capability. Quantification is the most time consuming task performed by QSs. Traditional CAD and measuring tool typically do not have the capability of performing such tasks automatically. This capability reduces the tediousness of performing quantification and subsequently, saves time, and improves cost accuracy. It greatly simplifies the cumbersome tasks. As pointed out by interviewee B:

"…very fast in obtaining accurate quantity as compared to manual ways…" (Interviewee B).

Interviewee H also conveyed the similar thought:

"…it is not as tedious as manual quantity takeoff…" (Interviewee H)

However, majority of the interviewees highlighted that not all elements are modeled into the model. Therefore, there are some quantities that require QSs to capture manually.

5.4.11 Intelligent for information management allows data to be stored in a central coordinated model (C11)

C11 was highlighted as a BIM capability by all interviewees except interviewee H. BIM model is a rich repository that allows all data and information to be stored in one single and coordinated place. Information from multi-disciplinary is superimposed into one model. This approach gives QSs easy access to information that provides immediate cost feedback on design alternatives, and reliable and accurate cost estimate. Traditionally, they have to request information from consultants manually. It often takes times and the information may be obsolete. Whereas, BIM uses a centralized model to coordinate all drawings plans, sections, elevations and other related documents which result in better coordinated construction documents that reduce errors and omissions. As explained by interviewee B:

"…model is a cube whereby every party inserts information into the cube to make it rich with information. Traditionally, the project involves many parties, which often caused loss of information. It causes information breakdown as every party works in silo when changes happen. However, BIM has the capability to keep all information in one single model that allows project parties to refer to the correct information source…" (Interviewee B).

It reduces time of handling multiple data. Besides, information contained in BIM is available throughout the entire design and construction process that is accessible by project parties. Nonetheless, this capability is difficult to achieve at the moment as pointed out by interviewees A and H. As quoted from interviewee A:

"…it is very difficult to achieve this capability currently as the model does not contain all detailed information from project parties. However, the aviation, and the oil and gas industries have achieved this capability…" (Interviewee A)

It needs efforts from multidisciplinary players to insert all information in the model which is not a practice in the construction industry. However, both of them conveyed the bright insight that this capability is achievable in the future.

5.4.12 Other Capabilities

A majority of the interviewees did not provide other capabilities of BIM in quantity surveying practice. Interviewees F, G, and H provided an insight that BIM application is an opportunity for QSs to diversify their roles. QSs can use the model for a variety of building analyses and related tasks such as construction time sequencing (4D), carbon foot print calculation, and facilities management. As the scope of the research was identify the BIM capability at pre-construction stage, hence the capabilities proposed by the interviewees were not applicable in this research. It is generally to note that BIM has the capability to simplify the cumbersome tasks such as quantity takeoff. It is then QSs can perform more value added tasks as suggested by the interviewees.

5.4.13 Other Highlights from Interviews

After the completion of data analysis for 8 interviewees, a few points emerged that had to be noted. First, it is noteworthy that all interviewees articulated that sufficient, precise and usable information in the BIM model is the pre-requisite in order for QSs to perform their tasks. The quality of the BIM models is a major concern. A majority of the interviewees defined it as *"rubbish in, rubbish out".* It means BIM is an automated tool that data (inputs) are automatically inserted to the model and information (outputs) is automatically generated. It is imperative to understand the input-output dynamics as quantities extraction according to the desired specifications depends on how and what elements are modeled. The accuracy of the outcomes produced by QSs depends on the quality and details of the information inputted by the consultants. The quality of the BIM model is critical to the development of accurate quantities.

Second, not all information is modeled into the model; it is hence, not all quantities are generated, except major building elements. Some quantities such as excavation, filling, and formwork cannot be directly extracted from the model. In fact, QSs should assess if the quantities extracted from the model provide an accurate representation of the actual building. Therefore, QSs are advised not to rely solely on quantities generated to avoid omission. It is advisable to perform manual checks for verification and confirmation. Hence, manual configuration is still required in some cases.

5.5 Summary of Interviews and Development for the Third Research Stage

In the content analysis outlined in the previous section, 5 interviewees were examined and confirmed all 11 BIM capabilities identified from the literature review. However, C5 was not confirmed by Interviewee A, C7 was not confirmed by interviewee C, and C11 was not confirmed by interviewee H, although they were identified in the literature. In sum, 8 capabilities of BIM were viewed by all interviewees as the capabilities of BIM in quantity surveying practice. The remaining 3 capabilities were not confirmed and this raised the question if these capabilities should be included in the next phase of the research. Table 5.3 illustrates the results.

It was noted that capabilities of C5, C7, and C11 were disagreed by 1 interviewee, but confirmed by the other 7 interviewees. The majority of the interviewees confirmed the capabilities of C5, C7, and C11. Thus, for the reason of inclusivity, it was decided that all of the eleven capabilities identified in the literature were considered and were carried forward into the next phase of the research. This provided the opportunity for further confirmation and investigation of all capabilities in the next stage of the research phase through a large scale questionnaire. It allowed further refinement of the findings.

Table 5.3: Summary Findings of the Preliminary Interview

Capability	Interviewee							
	A	B	C	D	E	F	G	H
C1	✓	✓	✓	✓	✓	✓	✓	✓
C2	✓	✓	✓	✓	✓	✓	✓	✓
C3	✓	✓	✓	✓	✓	✓	✓	✓
C4	✓	✓	✓	✓	✓	✓	✓	✓
C5	x	✓	✓	✓	✓	✓	✓	✓
C6	✓	✓	✓	✓	✓	✓	✓	✓
C7	✓	✓	x	✓	✓	✓	✓	✓
C8	✓	✓	✓	✓	✓	✓	✓	✓
C9	✓	✓	✓	✓	✓	✓	✓	✓
C10	✓	✓	✓	✓	✓	✓	✓	✓
C11	✓	✓	✓	✓	✓	✓	✓	x

5.6 Summary of Chapter

This chapter presents the findings of preliminary interviews with 8 QSs. The analyses of the interview results were used to confirm the BIM capabilities in quantity surveying practice derived from the literature reviews and further refined the conceptual framework proposed in chapter 3 for development of the third phase of the research.

Findings from the interviews indicated that 8 capabilities were confirmed by all interviewees as the capabilities of BIM in quantity surveying practice. The remaining 3 capabilities were not confirmed by 1 out of the 7 interviewees. Nevertheless, the majority of the interviewees confirmed the remaining 3 capabilities. Since these capabilities were identified in the literature, they were not withdrawn, but were included for further investigation in the next stage of the research. The next chapter explains the quantitative data collection with the main focus to achieve the second research objective.

CHAPTER 6

QUESTIONNAIRE DATA ANALYSIS

6.1 Introduction

This chapter presents the results of the quantitative data collected from the questionnaire survey. The data collected were aimed to examine the relationship between BIM capabilities in quantity surveying practice and project performance. The results of the analyses were divided into three types: descriptive analysis results, correlation analysis, and regression analysis. This chapter first describes the descriptive analysis based on the frequency distribution of the respondents. This is followed with ranking of BIM capabilities, and the last part of this chapter reports the results of correlation and regression analyses.

6.2 Characteristics of Respondents

This section provides the detail of the respondents regarding their positions, years of experience, size of organization, BIM project chosen, and project value.

6.2.1 Response Rate

The response rate was 48.9%, representing 64 respondents out of 131 questionnaires sent out. This response rate was deemed adequate for statistical analysis to be employed according to Hoxley (2008), Fellows and Liu (2009), who stated that the minimal response rate is 30%.

Table 6.1: Response of Questionnaire Survey

Population	Sample	Returned
318	131	64

6.2.2 Characteristics of Respondents' Position

Figure 6.1 displays the positions of the respondents in the organizations, which comprised of QSs, senior QSs, directors, and others. Based on the data obtained, some of the respondents who selected the category of "others" were assistance directors and associate directors.

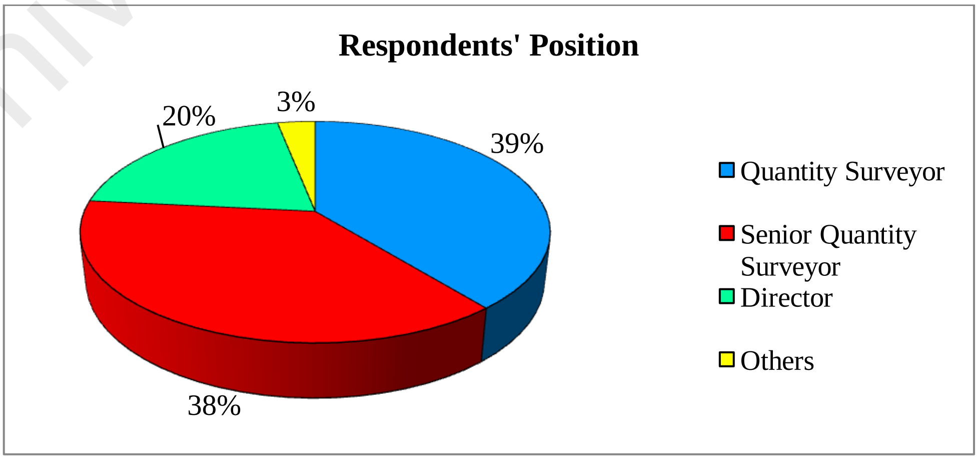

Figure 6.1: Respondents' Position

Majority of the respondents were QSs, which accounted for 39%. This was followed by 38% of senior QSs, 20% of directors, and 3% of others. It can be concluded that the majority of the respondents were experienced practitioners at senior and above levels. Therefore, the responses on the questionnaire received had been reliable and they provided the study with valuable information.

6.2.3 Characteristics of Respondents' Year of Experiences

Figure 6.2 indicates the working experience of the respondents in number of years. Based on the survey results, the majority of the respondents, which were 25%, had experience less than 5 years, while 23% had 5 to 10 years of experience. This was followed by respondents with 11 to 15 years of experience, which were 22%, and 19% of the respondents had more than 20 years of experience. Only 11% of the respondents had 16 to 20 years of experience. Most of the respondents had more than 5 years of experience and above in quantity surveying practice, thus possessed better understanding and experience about quantity surveying practice. Hence, the findings were deemed reliable.

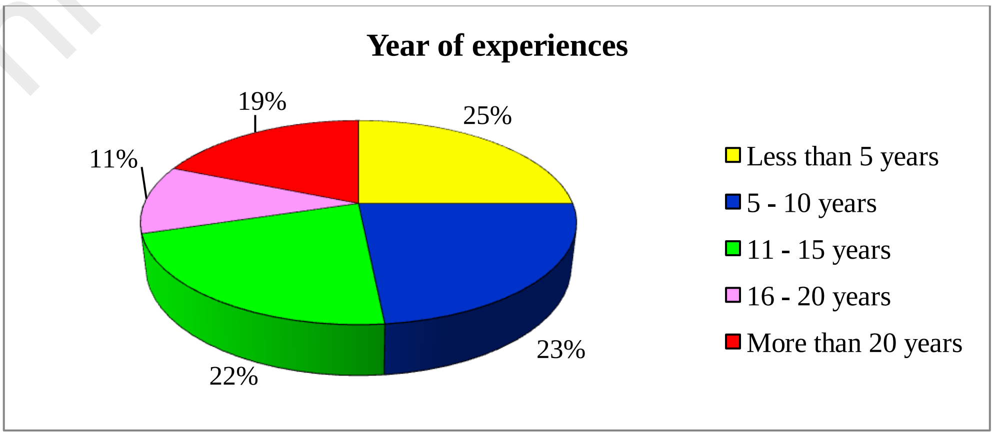

Figure 6.2: Year of Experiences

6.2.4 Characteristics of Respondents' Size of Organization

The size of the organizations is determined by the number of employees in the organizations. Based on Small and Medium Enterprises (SME) Corporation Malaysia (2013), the number of employees for small enterprise is between 5 to less than 30 employees; middle enterprise is between 30 to 75 employees; and large enterprise is more than 75 employees.

From the results, the respondents were from diverse firm sizes of small, medium, and large firms. Figure 6.3 reveals that 61% were from small organizations, followed by 25% of medium organizations, and 14% from large organizations. The results showed that the majority of respondents were from SME. Construction industry is dominated by SME. It is noticeable that SMEs are starting to adopt BIM in practice.

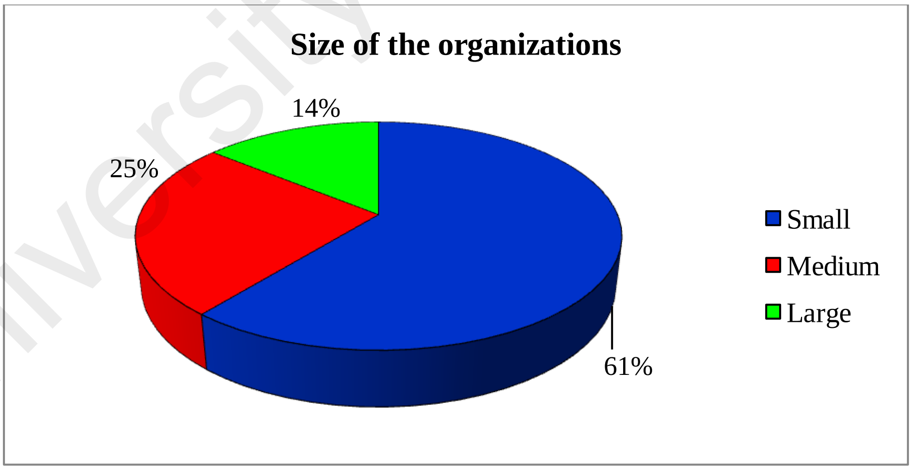

Figure 6.3: Size of the Organizations

6.2.5 Characteristics of the Types of BIM Projects

Figure 6.4 shows the types of BIM projects chosen by the respondents. The majority of the respondents adopted BIM for mixed development projects, which accounted for 45%. It is followed by 28% of non-residential projects, and 27% of residential projects. It substantiates the view that BIM adoption is widely used for complex mixed development project. This is because mixed development project comprises of various building elements and complex design structures that require more attention from the project parties which is cumbersome. Therefore, BIM technology is used to ease burden.

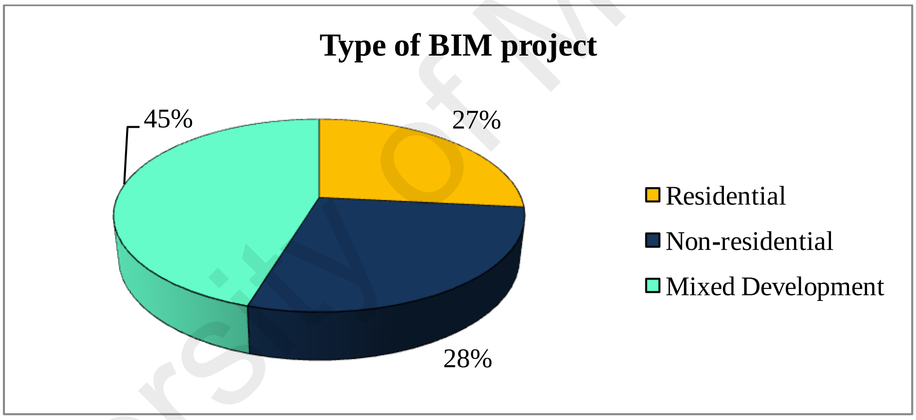

Figure 6.4: Type of BIM Project

6.2.6 Characteristics of the Value of BIM Projects

Figure 6.5 displays the value of BIM project chosen by the respondents. The top category fell on project value ranged between 50 and 100 million, which was 31%. It is followed by project value ranged between 100 and 300 million for 28%, and 19% for project value ranged between 10 and 50 million. 11% of project value between 300 and 500 million, 8% of project value more than 500 million, and 3% of project value less than 10 million. It substantiated the view that the majority of the respondents adopted BIM for big amount of project value.

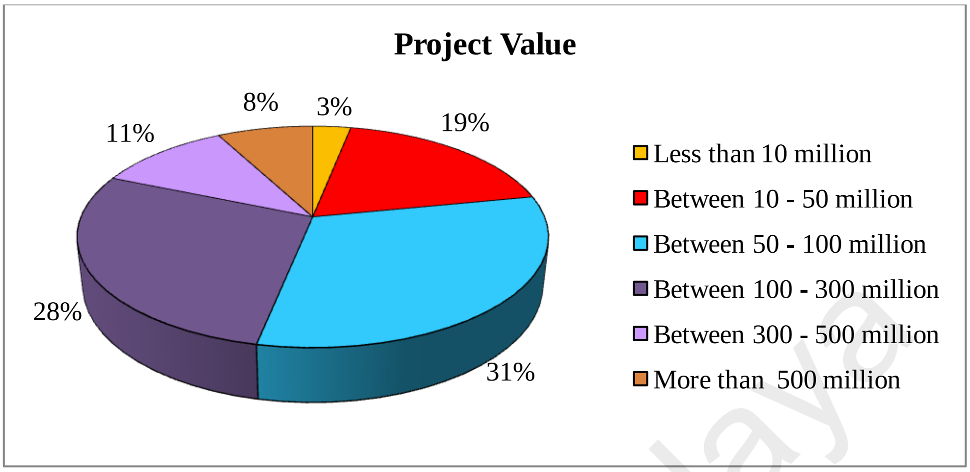

Figure 6.5: Value of the Project

6.3 Statistical Analysis

This section discusses in detail the analysis performed in this study. They were descriptive analysis, reliability test, ranking of BIM capabilities, correlation coefficient test, and logistic regression.

6.3.1 Descriptive Analysis

Table 6.2 displays the results of the descriptive analysis for three methods of performing tasks in quantity surveying practice. It was found that 3D and 5D modeling software had been the top efficient method ranked by the respondents, with a mean score of 3.93. The method of using quantity surveying software was ranked second with a mean score of 3.63. The manual method was the least efficient method ranked by the respondents with a mean score of 2.56. The results revealed that conventional working methods by using manual method and quantity surveying software had been inefficient compared to BIM application. Based on the respondents' experience of BIM application, BIM software has helped them perform tasks efficiently.

Table 6.2: Method of Performing Tasks in Quantity Surveying Practice

Method of performing tasks	Mean	Standard deviation
Manually/ paper-based	2.56	0.9900
Quantity surveying software	3.63	0.7238
3D, 5D modeling software	3.93	0.7222

6.3.2 Reliability Test

Reliability test was performed to check the internal consistency and the stability of the instrument. Cronbach's alpha was used to test the reliability. The results revealed that for this research instrument, the Cronbach's alpha reliability coefficient ranged between 0.844 and 0.862, which indicated that the scale and the data obtained were reliable. According to Leech et al. (2011), Cronbach's alpha of 0.60 and above indicates good reliability. From the corrected item-total correlation, the correlation for each item was more than 0.30, and the item was correlated with most of the other items which makes a good component of a summated rating scale as mentioned by Leech et al. (2011). Thus, the internal consistency reliability of the measure used in this study was considered good, as shown in Table 6.3.

Table 6.3: Reliability of the Questionnaire Result

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Capability 1	44.1094	44.861	.406	.859
Capability 2	44.7031	43.069	.596	.848
Capability 3	44.5781	44.597	.493	.854
Capability 4	44.5938	43.007	.620	.847
Capability 5	44.7188	44.650	.491	.854
Capability 6	44.6875	43.107	.641	.846
Capability 7	44.6875	42.917	.577	.849
Capability 8	44.4844	44.635	.473	.855
Capability 9	44.7813	41.221	.651	.844
Capability 10	44.0625	46.790	.332	.861
Capability 11	44.7813	42.713	.413	.863
Time performance	44.6094	44.432	.529	.852
Cost performance	44.6875	45.234	.491	.854
Quality performance	44.7188	44.364	.555	.851
The entire scale				**.862**

6.3.3 Ranking of BIM Capabilities

Table 6.4 displays the results from the analysis by outlining the relative important index (RII) and ranking. Using the RII, the rank orders of capabilities were obtained from all responses. The RII method was done via calculation using the following formula:

$$Relative\ importance\ Index\ (RII) = \frac{\sum W}{A(N)} = \frac{5n1 + 4n2 + 3n3 + 2n4 + 1n5}{5N}$$

W = weight given to each capabilities by the respondents and ranges from 1 to 5,

A = highest weight (i.e., 5 in this study), and

N is the total number of respondents.

Table 6.4: Ranking of BIM Capabilities

Tag	Capability	All response	
		RII	R
C1	Cost appraisal can be prepared quickly at feasibility stage	0.781	3
C2	Preliminary cost plan can be prepared by extracting quantities directly from the model	0.663	8
C3	Easily update cost plan more details as design is developed	0.688	5
C4	Easily generate accurate cost estimate for various design alternatives	0.784	2
C5	Design changes are reflected consistently in all drawings views	0.659	9
C6	Cost implication of design changes can be generated easily without manually re-measurement	0.666	6
C7	Clash detection reduces design errors and cost estimates revisions	0.666	6
C8	Cost checking can be performed quickly to ensure all items are captured	0.706	4
C9	Improve visualization for better understanding of design	0.647	10
C10	Automatically quantification for BQ preparation	0.791	1
C11	Intelligent information management allows data to be stored in a central coordinated model	0.647	10

As displayed in Table 6.4, the top ranked BIM capability was automatically quantification (C10) with RII of 0.791. Automatically quantification for bills of quantities (BQ) preparation had been indicated as the top capability of BIM that was ranked by the respondents. The finding is aligned with Cardwell and Gajbhiye (2013), who specified that 80% of time can be saved by QSs due to automation of quantity takeoff. Kiviniemi et al. (2007) mentioned that BIM has the capability to generate quantity takeoffs and measurement automatically from the model. This finding is also in line with previous studies by Popov et al. (2010) and Crowley (2013), who concluded that BIM can be used to reduce the time taken for calculating quantities manually, which can avoid uncertainties, errors, and inaccuracies. It had been noticeable that automatic quantification by BIM leads to significant improvement in time taken.

Next, easily generates accurate cost estimate for various design alternatives (C4) was ranked second with RII of 0.784. With manual method, it requires a great deal of human intervention and interpretation which is time-consuming. Stanley and Thurnell (2014) asserted that BIM facilitates the costing preparation of different design options at the early stage. The accurate and computable nature of BIM provides a reliable source for QSs to perform various estimating and cost feedback faster on different design alternatives at early stages. Considering different alternatives in early design stages is valuable because it can eliminate timely and costly construction designs. This in turn provides clients with quick feedback on various design scenarios. Clients can understand, evaluate, and compare design alternatives which speed up their decision making. This capability was affirmed by Boon and Prigg (2012), who mentioned QS is able to offer advice quickly and efficiently to the design team and client on the cost of each option which enables direct comparison for the options.

Meanwhile, the third rank of BIM capability was cost appraisal that can be prepared quickly at feasibility stage (C1) with RII of 0.781.C1 was ranked third high as BIM capability because information is barely available at the beginning stage, and thus, it is difficult for QSs to prepare accurate cost appraisal at the beginning stage. They make several assumptions on the costing as information is limited. BIM allows QSs to generate cost appraisal accurately with LOD 100. Project conceptualization is easier by using BIM with less guesswork. Kiviniemi et al. (2007) pointed out that BIM provides excellent opportunities by providing reliable information and available at early stage for QSs to prepare cost appraisal. Hence, it facilitates clients in decision making process which increases their level of cost awareness in the early design stage. Clients are satisfied as they can receive accurate cost appraisal for evaluation and decision making.

6.3.4 Correlation Coefficient Test

This section presented the correlation results between BIM capabilities and project performance for time, cost, and quality aspects.

a. Correlation between BIM capabilities and time performance

The relationship between BIM capabilities and project performance for time aspect was studied and analyzed with SPSS software. The results for correlation analysis are portrayed in Table 6.5.

The results of correlation analysis shown in Table 6.5 demonstrate that 7 capabilities of BIM were correlated significantly ($p < .05$) with time performance. There were C1 (cost appraisal at feasibility), C2 (preliminary cost plan), C3 (update cost plan), C4 (cost estimate for alternatives), C8 (cost checking), C9 (visualization), and C11 (intelligent information management) with coefficient values of .270, .351, .289, .413, .347, .309, and .273 respectively. The results fit with the research hypothesis for this research, based on the standard criteria of probability that is 5% of significant level (Field, 2009), which are stated as in the following:

H_0 ($p > .05$) - There is no significant correlation between BIM capabilities and project time performance.

H_1 ($p < .05$) - At least one of the BIM capabilities has significant correlation with project time performance.

Table 6.5: Correlation between Capabilities of BIM and Time Performance

Tag	Capability	Time Performance	
C1	Cost appraisal can be prepared quickly at feasibility stage	Correlation Coefficient	**.270***
		Sig. (2-tailed)	.031
C2	Preliminary cost plan can be prepared by extracting quantities directly from the model	Correlation Coefficient	**.351***
		Sig. (2-tailed)	.004
C3	Easily update cost plan more details as design is developed	Correlation Coefficient	**.289***
		Sig. (2-tailed)	.020
C4	Easily generate accurate cost estimates for various design alternatives	Correlation Coefficient	**.413***
		Sig. (2-tailed)	.001
C5	Design changes are reflected consistently in all drawing views	Correlation Coefficient	.130
		Sig. (2-tailed)	.305
C6	Cost implication of design changes can be generated easily without manually re-measurement	Correlation Coefficient	.147
		Sig. (2-tailed)	.245
C7	Clash detection reduces design errors and cost estimates revisions	Correlation Coefficient	.207
		Sig. (2-tailed)	.101
C8	Cost checking can be performed quickly to ensure all items are captured	Correlation Coefficient	**.347***
		Sig. (2-tailed)	.005
C9	Improve visualization for better understanding of design	Correlation Coefficient	**.309***
		Sig. (2-tailed)	.013
C10	Automatically quantification for BQ preparation	Correlation Coefficient	.188
		Sig. (2-tailed)	.137
C11	Intelligent information management allows data to be stored in a central coordinated model	Correlation Coefficient	**.273***
		Sig. (2-tailed)	.029

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

The findings revealed that the capability of cost appraisal can be prepared quickly at feasibility stage (C1) was correlated with the project time performance. This is in line with Eastman et al. (2008), who pointed out that BIM has the capability in strengthening the quality of decision made at this early stage based on quick feedback on the project feasibility to avoid wasting time. Realizing that a project is over budget and not feasible at the beginning stage can ensure the time performance which allows the project team to seek for better feasible alternatives. This contributes to timely feedback on the design and allow for early modification which avoid the potential delay associated with later stage changes. According to Samphaongoen (2010), BIM leads to significant improvement in time aspect by ensuring the concept and the feasibility study of the project are within acceptable time constrains. Thus, this capability has an impact on time performance.

From the result, it was found that the capability of preliminary cost plan can be prepared by extracting quantities directly from the model (C2) was correlated with time performance. This is in line with Nagalingam et al. (2013), who pointed out project time is saved as preliminary cost estimate can be prepared quickly. BIM has the capability in generating early cost estimates accurately which allows potential problems in the design to be identified early and hence, fewer issues occur later that avoid project delays (Eastman et al., 2008). By receiving cost plan earlier from the QSs, the project team can have a conceptual idea of the project scope. Any misinterpretation in the cost plan can be realized earlier and solutions can be provided for issues before they influence the project negatively. Therefore, project time performance is ensured when every project party reviews the cost plan earlier to ensure that the cost plan is in accordance with the design and the project objectives. This in turn can eliminate construction issues at the early stage by reducing conflicts and change orders during later stage that can affect time performance.

The BIM capability of easily update cost plan more details as design is developed (C3) was identified as correlated with the time performance. Gee (2010) noted that time is saved as BIM allows rapid updating quantities in the cost plan, so that the design develops within the project scope at the beginning stage which also ensures time performance. This is in agreement with Stanley and Thurnell (2014), who pointed out the ability to update quantity as design developed with BIM, is a major benefit for QSs for cost modeling at the early stage to ensure that the changes would not affect the project scope as defined by the client. Conventionally, for a design to be developed, the QSs need to update the cost plan regularly. It is time consuming and troublesome for QSs to detect the changes and updates in quantities and costing. However, BIM allows cost plan to be updated automatically as design is developed to ensure the project design progresses as in the agreeable schedule. Frequent and easy updates cost plan by using BIM allow early notification to the project team if the design is out of budget and scheduled at an earlier stage, rather than just after the project begins which could affect the time performance.

The results also indicated that the capability of easily generate accurate cost estimate for various design alternatives (C4) was found correlated with the project time performance. By performing manually, QSs tend to use more time to generate various cost estimates for different design alternatives. BIM allows QSs to generate various cost estimates faster which makes the project to perform well in time aspect. Li (2012) highlighted that cost implications of alternative design options can be provided in a fast manner by the QSs and project time performance can be enhanced for comparison with various analysis at the early stage. This statement is proven by the analysis result. Quantities can be changed quickly and easily which allows the QSs to see how the project will be affected with respect to cost and time in different options. Mascoro construction (2014) supports this statement by claiming that this results in advanced determination of the most efficient approach which often leads to a reduction in the overall duration of the project schedule. This is because QSs can provide cost advice on the design that can shorten the construction time.

The capability of cost checking can be performed quickly to ensure all items are captured (C8) had been displayed to correlate with the project time performance. This is consistent with Jiang (2011), who ascertained that errors and omissions can be significantly reduced at the early stage and thus, speeds up the construction process or shortens the construction period. QSs can quickly check for excessive or missing quantities in the model to confirm the accuracy and the completeness of the quantification. By doing this, project delays caused by omissions due to oversight by QSs can be avoided. This capability substantiates the view that cost checking manually is troublesome and increases the risk of making errors. BIM capability enables this to be done in a proper manner which also ensures the project time performance.

Furthermore, the result showed that the capability of improve visualization for better understanding of design (C9) was correlated with the time performance. This is consistent with Migilinskas et al. (2013), who highlighted that visualization can help to identify any possible problems that may arise during early stage which eliminates delays and enhances time performance. Similarly, Shen and Issa (2010) conducted a test and proved that 3D visualization can show performance improvement in terms of time. With this visualization capability, QSs can benefit from gaining understanding of the design and also help to detect any errors via visualization at the beginning stage. It allows QSs to grasp the details quickly and easily without confusion. This in turn reduces misinterpretation, lessens wrong assumption, and minimizes risk of making errors during early stage that can ensure time performance. This is further supported by Cardwell and Gajbhiye (2013), who highlighted 3D visualization via BIM model increases the confidence and understanding of the QSs which ensure that the project can be built to meet the target schedule.

In addition, the findings indicated that the capability of intelligent information management allows data to be stored in a central coordinated model (C11) correlated with the time performance. Information sharing in paper-based often causes miscommunication and information breakdown which cause serious impact on project time performance. Inability of QSs to receive timely information and documents will cause project delay. Aibinu and Venkatesh (2012) mentioned that part of the QSs' tasks involves collating and clarifying information from different design consultants which will lead to non-productive and inefficient work that could affect time performance. BIM acts as a central database with all information stored and accessible by all project parties. Besides, Aibinu and Venkatesh (2012) highlighted that BIM provides a platform for integrated information exchange through a single model which will enhance time performance. The quick and easy access to information helps the QSs in expediting their work performance. By acquiring information timely and promptly, QSs can perform their tasks efficiently by providing advice to clients which leads to improvement in client decision making that could influence on project time performance. This approach makes all the critical information available immediately and project-related decisions can be made more quickly.

b. Correlation between BIM capabilities and cost performance

The relationship between BIM capabilities and project performance in cost aspect was studied and analyzed through SPSS software. The results for correlation analysis are shown in Table 6.6.

A significant correlation was detected between 7 BIM capabilities and cost performance. They were C2 (preliminary cost plan), C4 (cost estimate for alternatives), C5 (design changes reflected consistently), C6 (cost implication), C7 (clash detection), C9 (visualization) and C10 (automatic BQ quantification) with correlation coefficient of .312, .288, .316, .295, .335, .460, and .276. The results fit with the research hypothesis for this research, based on the standard criteria of probability that is 5% of significant level (Field, 2009), which are stated in the following:

H_0 ($p > .05$) - There is no significant correlation between BIM capabilities and project cost performance

H_1 ($p < .05$) - At least one of the BIM capabilities has significant correlation with project cost performance.

Table 6.6: Correlation between Capabilities of BIM and Cost Performance

Tag	Capability	Cost Performance	
C1	Cost appraisal can be prepared quickly at feasibility stage	Correlation Coefficient Sig. (2-tailed)	.143 .259
C2	Preliminary cost plan can be prepared by extracting quantities directly from the model	Correlation Coefficient Sig. (2-tailed)	**.321*** .010
C3	Easily update cost plan more details as design is developed	Correlation Coefficient Sig. (2-tailed)	.215 .087
C4	Easily generate accurate cost estimate for various design alternatives	Correlation Coefficient Sig. (2-tailed)	**.288*** .021
C5	Design changes are reflected consistently in all drawing views	Correlation Coefficient Sig. (2-tailed)	**.316*** .011
C6	Cost implication of design changes can be generated easily without manually re-measurement	Correlation Coefficient Sig. (2-tailed)	**.295*** .018
C7	Clash detection reduces design errors and cost estimates revisions	Correlation Coefficient Sig. (2-tailed)	**.335*** .007
C8	Cost checking can be performed quickly to ensure all items are captured	Correlation Coefficient Sig. (2-tailed)	.075 .558
C9	Improve visualization for better understanding of design	Correlation Coefficient Sig. (2-tailed)	**.460*** .000
C10	Automatically quantification for BQ preparation	Correlation Coefficient Sig. (2-tailed)	**.276*** .027
C11	Intelligent information management allows data to be stored in a central coordinated model	Correlation Coefficient Sig. (2-tailed)	.235 .062

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

The findings indicated that the capability of preliminary cost plan can be prepared by extracting quantities directly from the model (C2) correlated with the cost performance. This capability is supported by the case study reported by Eastman et al. (2008) for One Island East Office Tower project. Due to the accuracy of the preliminary estimate by using BIM, the authors reported that the client was able to set lower contingency in their budget and ultimately saved cost for the project. This finding is further supported by Nagalingam et al. (2013), who pointed out cost overrun can be avoided as preliminary cost estimate can be prepared quickly, and hence, supported. BIM has the capability to enhance the cost accuracy of the cost plan by reducing human errors. Thus, it enhances the cost performance.

Besides, the capability of easily generate accurate cost estimate for various design alternatives (C4) was identified to correlate with the cost performance from the analysis result. Various design alternatives attached with cost can be evaluated and considered. This result is supported by the findings retrieved by Azhar et al. (2012), who conducted a case study and proved that cost savings can be achieved by using BIM to estimate various cost alternatives as the client can select the most economical options. The statement of Gee (2010) also revealed that client will be able to consider different design alternatives by evaluating the costs related to the alternatives which can result in valuable cost savings and resource utilization. This in turn enhances cost performance as a client can choose a few alternatives to assess different designs or material options to see which are the most beneficial. Hence, this capability can show improvement in cost performance.

Furthermore, the findings displayed that the capability of design changes are reflected consistently in all drawing views (C5) correlated with the cost performance. Design change results in all other affected drawings also need to be revised. Revising manually is time consuming as many drawing views are affected by the change. If changes are not updated in all drawing views, QSs have a tendency to mis-capture costing which could affect project cost. However, Burns and McDonnell (2008) stated that BIM allows greater flexibility for revisions during the time when design changes, which have the best opportunity to influence construction cost positively. This statement is supported by the finding. Design changes are reflected consistently and flexible in all drawing views that allow QSs to capture the cost difference accurately at the early stage of the project. Cost performance is ensured when changes can be readily accommodated consistently and aware at the early stage. This dramatically increases clarity and consistency which lead to better cost performance.

The analysis revealed that the capability of cost implication of design changes that can be generated easily without manually re-measurement (C6) correlated with the cost performance. This finding is verified by Gee (2010), who mentioned that project cost can be managed efficiently as cost implications regarding changes are shown at early project stages. QSs struggle with the ability to respond to the design and requirement changes and to understand the impact of those changes on the overall project budget. Re-measurement is tedious and mistakes tend to occur which may affect project cost performance. This capability will generate cost implication automatically when the design changes. Any changes can be picked up, and responded quickly and precisely to ensure that the changes are kept within the agreed tolerances. QSs are able to observe the change implication on project cost earlier and derive at other solutions to ensure cost performance. Hence, cost performance is enhanced with less human error.

Moreover, the results indicated that the capability of clash detection reduces design errors and cost estimates revisions (C7) correlated with the project cost performance. Migilinskas et al. (2013) highlighted that this capability saved about 0.5% of project cost. Besides, Ghanem and Wilson (2011) demonstrated BIM application through a case study on a project by showing BIM application is able to reduce cost by detecting clashes. The result is further supported by Li (2012), who asserted that clash detection prevents extra costs that are caused by design errors. Boon (2009) conveyed a similar thought that this capability assists QSs in detecting clashes earlier which could reduce cost estimation preparation that results in cost saving. It is due to design deficiencies that not detected earlier and they would incur extra costs. Hence, this capability assures identification of design errors and resolution of the issues before construction begins. Consequently, variation orders during construction can be avoided which could ensure project cost performance as well.

Furthermore, the results displayed that the capability of improve visualization for better understanding of design (C9) correlated with the project cost performance. Shen and Issa (2010) conducted a test and proved that 3D visualization can show performance improvement in terms of cost by enhancing accuracy, as human errors are reduced. This finding is also in accordance with Samphaongoen (2010), who addressed that the intent of the design can be visualized at an earlier stage through 3D representation, as this stage is made with little to no addition cost compared to later stage which in turn enhance cost performance. Better design understanding is gained through this capability prior to quantity takeoff. As a result, QSs are able to interpret accurately and capture precise costing. Cost performance is enhanced with this capability. This is further supported by Cardwell and Gajbhiye (2013), who highlighted

3D visualization via BIM model increases the confidence and the understanding of the QSs which ensure the project to be built to meet the target cost.

The findings also demonstrated that the capability of automatically quantification for BQ preparation (C10) correlated with cost performance. Based on a case study conducted in Dubai for project Dubai Mall, by integrating BIM in quantity surveying practice, this project achieved cost savings as quantity takeoff was accomplished with complete accuracy which allowed the construction team to purchase exactly the materials needed and thereby reduced wastage (Gulf construction, 2010). Quantity takeoff is a tedious task and prone to error. QSs have tendency to capture inaccurate costing which could affect project cost performance. Mistakes will occur, such as double counting and missed elements, as projects consist of multiple elements and drawings. However, through automatic calculation quantity takeoffs extracted directly from the model, cost savings can be achieved, according to Hsu (2004). Hence, cost performance is ensured.

c. Correlation between BIM capabilities and quality performance

The relationship between BIM capabilities and project performance in quality aspect was studied and analyzed through SPSS software. The results of correlation analysis are shown in Table 6.7.

Table 6.7: Correlation between Capabilities of BIM and Quality Performance

Tag	Capability	Quality Performance	
C1	Cost appraisal can be prepared quickly at feasibility stage	Correlation Coefficient	**.313***
		Sig. (2-tailed)	.012
C2	Preliminary cost plan can be prepared by extracting quantities directly from the model	Correlation Coefficient	**.418***
		Sig. (2-tailed)	.001
C3	Easily update cost plan more details as design is developed	Correlation Coefficient	**.331***
		Sig. (2-tailed)	.008
C4	Easily generate accurate cost estimate for various design alternatives	Correlation Coefficient	**.283***
		Sig. (2-tailed)	.024
C5	Design changes are reflected consistently in all drawing views	Correlation Coefficient	.164
		Sig. (2-tailed)	.196
C6	Cost implication of design changes can be generated easily without manually re-measurement	Correlation Coefficient	**.372***
		Sig. (2-tailed)	.002
C7	Clash detection reduces design errors and cost estimates revisions	Correlation Coefficient	**.308***
		Sig. (2-tailed)	.013
C8	Cost checking can be performed quickly to ensure all items are captured	Correlation Coefficient	**.264***
		Sig. (2-tailed)	.035
C9	Improve visualization for better understanding of design	Correlation Coefficient	**.465***
		Sig. (2-tailed)	.000
C10	Automatically quantification for BQ preparation	Correlation Coefficient	**.448***
		Sig. (2-tailed)	.000
C11	Intelligent information management allows data to be stored in a central coordinated model	Correlation Coefficient	.188
		Sig. (2-tailed)	.137

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

As shown in Table 6.7, it was found that C1 (cost appraisal at feasibility), C2 (preliminary cost plan), C3 (update cost plan), C4 (cost estimate for alternatives), C6 (cost implication), C7 (clash detection), C8 (cost checking), C9 (visualization), and C10 (automatic BQ quantification) were correlated significantly with quality performance. The correlation coefficient values were .313, .418, .331, .283, .372, .308, .264, .465, and .448. The result fits with the research hypothesis for this research, based on the standard criteria of probability that is 5% of significant level (Field, 2009), which are stated as in the following:

H_0 ($p > .05$) - There is no significant correlation between BIM capabilities and project quality performance

H_1 ($p < .05$) - At least one of the BIM capabilities has significant correlation with project quality performance.

The findings demonstrated that cost appraisal can be prepared quickly at feasibility stage (C1) correlated with the quality performance. Cost appraisal is important at the beginning stage as it affects the decision of a client to start the project. Therefore, client relies on the cost appraisal for early decision making. This result is in accordance with Eastman et al. (2008), who asserted clients are satisfied when they receive cost appraisal promptly and advise from QSs certainly as they can proceed with the expectation that their goals and financial requirements are achievable. Samphaongoen (2010) also highlighted that this capability is a tremendous assistance to a client during feasibility study for early decision making. BIM allows QSs to provide clients with quick feedback on the feasibility of the study by using BIM to offer the best value and confidence for clients. By providing cost appraisal accurately to client, it increases satisfaction of the client and ensures quality performance.

The result from the analysis displayed that the capability of preliminary cost plan can be prepared by extracting quantities directly from the model (C2) correlated with the project performance in quality aspect. By giving preliminary cost plan to client and showing them the cost breakdown earlier and accurately, they will have a conceptual idea on the costing. Hence, it increases client satisfaction. Eastman et al. (2008) pointed out preliminary cost plan can be prepared early which can provide client with quick feedback for assessing the predicted cash flow and the procuring finance of a project. Better decision making and budgeting up-front can be made through more accurate cost plan which increase the client’s satisfaction.

The analysis also showed that the capability of easily update cost plan more details as design is developed (C3) was found to be correlated with the project quality performance. This capability allows QSs to keep client updated on the project cost to ensure that the design develops in accordance to project requirements and scopes. As ascertained by Jiang (2011), BIM allows project client to be aware of the cost associated with the design progresses. By doing so, it increases client satisfaction. This is consistent with a statement by Stanley and Thurnell (2014), who described fewer variations are likely to occur during construction stage by updating quantities regularly which gain client satisfaction. Hence, it enhances the quality of the project. Eastman et al. (2008) further highlighted BIM greatly facilitates the development of cost plan as the design progresses which allow the client to make more informed decision and results in higher quality construction project. Hence, this capability has an impact on quality performance.

As displayed in the result, easily generate accurate cost estimate for various design alternatives (C4) was revealed to be correlated with the quality performance. Clients are able to receive more design alternatives with accurate cost from QSs. This finding is consistent with Pennanen et al. (2011) and Thurairajah and Goucher (2013), who stated that clients are satisfied as they receive earlier economic feedback on the alternatives available. This is due to the fact that clients have a greater understanding of the likely cost influence of design decisions (Deutsch, 2011). Hence, they can choose the best and the most suitable design which could enhance the project quality performance. A case study reported by Eastman et al. (2008), showed that the capability of providing design options to the client in the early process enables the client to explore more options, which ultimately provides better overall design in terms of time and cost requirements. Hence, it increases client satisfaction in quick and early exploration of different design options.

Besides, the analysis findings also displayed that cost implication of design changes can be generated easily without manually re-measurement (C6) correlated with the quality performance. By identifying the cost implication earlier, a few variations are likely to occur during later stage which enhances client satisfaction. This finding is consistent with Mascoro construction (2014), which asserted that clients are satisfied as they can make informed decision quickly after getting to know the cost implication. Tanyer and Aouad (2005) also stated that it helps client in decision making as BIM facilitates easy demonstration of the impact of changes on the project. Quantities and cost can be quickly updated when the design changes which allow the client to see how the project will be affected with respect to cost and time. If there is any negative implication, QSs can advise the client accordingly before it influences the project performance. It keeps client aware of the cost implications associated with a change in the design before it progresses to a detailed level. Hence, the client is satisfied with it.

Meanwhile, clash detection reduces design errors and cost estimates revisions (C7) had been identified to correlate with the quality performance. As design errors can be detected by merging all the designs together, the quality of the project is ensured. This is because all the errors are captured and resolved in the early stage before it impacts on the later stage which results in better constructability. Early insight into design problems can present opportunities for the QSs to highlight the errors to the design teams to correct the clashes before the construction stage. The findings verified that Li (2012) stated a smooth construction process can be sustained with this capability. This speeds up the construction process and reduces costs which make the clients satisfied.

The results also showed that the capability of cost checking can be performed quickly to ensure all items are captured (C8) to be correlated with the quality performance. Based on a case study reported by Eastman et al. (2008), BIM yields benefit to the client when the BIM model ensures quantity takeoff accuracy by verifying all items are counted and included, reducing the risk for errors and omission caused by oversight from the QSs. Everything that has been measured is represented in the 3D model. Jiang (2011) highlighted visualizing all the items being taken off in the 3D model reduces the chance of the missing items. Hence, it improves the quality of the project as it reduces the risk of missed out item in project costing. Detection of missing out elements at the early stage speeds up the construction process and minimizes disputes which in turn enhance client satisfaction.

Besides, the findings also indicated that the capability of improve visualization for better understanding of design (C9) was correlated with the quality performance. It offers a visualization platform to understand the building design and scope of work. By having good understanding on the design with 3D visualization, QSs are able to capture accurate costing and also detect any design flaws. It in turn enhances the quality of the project as it reduces misinterpretation that may affect the project performance. The result of this finding is similar to the findings reported by Thurairajah and Goucher (2013) and Samphaongoen (2010), who pointed out that clients are satisfied with this capability as it helps in scope clarification at the early stage with better visualization. Besides, Crotty (2012) asserted that this capability greatly improves the confidence among client by understanding the design through scope clarification and the project can proceed smoothly, subsequently with minimum changes that are caused by misinterpretation.

Furthermore, the results also revealed that automatically quantification for BQ preparation (C10) was correlated with the project quality performance. It is noticeable that QSs spend much time on quantification, as reported by previous scholars (Hannon, 2007; Mitchell, 2012; Autodesk, 2007a) that it leads to dissatisfaction among clients on the services provided by the QSs (Fortune, 2006). Therefore, the result is consistent with Eastman et al. (2008) and Autodesk (2007a), who pointed out that BIM facilitates the laborious tasks of quantity takeoff for BQ preparation and QSs have more time for other value added services that allows the client to reach an informed decision. When the tediousness of taking off is replaced by BIM, QSs can spend most of the times doing other value added tasks which could result in high quality estimate during BQ preparation. Subsequently, it enhances client satisfaction and the quality of the project.

6.3.5 Logistic Regression

This section presents the logistic regression results between BIM capabilities and project performance for time, cost, and quality aspects. The complete result of the SPSS logistic regression analysis is attached in Appendix C.

a. Regression between BIM capabilities and time performance

Binary logistic regression was conducted to assess if the 11 independent variables from BIM capabilities could significantly predict the project performance in time aspect.

In the analysis, SPSS coded the good time performance with 1 and poor time performance as 0. By using forward stepwise method, SPSS produced two steps to include the predictor that significantly contributed to the logistic regression model. As shown in Table 6.8, Step 1 revealed the first independent variable, C8 (cost checking) significantly predicting the time performance with X^2 = 8.583, p < .05. Then, Step 2 computed second independent variable, C9 (visualization) with X^2 = 6.080, p < .05. Hence, in total there were two independent variables that significantly predicted the time performance (X^2 = 14.663, p < .05).

Table 6.8: Logistic Regression Result (BIM Capabilities - Time Performance)

BIM capability		B	Sig	Model fit information		Pseudo R-square	Hosmer and Lemeshow Test	
				Chi-Square	Sig.	Nagelkerke	Chi-Square	Sig.
Step 1[a]	Cap 8	2.158	.015	8.583	.003	.297	.456	.796
	Constant	-4.134	.095					
Step 2[b]	Cap 8	2.761	.021	6.080	.014	.485	1.182	.997
	Cap 9	1.609	.038					
	Constant	-10.015	.025					

Based on the classification table in Table 6.9, 94% of the total cases were found to be correctly predicted. It indicates that the accuracy of prediction is high. 4 out of 64 cases were wrongly predicted. This indicates that the regression model is reasonably good in predicting of time performance.

Table 6.9: Logistic Regression Classification Table for Time Performance

Observed		Predicted		
		Good G	Poor P	Percent correct
Good	G	58	1	98.3%
Poor	P	3	2	40.0%
Overall				93.8%

As shown in Table 6.8, 48.5% of the variance in time performance could be predicted from the capabilities of C8 (cost checking) and C9 (visualization), as both coefficients were statistically significant at 5%. The results demonstrated that these two variables had an effect on the time performance.

Meanwhile, the p-value for Hosmer and Lemeshow goodness of fit was .997, which is more than .05. Thus, the model adequately fit the data. Then, the logistic regression equation is produced as follows:

$$Z = -10.015 + 2.761 \text{ (C8 - cost checking)} + 1.609 \text{ (C9 - visualization)}$$

Hence, C8 (cost checking) and C9 (visualization) were the significant BIM capabilities that affected the project time performance. These variables contributed significantly to the predictive ability of the model. The goodness of fit of the model is confirmed by the Hosmer and Lemeshow goodness of fit, Nagelkerke R-square, classification table, suggesting that the model was statically robust. By focusing on these two capabilities, the project time performance is most likely to be enhanced. Hence, QSs should put C8 (cost checking) and C9 (visualization) into their practice during pre-construction stage for better project outcomes.

b. Regression between BIM capabilities and cost performance

Binary logistic regression was conducted to assess if the 11 independent variables from BIM capabilities could significantly predict the project performance in cost aspect.

In the analysis, SPSS coded the good cost performance with 1 and poor cost performance as 0. By using forward stepwise method, SPSS produced two steps to include the predictor that significantly contributed to the logistic regression model. As shown in Table 6.10, Step 1 revealed the first independent variable, C4 (cost estimate for alternatives) significantly predicting the cost performance with $X^2 = 5.980$, $p < .05$. Then, Step 2 computed the second independent variable, C10 (automatic BQ quantification) with $X^2 = 6.602$, $p < .05$. Hence, two independent variables significantly predicted the cost performance ($X^2 = 12.582$, $p < .05$).

Table 6.10: Logistic Regression Result (BIM Capabilities - Cost Performance)

BIM capability		B	Sig	Model fit information		Pseudo R-square	Hosmer and Lemeshow Test	
				Chi-Square	Sig.	Nagelkerke	Chi-Square	Sig.
Step 1[a]	Cap 10	2.271	.040	5.980	.014	.283	2.894	.235
	Constant	-4.919	.164					
Step 2[b]	Cap 4	1.987	.053	6.602	.010	.567	.391	.996
	Cap 10	3.985	.055					
	Constant	-16.305	.059					

Table 6.11: Logistic Regression Classification Table for Cost Performance

Observed		Predicted		Percent correct
		Good G	Poor P	
Good	G	60	1	98.4%
Poor	P	2	1	33.3%
Overall				95.3%

Based on the classification table as shown in Table 6.11, 95% of the total cases were found to be correctly predicted. It indicates that the accuracy of prediction was high. 3 out of 64 cases were wrongly predicted. This indicates that the regression model was reasonably good in prediction of time performance.

As shown in Table 6.10, 56.7% of the variance in cost performance could be predicted from the capabilities of C4 (cost estimate for alternatives) and C10 (automatic BQ quantification), as both coefficients were statistically significant at 5%. The results demonstrated that these two variables had an effect on the cost performance.

Meanwhile, the p-value for Hosmer and Lemeshow goodness of fit was .996, which is more than .05. Thus, the model adequately fit the data. Then, the logistic regression equation is produced as follows:

Z = -16.305 + 1.987 (C4 - cost estimate for alternatives) + 3.985 (C10 - automatic BQ quantification)

Hence, C4 (cost estimate for alternatives) and C10 (automatic BQ quantification) were the significant BIM capabilities that affected the project time performance. These variables contributed significantly to the predictive ability of the model. The goodness of fit of the model is confirmed by the Hosmer and Lemeshow goodness of fit, Nagelkerke R-square, classification table, suggesting that the model was statically robust. By focusing on these two capabilities, the project time performance is most likely to be enhanced. Hence, QSs should put C4 (cost estimate for alternatives) and C10 (automatic BQ quantification) into their practice during pre-construction stage for better project outcomes.

c. Regression between BIM capabilities and quality performance

Binary logistic regression was conducted to assess if the 11 independent variables from BIM capabilities could significantly predict the project performance in quality aspect.

In the analysis, SPSS coded the good quality performance with 1 and poor quality performance as 0. By using forward stepwise method, SPSS produced two steps to include the predictor that significantly contributed to the logistic regression model. A shown in Table 6.12, Step 1 revealed the first independent variable, C9 (visualization) significantly predicting the cost performance with $X^2 = 15.182$, $p < .05$. Then, Step 2 computed the second independent variable, C7 (clash detection) with $X^2 = 5.890$, $p < .05$. Hence, two independent variables significantly predicted the quality performance ($X^2 = 21.072$, $p < .05$).

Table 6.12: Logistic Regression Result (BIM Capabilities - Quality Performance)

BIM capability		B	Sig	Model fit information		Pseudo R-square	Hosmer and Lemeshow Test	
				Chi-Square	Sig.	Nagelkerke	Chi-Square	Sig.
Step 1[a]	Cap 9	1.777	.002	15.182	.000	.399	.614	.893
	Constant	-2.829	.046					
Step 2[b]	Cap 7	1.381	.028	5.890	.015	.530	5.850	.557
	Cap 9	1.786	.008					
	Constant	-6.804	.009					

Table 6.13: Logistic Regression Classification Table for Quality Performance

Observed		Predicted		Percent correct
		Good G	Poor P	
Good	G	54	2	96.4%
Poor	P	3	5	62.5%
Overall				92.2%

Based on the classification table as shown in Table 6.13, 92% of the total cases were found to be correctly predicted. It indicates that the accuracy of prediction was high. 5 out of 64 cases were wrongly predicted. This indicates that the regression model was reasonably good in prediction of time performance.

As shown in Table 6.12, 53.0% of the variance in quality performance could be predicted from the capabilities of C9 (visualization) and C7 (clash detection), as both coefficients were statistically significant at 5%. The results demonstrated that these two variables had an effect on the quality performance.

Meanwhile, the p-value for Hosmer and Lemeshow goodness of fit was .557, which is more than .05. Thus, the model adequately fit the data. Then, the logistic regression equation is produced as follows:

$$Z = -6.804 + 1.381 \text{ (C7 - clash detection)} + 1.786 \text{ (C9 - visualization)}$$

Hence, C9 (visualization) and C7 (clash detection) were the significant BIM capabilities that affected the project quality performance. These variables contributed significantly to the predictive ability of the model. The goodness of fit of the model is confirmed by the Hosmer and Lemeshow goodness of fit, Nagelkerke R-square, classification table, suggesting that the model was statically robust. By focusing on these two capabilities, the project time performance is most likely to be enhanced. Hence, QSs should put C7 (clash detection) and C9 (visualization) into their practice during pre-construction stage for better project outcomes.

6.4 Summary of Chapter

This chapter discusses the findings resulted from the questionnaire survey. Several statistical analyses were performed to examine the relationships between BIM capabilities and project performance. From the statistical analysis, the top 3 BIM capabilities were C10 (automatic BQ quantification), C4 (cost estimate for alternatives), and C1 (cost appraisal at feasibility), and they are ranked according to relative importance index.

Furthermore, correlation results showed that C1 (cost appraisal at feasibility), C2 (preliminary cost plan), C3 (update cost plan), C4 (cost estimate for alternatives), C8 (cost checking), C9 (visualization), and C11 (intelligent information management) correlated with time performance; C2 (preliminary cost plan), C4 (cost estimate for alternatives), C5 (design changes reflected consistently), C6 (cost implication), C7 (clash detection), C9 (visualization), and C10 (automatic BQ quantification) correlated with cost performance; and C1 (cost appraisal at feasibility), C2 (preliminary cost plan), C3 (update cost plan), C4 (cost estimate for alternatives), C6 (cost implication), C7 (clash detection), C8 (cost checking), C9 (visualization), and C10 (automatic BQ quantification) correlated with quality performance.

Logistic regression results revealed that C8 (cost checking) and C9 (visualization) were the significant BIM capabilities that affected the project time performance; C4 (cost estimate for alternatives) and C10 (automatic BQ quantification) were the significant BIM capabilities that affected the project cost performance; and C9 (visualization) and C7 (clash detection) were the significant BIM capabilities that affected the project quality performance. The results obtained were validated through qualitative interview, as further discussed in the following chapter.

CHAPTER 7

INTERVIEW VALIDATION RESULTS

7.1 Introduction

This chapter discusses the semi-structured interview results in order to validate the questionnaire results. This involved validation of the ranking, correlation, and regression results that were obtained from the questionnaire survey. A brief summary of the interview results is discussed at the end of the chapter to conclude how BIM capabilities in quantity surveying practice influence project performance for time, cost, and quality aspects. Lastly, a relationship framework was developed for this research.

7.2 Semi-structured Interview Results

Quantitative survey results demonstrated that several BIM capabilities were correlated with project performance for time, cost, and quality aspects. Hence, qualitative interview was conducted to serve as a purpose to validate, confirm, and corroborate the questionnaire results.

The interview questions were constructed based on the ranking analysis, correlation analysis, and regression results obtained from the previous stage. A set of interview questions is attached in Appendix D. Some conversations of the interviewees are quoted in the discussion of findings to further explain and interpret the results. 15 interviews were carried out with quantity surveyors (QSs) who adopted BIM in their practices. These 15 interviewees are new respondents and have not involved in the previous two research phases. The details of profiles of the interviewees are shown in Table 7.1. Each interviewee was assigned with an identification tag to ensure anonymity and confidentiality. A summary of the interview validation results is illustrated in Table 7.2 to depict an overview of the findings.

Table 7.1: Interviewees' Profiles

Interviewees' tag	Position	Years of experience in construction industry
Interviewee 1	**Senior QS** in quantity surveying consultancy company (private)	6
Interviewee 2	**Senior QS** in quantity surveying consultancy company (private)	5
Interviewee 3	**Director** in quantity surveying consultancy company (private)	38
Interviewee 4	**QS** in quantity surveying consultancy company (private)	5
Interviewee 5	**QS** in quantity surveying consultancy company (private)	5
Interviewee 6	**Senior QS** in quantity surveying consultancy company (private)	15
Interviewee 7	**Senior QS** in quantity surveying consultancy company (private)	5
Interviewee 8	**Senior QS** in quantity surveying consultancy company (private)	7
Interviewee 9	**Team Leader** in quantity surveying consultancy company (private)	10

Table 7.1: Interviewees' Profiles (continued)

Interviewees' tag	Position	Years of experience in construction industry
Interviewee 10	**QS** in quantity surveying consultancy company (private)	5
Interviewee 11	**Senior QS** in quantity surveying consultancy company (private)	7
Interviewee 12	**General Manager** in quantity surveying consultancy company (private)	7
Interviewee 13	**Team Leader** in quantity surveying consultancy company (private)	10
Interviewee 14	**Senior Manager** in quantity surveying consultancy company (private)	9
Interviewee 15	**QS** in quantity surveying consultancy company (private)	5

Table 7.2: Summary of Validation Results

Capability	Project Performance	Interviewee														
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
a) Ranking Results																
C10 Automatic BQ quantification	Rank (1)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
C4 Cost estimate for alternatives	Rank (2)	✓	✓	✓	✓	✓	✓	x	✓	✓	✓	✓	✓	x	x	✓
C1 Cost appraisal at feasibility	Rank (3)	✓	✓	✓	✓	✓	✓	x	✓	x	✓	✓	✓	✓	x	✓
b) Correlation Analysis Results																
C1 Cost appraisal at feasibility	Time	✓	✓	✓	✓	✓	✓	x	✓	x	✓	✓	✓	✓	x	✓
	Quality	✓	✓	✓	✓	✓	✓	✓	✓	x	✓	✓	✓	✓	✓	✓
C2 Preliminary cost plan	Time	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Cost	✓	✓	✓	✓	✓	✓	x	✓	✓	✓	✓	✓	✓	✓	✓
	Quality	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
C3 Update cost plan	Time	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Quality	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
C4 Cost estimate for alternatives	Time	x	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Cost	✓	✓	✓	✓	✓	✓	x	✓	✓	✓	✓	✓	✓	x	✓
	Quality	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Table 7.2: Summary of Validation Results (continued)

Capability	Project Performance	Interviewee														
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
C5 Design changes reflected consistently	Cost	✓	✓	✓	✓	**x**	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
C6 Cost implication	Cost	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Quality	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
C7 Clash detection	Cost	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Quality	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
C8 Cost checking	Time	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Quality	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
C9 Visualization	Time	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Cost	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Quality	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
C10 Automatic BQ quantification	Cost	✓	✓	✓	✓	✓	✓	**x**	✓	✓	✓	✓	✓	✓	✓	✓
	Quality	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
C11 Intelligent information management	Time	✓	✓	✓	✓	✓	✓	**x**	✓	**x**	✓	✓	✓	**x**	✓	✓

Table 7.2: Summary of Validation Results (continued)

Capability	Project Performance	Interviewee														
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
c) Regression Analysis Results																
C8 Cost checking	Time	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
C9 Visualization	Time	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
C4 Cost estimate for alternatives	Cost	✓	✓	✓	✓	✓	✓	**x**	✓	✓	✓	✓	✓	✓	**x**	✓
C10 Automatic BQ quantification	Cost	✓	✓	✓	✓	✓	✓	**x**	✓	✓	✓	✓	✓	✓	✓	✓
C7 Clash detection	Quality	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
C9 Visualization	Quality	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

7.2.1 Validation of Interview Result to Ranking Analysis Result

Based on the ranking analysis results of BIM capabilities in quantity surveying practice, the three top ranking capabilities were automatically quantification for BQ preparation (C10), easily generate accurate cost estimate for various design alternatives (C4), and cost appraisal can be prepared quickly at feasibility stage (C1). Thus, the interview questions focused on discussing these three capabilities of BIM. The interviewees were asked about the significance of the ranking by providing reasons. The content analysis result for ranking of BIM capabilities is shown in Table 7.3

Table 7.3: Content Analysis Results of Ranking of BIM Capabilities

Themes	Segments and Emerging Codes	Interviewee
C10: Automatically quantification for BQ preparation	manual method is tedious	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
	improve QS's efficiency	*3,6, 11, 14*
	generate quantity faster	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
	cut down mistakes	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
	automatically deduct openings and overlapping	*9.10, 14, 15*
	top BIM capability	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
C4: Easily generate accurate cost estimate for various design alternatives	manipulate quantity for different options	*2, 3, 5, 11*
	explore more cost options	*2,3, 8, 12, 15*
	provide client more options	*2,3, 8, 12, 15*
	advice client in choosing options	*2,3, 8, 12, 15*
	top BIM capability	*1,2,3,4,5,6,8,9,10,11, 12, 15*
C1: Cost appraisal can be prepared quickly at feasibility stage	measure several times for manual method	*6, 12*
	manual method tedious	*2, 3, 6, 12, 13*
	quantity generated faster at feasibility stage	*1,2,3,4,5,6,8,10,11,12, 13,15*
	provide cost information for client	*2, 3, 15*
	client decision making	*1, 3, 15*
	top BIM capability	*1,2,3,4,5,6,8,10,11,12, 13,15*

Each capability is discussed as follows:

i. Automatically generate quantities for BQ (C10)

C10 was ranked first in the ranking analysis result. All the interviewees confirmed that C10 is the top capability of BIM in quantity surveying practice. Most of the interviewees addressed that manual taking off method is very tedious, time consuming, and prone to errors. But BIM has the capability to take away the tedious tasks. By using BIM for quantity generation during BQ preparation, it improves the efficiency of QS in performing this task with fewer mistakes. Interviewee 7 quoted:

"…it helps a lot in measurement and generates quantity faster…" (Interviewee 7)

Some of the interviewees highlighted that BIM does not only have the capability to takeoff the major building elements, but also automatically deduct the openings and overlapping during quantification. Interviewees 14, 10, and 9 coincidentally gave an example of wall measurement. QSs have to takeoff the quantities for wall and finishes, after that have to do deductions for the openings and adjacent elements such as beams, columns, doors and windows. Hence, QSs have to study different sets of drawings, and the process of quantification becomes tedious and prone to errors. However, BIM allows quantification and deduction to be done automatically. Therefore, it is accurate and faster compared to manual method. Interviewee 15 has a similar thought as well, whereby BIM expedites the process of quantification. Interviewee 15 highlighted that:

"…quantification becomes faster and accurate, it replaces the manual taking off, the auto-deductions for the adjacent elements is very fast; but for manual measurement, you

can't really concern all of the deductions accurately, it is time consuming and tedious…" (Interviewee 15)

ii. Easily generate accurate cost estimate for various design alternatives (C4)

12 of the 15 interviewees confirmed that easily generate accurate cost estimate for various design alternatives (C4) is the second top capability of BIM in quantity surveying practice. With this capability, QSs can calculate and manipulate the quantity faster for different design options. From that, they are able to calculate the time and the cost implications of any alternative considered. It helps them to explore more options in the earlier stage and analyze the options on project performance. From that, it helps the client to recognize the options with most impact on the cost and the schedule to improve project outcome. QSs are able to drive the client to choose the best approach among the alternatives. Quoted from interviewees 2 and 3:

"…we can generate a few cost options for our client by using BIM, they can choose the one that suits the budget, but manually it's hard to give a few cost options for different designs…" (Interviewee 2)

"…with BIM, I can manipulate the quantity easily for different options to see how it affects cost and time…" (Interviewee 3)

iii. Cost appraisal can be prepared quickly at feasibility stage (C1)

12 of the 15 interviewees confirmed that cost appraisal can be prepared quickly at the feasibility stage (C1) is the third top capability of BIM in quantity surveying practice. Feasibility stage is the critical stage which involves a lot of decision making. QS is an

important key person at this crucial stage to advise the client on the viability of the project. Therefore, cost appraisal has to be prepared quickly and accurately which would allow the client to commit to decisions earlier. Interviewees 6 and 12 mentioned that they have to measure several times in order to get the average quantity for the cost appraisal. It is tedious to get the quantity accurately, but with BIM, it can be done quickly and accurately. As pointed out by interviewees 3 and 1:

"...quantity can be generated certainty, we can provide cost information to the client, and they can make the right decision with information provided. You cannot expect the client to make decision without any information at this early stage…" (Interviewee 3)

"…BIM fastens the preparation, client has adequate time to plan and make decision to evaluate the project whether it is feasible and profitable…" (Interviewee 1)

The ranking analysis results revealed 3 of the most significant BIM capabilities as C10 (automatic BQ quantification), C4 (cost estimate for alternatives), and C1 (cost appraisal at feasibility). In conclusion for the validation result of BIM capability ranking, the interview results demonstrated that the majority of the interviewees confirmed that these 3 as the significant BIM top capabilities in quantity surveying practice. Hence, the interview results validated the ranking analysis results of BIM capabilities.

7.2.2 Validation of Interview Results to Correlation and Regression Analyses Results

The results of correlation and regression analyses were discussed together in this section. There were 3 parts of interview results to validate the correlation and regression analyses results that involved:

a. Relationship of BIM capabilities with time performance
b. Relationship of BIM capabilities with cost performance
c. Relationship of BIM capabilities with quality performance

7.2.2.1 The Relationship between BIM Capabilities and Time Performance

Based on the correlation analysis results, 7 BIM capabilities were significantly correlated to the time performance, as follows:

i. Cost appraisal can be prepared quickly at feasibility stage (C1)
ii. Preliminary cost plan can be prepared by extracting quantities directly from the model (C2)
iii. Easily update cost plan more details as design is developed (C3)
iv. Easily generate accurate cost estimate for various design alternatives (C4)
v. Cost checking can be performed quickly to ensure all items are captured (C8)
vi. Improve visualization for better understanding of design (C9)
vii. Intelligent information management allows data to be stored in a central coordinated model (C11)

Whereas, regression analyses revealed that C8 (cost checking) and C9 (visualization) were the significant BIM capabilities that affected the project time performance. Therefore, the significant relationship between these BIM capabilities and project time performance is discussed in the interview. The content analysis result for correlation and regression results for the relationship between BIM capabilities and time performance is shown in Table 7.4.

Table 7.4: Content Analysis Results of Correlation and Logistic Analysis (BIM Capabilities - Time Performance)

Themes	Segments and Emerging Codes	Interviewee
C1: Cost appraisal can be prepared quickly at feasibility stage	get quantity faster at feasibility	*1,2,3,4,5,6,8,10,11,12,13, 15*
	more time for cost analysis	*2, 3,11,12*
	client gets it earlier	*3, 11, 12*
	plan for uncertainty earlier	*3, 11, 12*
	early decision making	*3, 11, 12*
	time performance is ensured	*1,2,3,4,5,6,8,10,11,12,13, 15*
C2: Preliminary cost plan can be prepared by extracting quantities directly from the model	quantity generated faster	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
	received cost plan earlier	*2,3,4,5,10*
	more cost information and breakdown	*1,2,3, 10, 13,14,15*
	client aware of cost breakdown	*2,3,10, 11,12,13,14,15*
	early decision making	*2,3,10, 11,12,13,14,15*
	time performance is ensured	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
C3: Easily update cost plan more details as designed is developed	changes always happen	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
	QS notices changes earlier	*2,3,4,7,12, 14,15*
	quick assess changes	*2,3,7, 12*
	update cost plan easily	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
	ensure changes not affect time performance	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
C4: Easily generate accurate cost estimate for various design alternatives	QS quickly explore alternatives in time aspect	*3,4,5,6,11,12*
	more design options for client	*6, 11,12*
	faster than manual method	*3, 6, 11,12*
	time performance is ensured	*2,3,4,5,6,7,8,9,10,11, 12,13,14,15*

Table 7.4: Content Analysis Results of Correlation and Logistic Analysis (BIM Capabilities - Time Performance) (Continued)

Themes	Segments and Emerging Codes	Interviewee
C8: Cost checking can be performed quickly to ensure all items are capture	detect missed out elements	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
	avoid human errors	*3,4,5,9,11,15*
	detect under-measured or over-measured	*1,2,10,15*
	visual/see the model for checking	*4,5,9,11, 15*
	time performance is ensured	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
C9: Improve visualization for better understanding of design	walk through model	*2,3,4,5,10,11,12,13,14,15*
	turn the model from different angles	*1,2,3,4,5,10, 15*
	gain understanding faster	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
	better visualization	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
	reduce misinterpretation	*1,2,3,4,5,8,9,11,12*
	capture correct quantity and cost	*1,2,3,4,5,8,9,11,12,13,14*
	time performance is ensured	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
C11: Intelligent information management allows data to be stored in a central coordinated model	information in central	*2,3,6,10,15*
	easy access to information	*2,3,6,10,15*
	get information faster	*2,3,6,10,15*
	less miscommunication	*1, 2,3,4,6,11,12*
	less information breakdown	*1, 2,3,4,6,11,12*
	time performance is ensured	*1,2,3,4,5,6,8,10,11,12, 14,15*

Each capability is discussed as follows:

a) <u>Cost appraisal can be prepared quickly at feasibility stage (C1)</u>

12 of the 15 interviewees agreed that C1 significantly influenced the performance. It does contribute in improving time performance. By using BIM, QSs can get the quantity faster and accurately at feasibility stage, thereby they have more time in generating pricing and factoring risks which enhances the project time performance. As quoted from interviewee 12:

"...it helps me to get the quantity faster and accurately, I have more time to do cost analysis, get quotation from suppliers, find information for rate, generate cost appraisal accurately for client at the early stage for their decision making, previously I used manual method, the quantities are roughly estimated and I have to measure a few times to get the average..." (Interviewee 12)

A few interviewees highlighted time is limited during feasibility stage as client is rushing to know the indicative budget of the project. BIM adoption expedites the whole process especially quantity generation; QSs can allocate their efforts on cost analysis rather than quantification. Hence, client can get cost appraisal earlier. By then, client is able to make firm decision faster with the management team based on cost appraisal prepared by the QSs. Interviewee 3 mentioned that:

"…a lot of decision is made at the early stage, when we use BIM, definitely it shortens a lot of things and we need information to make decision, so it shortens the time of information and advice provision, hence decision can be made earlier and this improves time performance…" (Interviewee 3)

Decision making is crucial at this earlier stage as it affects the whole project process. Cost appraisal prepared by the QSs is the main source of information for the client to make decision. Once the client obtains information timely, he/she can discuss with the management board to plan the budget and time for the project. When more time and effort spent on planning and preparation at feasibility stage by using BIM, it cuts down risk of uncertainty from happening during project stage which ensures time performance.

b) Preliminary cost plan can be prepared by extracting quantities directly from the model (C2)

As confirmed by all interviewees, C2 does contribute in improving time performance. BIM has the capability to takeoff the quantity automatically during cost plan preparation, as cost plan can be prepared quickly for client to aid in enhancing time performance. Hence, the cost plan is presented in more detailed and accurately to cover client's requirements. As quoted from interviewee 1:

"...at this preliminary stage, everything has to be faster, the more information we can provide, less surprise and not many changes at the later stage, so it can cut short the time after that, and BIM helps on it..." (Interviewee 1)

As the quantification is sped up by BIM, QSs have more time for cost estimation and allocation for building elements in the cost plan. Interviewee 3 provided an insight that QSs spend much time on quantification rather than estimation conventionally. As quoted from interviewee 3:

"...As the design comes out for cost plan preparation, most of the time, it goes back to 80:20 rules, we spend 80% of the time on quantification, but only 20% of the time on estimating; but BIM adoption reduces the 80% of time for quantification, it shortens the time taken and the whole process of cost plan preparation is sped up, client can get the cost plan earlier, again for early decision making and planning..." (Interviewee 3)

By getting the cost plan earlier from QSs, client would be aware of the cost breakdown for each building elements. Client gets to know the cover and uncover items in the project which would allow them to have a conceptual idea of the project.

Decisions can be made faster and unforeseen circumstance can be captured which enhance the project time performance. Interviewee 2 addressed that:

"…Client gets to know the cover and uncover costs of the project, this is important for them to know so that they can plan for their project, as planning earlier can enhance time performance, or else, they will be in a misconception that the cost plan covers everything, but then during later stage, one of the element actually does not cover under the cost plan, then it affects the progress of the project…" (Interviewee 2)

c) Easily update cost plan more details as design is developed (C3)

All interviewees recognized that C3 does contribute in improving time performance; client is able to keep up to date of the cost plan breakdown as the design is developed progressively. QSs are able to update the cost plan as the design is developed using BIM. If any changes affect the time performance, QSs are able to notice it earlier and highlight it to the client and the project team at the early stage. By updating timely and identify earlier of the negative impacts, project time performance is ensured.

Most of the interviewees claimed that design change frequently occurs during cost planning stage which requires them to update the cost plan regularly. Doing it manually is tedious and time-consuming as updates involve changing each sheet manually with multiple linking. Nonetheless, with BIM, QSs can identify the changes faster by superimposing the revise drawings into the model. They can quickly assess any changes made and check that the changes have not negatively influenced the time performance. As compared to manual ways, QSs have to read several sets of drawings for updating. Therefore, by using BIM, QSs can keep updating the cost plan to ensure the change is within the budget without affecting project time performance later. As pointed out by interviewee 7:

"…cost plan tends to change because client has not made up their mind, using BIM for changes, easier to trace the changes, it recalculates back automatically and it is faster to know how it is going to affect the project time; but as for manual, you have to redo or re-measure the changes…" (Interviewee 7)

Interviewee 12 also conveyed the similar thought:

"…changing of floor height is one of the changes that often happen, and this change affects a lot of elements and it is tedious to update one by one; but BIM expedites this process and updates quantity faster for the affected elements, so we can tackle the changes very well and update accurately in the cost plan to see the change effect earlier, no surprise appears later that will affect time performance…" (Interviewee 12)

Therefore, it is crucial to keep the cost plan updated based on the latest design. This is to ensure that the cost is within the client's budget without any negative implication whenever the design is developed. Changes have captured into the cost plan and many uncertainties which could affect project time can be identified earlier and avoided. Therefore, project time performance is ensured. As quoted from interviewee 11:

"…Client and consultants change their designs very frequently; we have to update the cost plan each time if there are changes. It is tedious doing manually, but with BIM, it is very fast and easy. We can update the quantity and cost plan faster as the design is

developed. We can see the impact of design changes on project time and advice our client accordingly…" (Interviewee 11)

d) Easily generate accurate cost estimate for various design alternatives (C4)

It does contribute in improving time performance, as acknowledged by 14 interviewees; by generating cost options faster at the early stage, client is able to choose the most efficient approach that can result in shortened project time. By using BIM, quantity can be generated automatically; QSs can rapidly explore design alternatives in time aspect. Multiple design options that can improve project time performance are easily explored and developed. BIM facilitates QSs in evaluating different design alternatives in terms of time parameter. By considering different design options at the earlier stage, QSs can propose better option that does not only suit to the client's budget, but also shortens the construction period. As BIM allows QSs to provide immediate feedback on design alternatives at the early stage, the project time performance can be ensured. As quoted from interviewee 6:

"...It is faster to generate a few cost options for the client, compared to the manual ways. Quantity is automatically generated for different design options, and we can advise accordingly on the options that suit to the client's schedule to improve project time performance..." (Interviewee 6)

e) Cost checking can be performed quickly to ensure all items are captured (C8)

It does contribute in improving time performance as pointed out by all interviewees. By being able to detect missed out elements or careless human errors before construction begins, it helps to keep the project on schedule by preventing potential setbacks. It is noted by most of the interviewees that cost checking plays an important task in the quantity surveying practice. According to the majority of the interviewees, checking is very important to avoid any missed out elements or to detect any under-measured or over-measured quantities which will cause big problems at the later project stage. If checking is not performed accordingly, the impact on the project performance is huge on time performance. It affects the contractor's progress and planning which may cause the contractor to claim for extinction of time.

Besides, visual checking on BIM model allows QSs to perform checking easily and confidently, according to all of the interviewees. QSs can see the model easily, which helps guarantee its accuracy and completeness. Hence, it reduces the possibility for errors and omissions which ensure project performance. As quoted from interviewee 15:

"…we can see the solid 3D model, if there is any missing element, we can see the empty space easily, it is quite easy to detect if we missed out anything, and we spot it immediately before it affects the time performance…" (Interviewee 15)

Conventionally, a stack of drawings is hard for checking. However, it is clear to see on a 3D model rather than hard copy drawings and it gives visibility to the QSs when performing checking. It gains the confident of QSs in ensuring every building element is captured which cuts down uncertainty and missed out items. Moreover, a 3D model serves as a visible record for future updating and checking during the construction stage. Thus, time performance is enhanced. For everything that causes discrepancy that needs further clarification, QSs can always refer to the 3D model quickly for checking. Quoted from interviewees 6 and interviewee 11:

"... by using BIM, you can actually know where is not covered and see it clearly; by manual checking, it is hard to identify, you have to check one by one, very tedious; once missed out any item, it is very troublesome and it affects the project time performance because the contractor is unable to have prior consideration in his progress plan..." *(Interviewee 6)*

"...it really helps a lot, it increases my confident level when it comes to checking because I can visual it on a 3D screen, as it reduces risk of missing out elements, and time performance is ensured because the missed out elements due to careless checking will affect the contractor's progress..." *(Interviewee 11)*

f) Improve visualization for better understanding of design (C9)

It does contribute in improving time performance, as agreed by all interviewees. BIM provides 3D representations of the structure. Understanding the design is the key to takeoff the quantity correctly, as pointed out by all the interviewees. By having good visualization, QSs can easily see the complexity and the scope of a project in 3D which in turn captures accurate quantity and cost. It reduces misunderstandings that can happen with 2D drawings.

Furthermore, all of the interviewees claimed that they spent longer time on understanding the design, especially for complex structures. But with BIM, QSs can view the 3D model from different angles for better visualization. It reduces the time taken to interpret the design. Moreover, it reduces confusion and misinterpretation. Misinterpretation of design during early stage results in project delays as more time is spent on request for clarification and information. Hence, project time is enhanced as

QSs clearly understand the project design and scope at the early stage. Any potential discrepancy can be identified, tracked and the QSs are alerted about it. Hence, mistakes can be highlighted earlier and clarified before construction takes place to ensure time performance. Interviewee 11 highlighted:

"…We can walk through the model and imagine easily, it really helps a lot and saves time from understanding it. When it comes to takeoff, it is easier once you get the whole picture of the design. Time performance is ensured when you really understand the project design …" (Interviewee 11)

g) <u>Intelligent information management allows data to be stored in a central coordinated model (C11)</u>

This capability is not widely practiced in the Malaysian construction industry due to lack of experience in using single model for project. However, this capability does contribute in improving time performance, as confirmed by 12 interviewees; BIM application facilitates easy information access, and QS can perform their tasks faster and smoothly without any delay. The majority of the interviewees highlighted that information breakdown and miscommunication among project consultants tend to happen. Moreover, it is difficult to get information and details from the designers on time which affects QSs' work progress.

BIM substitutes the conventional review, comment, response, and feedback process with a central model with information. BIM model becomes a single source for information that everyone has immediate access to information. Information can be shared seamless and everyone refers to the latest updated information. This process enhances the sharing and the transfer of information among project consultants. Collaboration with other consultants is simplified with this common platform which streamlines the entire process. Early and easy access to the information in the models help QSs gain more insight into projects. Project time performance is ensured too because information is obtained faster, resulting in improved efficiencies, and hence substantial project time saving. Establishing good information sharing in a central at the beginning of the project is essential for smoother construction stage with less conflict and information loss. As quoted from interviewees 2 and 6:

"…all the information is inside the central, it is easier to obtain information from the central and we need not always update and follow up with project teams, cut down difficulties to request information from them; discrepancies or unclear matters resulting in time delay because we spend time in clarification, request additional information…" (Interviewee 2)

"...quick and easy access to information in the model helps to enhance time performance as coordination becomes easier, less miscommunication problems, as you don't need to call up or email one by one, everyone has the understanding and the information is passed correctly…" (Interviewee 6)

In conclusion, all interviewees acknowledged that the BIM capabilities had significantly relationship towards time performance during the interview session. Hence, the interview results validated the correlation and the regression analyses result between BIM capabilities and project time performance. Therefore, QSs must take into account these BIM capabilities in their practice to enhance the project time performance.

7.2.2.2 The Relationship between BIM Capabilities and Cost Performance

Based on the correlation analysis result, 7 BIM capabilities were significantly correlated to the cost performance, as follows:

i. Preliminary cost plan can be prepared by extracting quantities directly from the model (C2)
ii. Easily generate accurate cost estimate for various design alternatives (C4)
iii. Design changes are reflected consistently in all drawing views (C5)
iv. Cost implication of design changes can be generated easily without manually re-measurement (C6)
v. Clash detection reduces design errors and cost estimates revisions (C7)
vi. Improve visualization for better understanding of design (C9)
vii. Automatically quantification for BQ preparation (C10)

Meanwhile, regression analysis revealed that C4 (cost estimate for alternatives) and C10 (automatic BQ quantification) were the significant BIM capabilities that affected the project cost performance. Therefore, the significant relationship between these BIM capabilities and project cost performance is discussed in the interview. The content analysis result for correlation and regression results for the relationship between BIM capabilities and cost performance is shown in Table 7.5.

Table 7.5: Content Analysis Results of Correlation and Logistic Analysis (BIM Capabilities - Cost Performance)

Themes	Segments and Emerging Codes	Interviewee
C2: Preliminary cost plan can be prepared by extracting quantities directly from the model	quantity generated accurately	*1,2,3,4,5,6,8,9,10,11, 12,13,14,15*
	more time for estimation	*2, 3, 9,10,11,12,13*
	reduce careless mistakes	*1,2,3,6, 8, 13,15*
	cost planning at early stage	*1,2,3,8, 14,15*
	cost performance is ensured	*1,2,3,4,5,6,8,9,10,11, 12,13,14,15*
C4: Easily generate accurate cost estimate for various design alternatives	what-if analysis	*3,6,15*
	compare different options in cost aspect	*1, 3,6,8,10, 11,12,13,15*
	for client's evaluation	*1,2,3,4,5,6,8,9,10,11, 12,13,15*
	cost performance is ensured	*1,2,3,4,5,6,8,9,10,11, 12,13,15*
C5: Design changes are reflected consistently in all drawing views	hardcopy drawings hard to detect changes	*1,2,4,10,11,14*
	BIM overlaps revised drawings	*2,3,8,10,11,12,14,15*
	Design changes reflected consistently	*2,3,8,10,11,12,14,15*
	avoid obsolete drawings	*2,3,11*
	QS captures changes easily in costing	*1,2,3,4,6,7,8,9,10,11, 12,13,14,15*
	cost performance is ensured	*1,2,3,4,6,7,8,9,10,11, 12,13,14,15*
C6: Cost implication of design changes can be generated easily without manually re-measurement	no need re-measurement	*1,2,4,5,6,7,8,9,10,12,13*
	quantity automatically recalculated	*1,2,4,5,6, 12, 15*
	obtain cost different accurately	*1,2,4,5,6, 12, 15*
	highlight to client	*3, 6,12, 15*
	avoid major discrepancy	*3, 6,12, 15*
	cost performance is ensured	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
C7: Clash detection reduces design errors and cost estimates revisions	detect clashes earlier	*31,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
	merge different sets of drawings	*11, 12,14*
	reduces variation	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
	cost performance is ensured	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*

Table 7.5: Content Analysis Results of Correlation and Logistic Analysis (BIM Capabilities - Cost Performance) (Continued)

Themes	Segments and Emerging Codes	Interviewee
C9: Improve visualization for better understanding of design	better understanding	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
	visual clearly from different views	*1,2,3,4,5,9,11,12,13,14, 15*
	better imagination	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
	avoid misinterpretation	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
	takeoff accurately	*1,2,3,4,5,9,11,12,13,14, 15*
	cost performance is ensured	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
C10: Automatically quantification for BQ preparation	quantity accurately takeoff automatically	*1,2,3,4,5,6,8,9,10,11, 12,13,14,15*
	manual method tedious	*1,2,3,4,5,6,8,9,10,11, 12,13,14,15*
	avoid human mistakes	*1,2,3,4,5,6,10,11,12,14*
	affect client's budget and contractor's progress	*2,3,6,7,9,11,12,13,14*
	cost performance is ensured	*1,2,3,4,5,6,8,9,10,11, 12,13,14,15*

Each capability is discussed as follows:

a) Preliminary cost plan can be prepared by extracting quantities directly from the model (C2)

According to 14 interviewees, C2 does contribute in improving cost performance when quantity is automatically generated. Cost plan is the brief cost breakdown of the major elements. It clearly shows the cost allocation for the major elements. The quantity can be automatically generated by BIM, and assist QSs in the creation of cost plan, hence human mistake is reduced. Budget is in line with the intent of the project clients, and cost accuracy is ensured. As pointed out by interviewee 3:

"...again with the 80:20 rule, when we cut down 80% of time of quantification, quantity is automatically generated by BIM, we have more time for cost estimation, and cost become more accurate definitely…." (Interviewee 3)

By allocating accurate and adequate amount for each building elements, the project team can plan for the project which comply with the baseline cost of each element as the accuracy of the cost plan is one of the concerns of clients. A few interviewees mentioned that client is more concerned on the cost accuracy of the cost plan as it sets the project budget that is going to be borne by the client. BIM ensures the cost accuracy, as compared to conventional method. As quoted from interviewee 8:

"...our client is stressed on cost accuracy of the cost plan, the final amount cannot run too far away from the final tender cost. Hence, using BIM, the accuracy is ensured as the risk of making careless mistakes is reduced, while cost performance is enhanced..." (Interviewee 8)

b) Easily generate accurate cost estimate for various design alternatives (C4)

C4 does contribute in improving cost performance as revealed by 13 interviewees; this is because client can consider various options that suits his/her budget. Quantities are automatically generated by using BIM and costing for each option can be easily known. BIM allows a rapid comparison of various design alternatives with real-time cost estimating generated simultaneously. As quoted from interviewee 3:

"…quantity is automatically generated. We can perform what-if analysis at early stage, with different types of design structures, we can see easily how it affects cost and we can advise the client easily in cost aspect and it enhances the cost performance…" (Interviewee 3)

Besides, QSs can generate a few options with different types of design structures or shapes with BIM. It helps to analyze the costs to evaluate the cost effects for each alternative. Therefore, QSs would be able to drive the client to make more informed decisions about the alternatives. By considering a few cost options at the early stage, the client is able to choose the most cost efficient approach by evaluating the cost alternative. Hence, cost performance is ensured. As quoted from interviewee 1:

"…I have done cost comparison for two different designs by using BIM, it helped me to see the overall cost for each design and I can advise my clients accordingly with the design that suits his budget…" (Interviewee 1)

c) Design changes are reflected consistently in all drawing views (C5)

14 interviewees agreed that C5 does contribute in improving cost performance. All the interviewees explained that when new drawing is overlaid into the model, the model automatically updates with the new revision. All affected views or elements are updated according to the new drawing. Design changes are reflected consistently in all views. BIM coordinates plans, sections, and details to show everything in a model. Every change is in sync in all view when changes are made. It eliminates many errors due to drawings not being coordinated without having to pay for it in the construction stage.

When changes are reflected consistently in all drawing views, QSs are able to capture the differences easily. Previously, they had to spend longer time identifying the changes in all drawing views which tend to cause missing out that could affect cost performance. Manually detecting the changes is tedious as QSs have to compare different sets of drawings which can be easily missed out or overlooked. As highlighted by interviewee 11:

"...Previously, we spend quite some time and efforts in identifying out the changes with a lot of hardcopy drawings and also manual measure to update changes. Sometimes, the drawings are not updated to the latest. Cases of missed out tend to happen which affect the cost performance, but now, we can do it easily and accurately with BIM..." (Interviewee 11)

With BIM practice, design changes are reflected consistently in all drawing views whenever QSs superimpose new revise drawings into the 3D model. By seeing it clearly, cost is accurate as QSs are able to capture the design changes consistently without causing any variation during construction stage. Cost performance is improved as QSs can update the quantity and costing accurately and easily after detecting the design changes in the 3D model. Interviewee 8 highlighted that:

"...BIM allows for overlapping new drawings, it would be faster to identify the location for changes and update the cost. If performs manually, there are many sets of drawings, and there will be some changes without highlighting and updating in the drawings, and we may tend to overlook certain changes without updating and this affect the cost performance…" (Interviewee 8)

d) Cost implication of design changes can be generated easily without manually re-measurement (C6)

C6 does contribute in improving cost performance, as verified by all interviewees. By engaging BIM, QS is able to calculate the cost and evaluate the proposed change if there is a mass change. Majority of the interviewees highlighted that cost implication can be aware at the early stage by using BIM. Manual re-measurement is no longer needed whenever there is a change which cuts down the risk of human errors. BIM allows automatic recalculation for the quantity when there is a change, hence the quantity is accurate. Using BIM enables the QSs to inform the cost effects of the design changes, it can help to curb excessive cost overruns due to design changes. Interviewee 6 said that:

"...don't need to do re-measurement, I won't confuse, I can visual the changes on screen, and the quantity is automatically recalculated back, then I can get to generate the cost implication and present it to the client, as the cost is ensured within the bottom line…." (Interviewee 6)

Changes that incur cost may have effect on project cost. Therefore, by getting to know the cost implication earlier, QSs are able to know if it is a positive or a negative effect on the project cost. Any negative implications can be identified earlier and suitable action can be taken before it affects the project cost. Project cost is enhanced as QSs can monitor the cost efficiently. Both interviewees 12 and 15 provided similar thoughts:

"...once we detect the changes faster, quantity is updated automatically, we can calculate the cost implication faster and highlight it to the client regarding the changes on cost. If the cost is a lot, we can highlight it to the client earlier, so that the client can make decision and find other alternatives that within cost budget..." (Interviewee 12)

"…when the design changes, we just import the new review drawing into the model, let's say the column heights change, once we update the new column size, then all the relevant quantity of the brickwork, plastering, finishes will be changed simultaneously and automatically; we will know the cost difference from the changes easily and make comparison, so the cost is ensured…" (Interviewee 15)

e) <u>Clash detection reduces design errors and cost estimates revisions (C7)</u>

All interviewees acknowledged that C7 does contribute in improving cost performance; whereby by detecting the clashes at the early stage, variation reduces at the later stage which enhances the cost performance without causing any big variation. Most of the interviewees addressed that they can foresee what will happen during the construction stage. By using BIM for clash detection, any discrepancy can be pre-identified and rectified before it enters into construction. Cost performance is ensured as majority of the variations are due to clashes that have been identified and solved at the early stage. Interviewee 11 explained:

"…By merging the architectural and structural drawings, we can detect clash and discrepancy at the early stage, it reduces variations and save our works. Or else, it will give impact on cost performance during the later stage…" (Interviewee 11)

Besides, a few interviewees commented that manual method does not allow them to identify clashes easily during early stage, which eventually causes problems such as variation orders or design change during construction stage. As quoted from interviewee 12:

"…if without BIM, it is hard to identify clashes, in future, there will be a lot of variation orders, a lot of additional work such as hacking work which will affect the project cost..." (Interviewee 12)

Interviewee 3 shared the experience of using BIM for clash detection during construction stage, whereby the project has begun the construction stage:

"…the contractor used BIM and detected many clashes that caused additional million ringgit and it affected the client's budget; if this can be detected earlier during pre-construction stage, early detection, early reporting, and early action could have been taken, so no abortive works or less abortive works would take place, and then these additional costs can be avoided and cost performance is ensured…" (Interviewee 3)

However, once they adopt BIM in their practice, they can detect discrepancies and clashes easily. This helps to enhance cost because variations due to discrepancy may have required reworks, unnecessary hacking works and change orders. All of these should be pre-identified earlier during the pre-construction stage so that it would not affect the later stage. In addition, early identification and resolution of these clashes should be performed at the design stage, not in the construction stage. Therefore, it improves the cost performance by eliminating costly reworks and variations. As quoted from interviewee 14:

"…we have three different sets of drawings from Architects, Engineers, and Landscape designer. Conventionally, we have to study three different sets and make use of these three sets. But with BIM, we can combine three different sets of drawings and

merge into one model, and we actually can view it clearly and detect clashes. From that, we can predict or foresee things that are not in order, in that sense; we can query the consultants for clarification. If things do not match, we cannot see them on 2D drawings, and they could affect the cost performance later...” (Interviewee 14)

f) Improve visualization for better understanding of design (C9)

All interviewees highlighted that C9 does contribute in improving cost performance; whereby by having good visualization, QSs gain understanding of the project and capture accurate cost. One of the interviewees pointed out that understanding the design is the priority before getting started to measure the quantity. Hence, it can be concluded that visualization is the first step to understand the design and then takeoff quantity correctly. As quoted from interviewee 11:

“…with BIM, we have better understanding of the design, and we can avoid human error such as wrong interpretation, then we are able to takeoff correctly and accurately. Project cost is more accurate when we have more understanding on the design…” (Interviewee 11)

Some of the interviewees stated that sometimes, it is difficult to imagine how the elements would look like which causes difficulties during taking off and costing. It may lead to wrong interpretation which may affect the project cost. Misinterpretation of design during early stage results in additional cost due to change orders. Conventionally, what they see on plan is different from the 3D model, and that causes different quantification. With BIM, they can visualize the model clearly by turning the model in different perspectives for different views. It gives QSs better understanding when doing quantification and estimating. Project cost is ensured to correlate with good understanding of the design. Interviewee 12 pointed out:

"…it's interesting to see the 3D model compared to the 2D drawings, we have better imagination and when it comes to taking off, it is easier and it cuts short your mistakes which may affect the costing. The impact on cost will be huge if wrong visualization and interpretation are done during quantification…" (Interviewee 12)

g) <u>Automatically quantification for BQ preparation (C10)</u>

14 interviewees concurred that C10 does contribute in improving cost performance when quantity is automatically generated with using BIM. Manually quantification is a process fraught with the potential for error. Human mistakes such as arithmetical errors, and over or under measured that are caused by manual method can be avoided. These mistakes have big effects on cost performance which do not only influence the client's budget but also the contractor's cash flow. Quantity that is too much will cause the contractor to over purchase materials and this causes wastage; whereas inadequate quantity will cause variation. In return, it affects the client's budget as well. Interviewee 14 quoted that:

"…if you are doing manual measurement, for instance, you may scale wrongly or key in wrongly, you may miss a "zero", or miss a decimal point in your quantity, and it brings negative impact on your cost performance. But with BIM, you may avoid and minimize all these careless mistakes which could ensure cost performance…" (Interviewee 14)

Interviewee 14 mentioned that QSs have to study three different sets of drawings at the same time from Architect, Engineer, and Landscape Architect to takeoff the quantity. Therefore, quantification becomes tedious as they have different types of drawings. Moreover, quantification is involved in deductions for opening and also for overlapping. As explained by interviewee 14:

"…in manual measurement, for instance, we measure wall area separately and then do manual deduction for beams, doors, windows or opening, so you have to look at different sets of drawings, and it is tedious and error prone; but BIM helps us to do everything, the quantification and deduction automatically, so the quantity is accurate, mistake is reduced, save costs and resources…" (Interviewee 14)

Therefore, with BIM, quantities can be accurately generated and cost performance is enhanced. There is less problem of over or under measure of quantity which ensures cost performance. It allows the contractor to price correctly and purchase adequate amount of materials without wasting.

In conclusion, all interviewees acknowledged that these capabilities have significant relationship towards cost performance during the interview session. Hence, the interview results validated the correlation and regression analysis results between BIM capabilities and project cost performance. Therefore, QSs must take into account these BIM capabilities in their practice to enhance the project cost performance.

7.2.2.3 The Relationship between BIM Capabilities and Quality Performance

Based on the results of correlation analysis, 9 BIM capabilities were significantly correlated to the quality performance, as follows:

i. Cost appraisal can be prepared quickly at feasibility stage (C1)
ii. Preliminary cost plan can be prepared by extracting quantities directly from the model (C2)
iii. Easily update cost plan more details as design is developed (C3)
iv. Easily generate accurate cost estimate for various design alternatives (C4)
v. Cost implication of design changes can be generated easily without manually re-measurement (C6)
vi. Clash detection reduces design errors and cost estimates revisions (C7)
vii. Cost checking can be performed quickly to ensure all items are captured (C8)
viii. Improve visualization for better understanding of design (C9)
ix. Automatically quantification for BQ preparation (C10)

On the other hand, the regression analysis revealed that C7 (clash detection) and C9 (visualization) were the significant BIM capabilities that affected the project quality performance. Therefore, the significant relationship between these BIM capabilities and project quality performance is discussed in the interview. The content analysis result for correlation and regression results for the relationship between BIM capabilities and quality performance is shown in Table 7.6.

Table 7.6: Content Analysis Results of Correlation and Logistic Analysis (BIM Capabilities - Quality Performance)

Themes	Segments and Emerging Codes	Interviewee
C1: Cost appraisal can be prepared quickly at feasibility stage	QS prepare cost appraisal faster	*1,2,3,4,5,6,7,8,10,11, 12,13,14,15*
	more costing information	*1,3,4,10,11*
	QS provide early cost advice	*1,3,4,5,6,7,10,11*
	facilitate client in making decision	*3, 6,8,10,11,12,14,15*
	evaluate feasibility of project	*3, 6,8,10,11,12,14,15*
	client is satisfied.	*1,2,3,4,5,6,7,8,10,11, 12,13,14,15*
C2: Preliminary cost plan can be prepared by extracting quantities directly from the model	quantity generated accurately	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
	client aware of cost allocation for building elements	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
	for client cost planning	*3, 7,13*
	client is satisfied.	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
C3: Easily update cost plan more details as designed is developed	update cost plan easily when design is developed	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
	monitor cost rapidly	*3,9,12,14*
	advice client on changes	*3,6,7, 9,10,11,14,15*
	ensure design developed as project's scope	*3,6, 7,9,10,11,14,15*
	keep client up to date on cost plan	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
	client is satisfied	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
C4: Easily generate accurate cost estimate for various design alternatives	evaluate options in time and cost aspects	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
	more cost options for consideration	*2,3,4,6, 10,11,14*
	QS provides cost advice	*2,3,4,6, 8,10,11,12,14*
	client chooses options suit to his/her requirements	*2,3,4,6, 8,10,11,12,14*
	client is satisfied	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
C6: Cost implication of design changes can be generated easily without manually re-measurement	QS prepare cost implication faster	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
	QS highlight cost implication earlier	*1,2,3,4,7,8,9,10,11, 12,14,15*
	clients aware cost implication earlier	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
	for decision making	*2,3,4,5,6,7,8,9,10,11,13, 14,15*
	client is satisfied	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*

Table 7.6: Content Analysis Results of Correlation and Logistic Analysis (BIM Capabilities - Quality Performance) (Continued)

Themes	**Segments and Emerging Codes**	**Interviewee**
C7: Clash detection reduces design errors and cost estimates revisions	pre-identified clashes before construction	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
	detect clashes earlier	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
	rectified earlier	*2,3,6,7,8,9,13 14*
	avoid variation	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
	client is satisfied	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
C8: Cost checking can be performed quickly to ensure all items are capture	everything shown in model	*2,3,12,13,14,15*
	visual checking	*2,4,5,8,11,12,14,15*
	reduce missed out elements	*1,2,3,4,5,8,9,10,11,12, 13,14,15*
	ensure all elements have captured	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
	manual checking is tedious	*1,2,3,4,5,8,9,10,11,12, 13,14,15*
	client is satisfied	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
C9: Improve visualization for better understanding of design	better understanding	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
	visual 3D model	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
	capture accurate cost and quantity	*2, 3,4,5,6,7,9,10,11,14*
	visual possible design errors	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
	client is satisfied	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
C10: Automatically quantification for BQ preparation	quantity accurately generated	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
	save time from manual measurement	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
	more time for cost estimation	*2,3,4,8,9,10,11,12,14*
	avoid human mistake	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*
	save measurement in model	*1,2,3,12,14,15*
	client is satisfied	*1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15*

Each capability is discussed as follows:

a) Cost appraisal can be prepared quickly at feasibility stage (C1)

This capability does contribute in improving quality performance with better client satisfaction, as outlined by 14 interviewees. Feasibility stage is crucial for client to make decision pertaining to the project. It is the critical stage which has major effects on the later stage. Cost appraisal and professional advice from the QS are indispensable at this stage. Client needs them to evaluate the feasibility of the project and deal with their management team to get funding, approval, or other matters.

BIM has the capability for QSs to prepare cost appraisal quickly at this stage. BIM expedites the whole process of preparation and allows the client to get to know the indicative budget to confirm that the design is feasible and in alignment with the proposed budget and schedule of the project. Immediate feedback is beneficial at the early stage as it has the greatest impact on the eventual project performance. As quoted from interviewee 6:

"…in this early crucial stage, along the way, if anything goes wrong, we can amend, we try to fix and make sure things are in order before it goes to construction, therefore the client pays more attention at this stage to evaluate the feasibility of the project, as BIM has the capability for us to get the indicative cost, which will facilitate them in decision making, they will be satisfied…" (Interviewee 6)

Most of the interviewees claimed that project client always wanted to know the indicative budget within a shorten time. Most of them face difficulty in getting accurate quantity and lack of time for searching costing information. With BIM, QSs can quickly provide cost feedback that allows the clients to plan early. By doing so, the client is satisfied when he/she receives the cost appraisal on time and focuses on planning issue. Interviewee 3 addressed:

"…client relies on our cost appraisal to make decision, wrong advise and wrong decision made, late information received and late decision made, which affect the whole project progress; so with BIM, we can obtain the quantity faster, providing them with more costing information, so that they can make their decisions in certainty and faster.." (Interviewee 3)

b) <u>Preliminary cost plan can be prepared by extracting quantities directly from the model (C2)</u>

It was found that all interviewees highlighted that C2 does contribute in improving quality performance with better client satisfaction as cost plan quantities can be extracted accurately by using BIM. By getting accurate cost plan with complete breakdown, client gets to know the cost allocation for each building elements. As explained by interviewee 3:

"…cost plan is important for the client, once you prepare cost plan by using BIM, it is faster and accurate. It is for them to know the cost exposure, the anticipated cost, the cost breakdown for each element. It is also for their planning within the overall parameter, the client can manipulate the figure, but still comply to the bottom line figure, as certain elements has the allocation…" (Interviewee 3)

Interviewee 2 shared the experience of using BIM for cost plan preparation and it satisfied the client when the client viewed the 3D model. Interviewee 2 stated that:

"…I just completed the cost plan by using BIM. When we presented the model to our client to show what was covered under the cost plan, the client was satisfied as they were able to see to know the whole picture…" (Interviewee 2)

Once the cost plan clearly indicates the cost limits for each building elements, client is aware of the cost of each elements for cost control and planning. It reduces uncertainty and contingency that may occur to the project. Therefore, client is satisfied when they are aware of the cost information for the project. Interviewee 7 claimed that:

"…Clients are satisfied as they can receive the accurate cost plan earlier for decision making and planning, they can know what's inside the project and have further planning..." (Interviewee 7)

c) Easily update cost plan more details as design is developed (C3)

All interviewees concurred that C3 does contribute in improving the quality of performance with better client satisfaction. As highlighted by the majority of the interviewees, cost plan tends to be updated frequently as design is developed into details. Design changes might affect client's budget and project schedule. By using BIM, quantity is automatically generated whenever the design is developed, and QSs are able to update the cost plan each time there is a change. As addressed by interviewee 3:

"….we can spot the changes virtually when the drawings are superimposed, we will know the difference, as the quantity generated by BIM is easier for QS, speedy, and ease of generating and updating cost plan every time, so you can monitor the cost at a rapid interval…" (Interviewee 3)

It is important for QSs to update the cost plan whenever changes occur to ensure the project cost is kept to date with the latest design. The purpose is to make the client aware of the cost changes at the earlier stage which allows them to make early decision and planning. As explained by interviewee 6:

"…every single amendment affects time and cost, by updating cost plan faster and accurately by using BIM, we can advise the client accordingly, as the client can see the impacts, and from there, another decision can be made based on our updated cost plan…" (Interviewee 6)

Thus, cost plan is updated faster and accurately as design is developed with BIM. As design is being developed, QSs are able to confirm that the evolving design stays on-track. QSs can monitor and control the cost by ensuring that the changes still comply with the bottom figure of the project. The client is satisfied if they are kept updated about the cost plan breakdown in relation to their budget and targeted completion time. Thus, less uncertainty may happen during construction which may affect the project performance. Quote from interviewee 7:

"…client is satisfied once they know what the cost covers, and what they want, but if you are unable to update the cost plan, the costing may still be in an initial stage, and whatever changes you have not picked up, perhaps the consultants have changed to

something very expensive, but you do not update it accordingly. When it comes to construction, the client does not have the budget and this could affect the project outcome…" (Interviewee 7)

d) Easily generate accurate cost estimate for various design alternatives (C4)

C4 does contribute in improving quality performance with better client satisfaction, as highlighted by all interviewees; whereby with various design alternatives, client can make evaluation, and subsequently, choose the right approach that suits to her/his goal. These options can be analyzed by QSs in terms of both cost and time by using BIM. It increases client satisfaction as it contributes to the decision making process based on these options. It helps in identifying ways to improve project performance and closer alignment to the client's objectives. Based on quick alternatives generation, QSs can develop a better understanding of time and cost with project clients to evaluate the alternatives.

In addition, a majority of the interviewees highlighted that clients tend to request different design alternatives. They would like to know the cost for comparison and choose among the options to discover what performed best among the options that best fit their requirements. By using BIM, QSs can get the quantity faster and accurately, in turn they can advise the client on the options. Clients are satisfied as they can identify the benefits or the consequences on various design options in order to select the most suitable and the most cost efficient proposals. Besides, early design assessment on various options to ensure client's requirements is met. Interviewees 3 and 6 stated that:

"...by using BIM for options study, they can choose the most efficient approaches that suit to his/her budget, time, etc…" (Interviewee 3)

"…By considering various cost options at the early stage, client can go for better option which does not only save his/her budget, shorter the construction period, but also with better quality of the building…" (Interviewee 6)

e) <u>Cost implication of design changes can be generated easily without manually re-measurement (C6)</u>

It does contribute in improving quality performance with better client satisfaction, as pointed out by all interviewees; whereby by knowing the cost implication of the changes earlier via BIM. Clients emphasize on the cost implication of design change. By using BIM, QSs can get the quantity faster and prepare cost implication for the clients. With that, QSs can highlight the implication earlier to the client and advice accordingly before it incurs extra costs at a later stage. Hence, it ensures client satisfaction.

Getting to know the cost implication is crucial as it may affect the cost performance. Client can know the cost difference due to the changes, whether it's within or over their budget, as they bear the cost. From that, the client is able to make decision and identify a solution before it brings negative impacts on the project. Interviewees 3 and 7 mentioned:

"...client deserves the right to know the cost implications, for cost monitoring, checking and balancing..." (Interviewee 3)

"…we have to inform the clients about the cost implication of changes, whether is it viable for the changes. It ensures their satisfaction by knowing the changes and its effect on cost at this early stage, as it will facilitate their decision making, either they want to change or stick to the original plan…" (Interviewee 7)

f) Clash detection reduces design errors and cost estimates revisions (C7)

All interviewees outlined that C7 does contribute in improving quality performance with better client satisfaction; it offers QSs a unique early insight into important design characteristics and assists in identifying flaws. By identifying clashes and constructability issues in the early stage before they occur in the construction stage, it reduces variations and mistakes that may affect the project time and cost. Clients will be satisfied if there is no additional cost or time that could affect the progress of the project.

Furthermore, some interviewees pointed out that variation due to design clashes is one of the issues that affect client satisfaction. It brings negative impacts on cost and time which could lead to project delay and burst in the budget. A majority of the interviewees had experiences of big amount of variation order and it made the client dissatisfied. As shared by interviewee 3:

"…currently we have a project, the contractor performed the clash analysis by using BIM during the construction stage, the analysis detected many clashes and these clashes caused millions of ringgit variation which make the client dissatisfied with the additional cost; if all these clashes can be detected before construction, all these problems and dissatisfaction can be avoided…" (Interviewee 3)

In addition, most interviewees stated that it is inevitable to perform clash detection during pre-construction stage. By identifying all the problems earlier, it can ensure project performance without any variation due to design clashes. As affirmed by interviewee 6:

"...clash detection is very important for cost assurance, as it should be performed before tender out, one must do it earlier and sort out these things in order; if you fail to detect it earlier, and once it enters the construction stage, then suddenly you find out about the clashes, the work stops, one must wait for clarification or to get information, get approval, time is dragged, and cost is badly affected which will affect client's satisfaction…" (Interviewee 6)

However, with BIM, QSs can pre-identify the discrepancies before the construction stage. Some interviewees highlighted that the project would continue smoothly with less variations. With that, the client is satisfied with the performance of the project. As commented by interviewees 14 and 13:

"...it does help the QSs to look carefully on the whole design structures before the building starts to construct, when we highlight the clashes to the consultants and notify the client, the client is aware that we have pre-identified all these discrepancies before the construction..." (Interviewee 14)

"...when we view the model, we can know exactly what will happen during the construction stage, we can identify the clashes and inform the consultants to revise, we can also notify the client regarding this, hence, the client is satisfied as we rectify the problems before it leads to costly delays and rework.." (Interviewee 13)

g) Cost checking can be performed quickly to ensure all items are captured (C8)

This capability does contribute in improving quality performance with better client satisfaction, as acknowledged by all interviewees. QSs can complete cost checking with confidence to avoid missed out items. It reduces mistakes and surprises during the construction stage.

According to the majority of the interviewees, missed out item is a very big mistake which can affect the project time and cost. Many clients have complaint and are dissatisfied with it. Nonetheless, with BIM, this risk can be minimized and it increases client satisfaction. As quoted from interviewee 11:

"...It reduces the risk of missing out elements. With BIM, you can avoid this before the construction stage which may cause a big variation that can influence on time and cost; so client is more satisfied when QSs can avoid all these problems, by ensuring that all elements have been captured." (Interviewee 11)

As highlighted by interviewee 14, QSs have to study and takeoff three different sets of drawings. After that, they have to double check the three different sets of drawings to make sure that they have captured all the elements. This process is tedious and daunting. Using BIM expedites the checking process and most importantly, visual checking builds confident among the QSs and also the client. By presenting it to the client, the client is satisfied. As explained by Interviewee 2:

"...after we have completed the measurement in the model, everything that is tackled by us will be shown in the model, we can visual it for checking and also show to

client, as they can view our measurements and they will understand better, they are satisfied with our performance because they themselves can view it clearly." (Interviewee 2)

h) <u>Improve visualization for better understanding of design (C9)</u>

All interviewees verified that C9 does contribute in improving quality performance with better client satisfaction. It is difficult to interpret design in the conventional 2D drawings. However, BIM bring benefits to QSs by letting the visual of the building in detail to improve visualization. Once QSs obtain good visualization with BIM, the client is satisfied as QSs can capture accurate quantity and costing. With better understanding, QSs can provide advice to clients to enhance the project performance. Interviewee 2 mentioned that:

"…once we have the understanding via visualization and capture the quantity and cost accurately, it builds our confidence, we can explain further and clearly to the client, the client will be satisfied as they obtain advise correctly about the project…" (Interviewee 2)

Moreover, visualization allows QSs to understand and to evaluate these building structures to see how they assemble together. They can identify possible discrepancies of the designs at the early stage. By doing this, QSs can clarify and rectify the design errors with project teams, instead of having to rework in the later stage. Besides, clients are satisfied if QSs manage to identify the possible conflicts that may arise during the construction by using BIM visualization. It minimizes the change orders during construction which saves time and cost. As quoted from interviewee 14:

"…BIM visualization is very useful, QSs can see what are measured, understand the design, detect any discrepancy, visual carefully on whole building structure before the construction; client is satisfied when QSs can pre-identify all these problems…" (Interviewee 14)

i) <u>Automatically quantification for BQ preparation (C10)</u>

C10 does contribute in improving quality performance with better client satisfaction, as claimed by all interviewees. Doing manually, QSs spend much time on taking off. The manual way is prone to errors and time consuming which increases the risk of affecting the project performance that may cause dissatisfaction to the client. Formerly, the client is dissatisfied with QSs' performance that spends too much time on quantification. However, tedious taking off is now taken care by BIM with automatic quantity generation. As the building design is firm and details are accurately modeled, quantity takeoff can be extracted from the model. QSs have more time for estimating, plan for contingency, and consider the labor and material for all building elements which can enhance the cost accuracy. Quoted from interviewee 4:

"…QSs spend less time in doing measurement, they have more time in performing estimating and cost analysis, project cost is more accurate, and definitely the client is satisfied…" (Interviewee 4)

Some of the interviewees presented the measurement model to the clients and obtained positive comments. Moreover, BIM helps the QSs to takeoff quantities and save in 3D model, whereby everyone can have a realistic depiction of the project. It gives visibility and also confidence for QSs and clients. QSs are no longer limited to the

2D presentation in conventional plane, black and white drawings. From that, clients are able to quickly and effectively understand the project. Hence, clients can rely on the QSs' advice with confidence and satisfaction. As shared by interviewee 12:

"…clients are more confident on our measurement when they view our measurement in 3D, as the quantity is automatically generated by BIM, and human errors are cut down..." (Interviewee 12)

In conclusion, all interviewees acknowledged that these capabilities have significant relationship towards quality performance during the interview session. Hence, the interview results validated the correlation and the regression analyses result between BIM capabilities and project quality performance. Therefore, QSs must take into account these BIM capabilities in their practice to enhance the project quality performance.

7.3 Discussion of the Overall Results

Overall, the interview results validated the questionnaire survey results by ascertaining QSs' views concerning the BIM capabilities and their relationship with project performance. In this research, the experiences of interviewees by using the identified BIM capability for construction project have been reported to provide more concrete information on the relationship identified between BIM capabilities and project performance. The findings from the interviews highlighted that BIM has the capabilities to enhance the QS's performances by taking away tediousness and laborious tasks.

The top BIM capabilities ranked by the questionnaire respondents were validated by the interviewees based on their experience of using BIM in projects. A majority of the interviewees highlighted that BIM application reduces mistakes, enhances accuracy, and shortens the time taken for completing tasks as compared to conventional method. The capabilities of BIM in quantity surveying have been stressed during the interview. For instance, QSs can gain visualization faster through 3D visualization capability (C9) before quantity takeoff. Less time is spent on getting understanding on a design. Another example is time taken for quantification is reduced due to the capability of automatic BQ quantification (C10) during BQ preparation. QSs have more time to spend on checking and estimating which could improve their professional services. Hence, it has been confirmed that the implementation of BIM capability in quantity surveying practice can enhance the performance of QSs.

As for correlation and regression results, all of the interviewees have acknowledged that there is a relationship between BIM capabilities in quantity surveying practice during the pre-construction stage and project performance for time, cost, and quality aspects. For instance, design clashes can be costly, but normally are not discovered until construction is progressed. At the construction stage, rework and demolish works can cause financial burden and time delay which affect the project performance. However, the BIM capability of clash detection (C7) during the pre-construction stage allows QSs and project team to identify design errors in the early stage which can reduce time, construction cost, and ensure completion of a quality construction project. Thus, the identified BIM capabilities have an impact on project performance. The interview session depicted that when QSs adopt BIM in their practice; it in turn appears to result in better project performance. Overall, the identified BIM capabilities and their relationships with project performance for time, cost, and quality aspects were developed in a relationship framework, as depicted in Figure 7.1. By organizing the identified relationships into a framework, BIM capabilities and their relationships with project performance are made more accessible and obvious to the QSs for reference and understanding.

The literature review highlighted that prior studies of the impact of BIM application on project performance have been observed by several authors (Suermann and Issa, 2007; Griffis et al., 1995; Fischer and Koo, 2000; Eisenmann and Park, 2012; Parvan, 2012; Sacks and Barak, 2008; Sun and Zhou, 2010; Yang et al., 2007). The focus of the previous researches was mainly on the overall BIM application and its impact on project performance, but lacked of concentration on the pre-construction stage and also quantity surveying profession, which could make the QSs unaware of the benefits of their involvement in BIM application and its relationship with project performance. Compared to these previous studies, this study was concerned about the lack of study on the impact of BIM capabilities in quantity surveying practice during the pre-construction stage on project performance to examine the relationship. The objective within this research had been to address this aspect by focusing on quantity surveying profession in order to further discuss the capabilities of BIM in quantity surveying practice during early stage with an impact on the project performance. The lack of study on the relationship could make it difficult for QSs as increased awareness on BIM capabilities has been highlighted by several scholars (Pittard, 2011; RICS, 2011; Alufohai, 2012; Nagalingam et al., 2013) as a prior step of BIM application. Besides, this research examined how BIM application could help the QSs in a project by studying the relationship, as urged by Wang et al. (2014) due to few studies focused on the potential of capabilities of 5D BIM in a project.

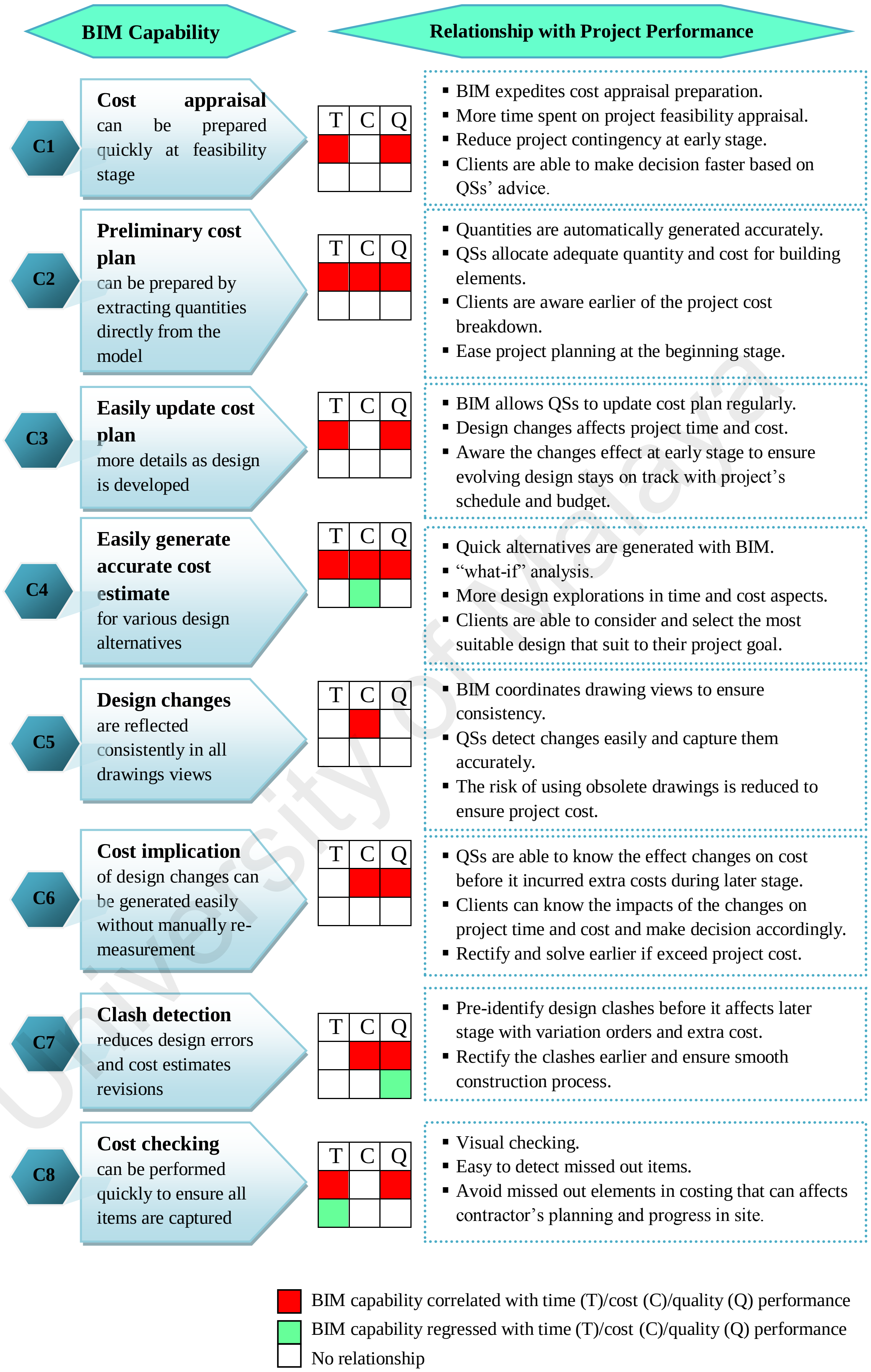

Figure 7.1: Relationship Framework of BIM Capabilities in Quantity Surveying Practice and Project Performance

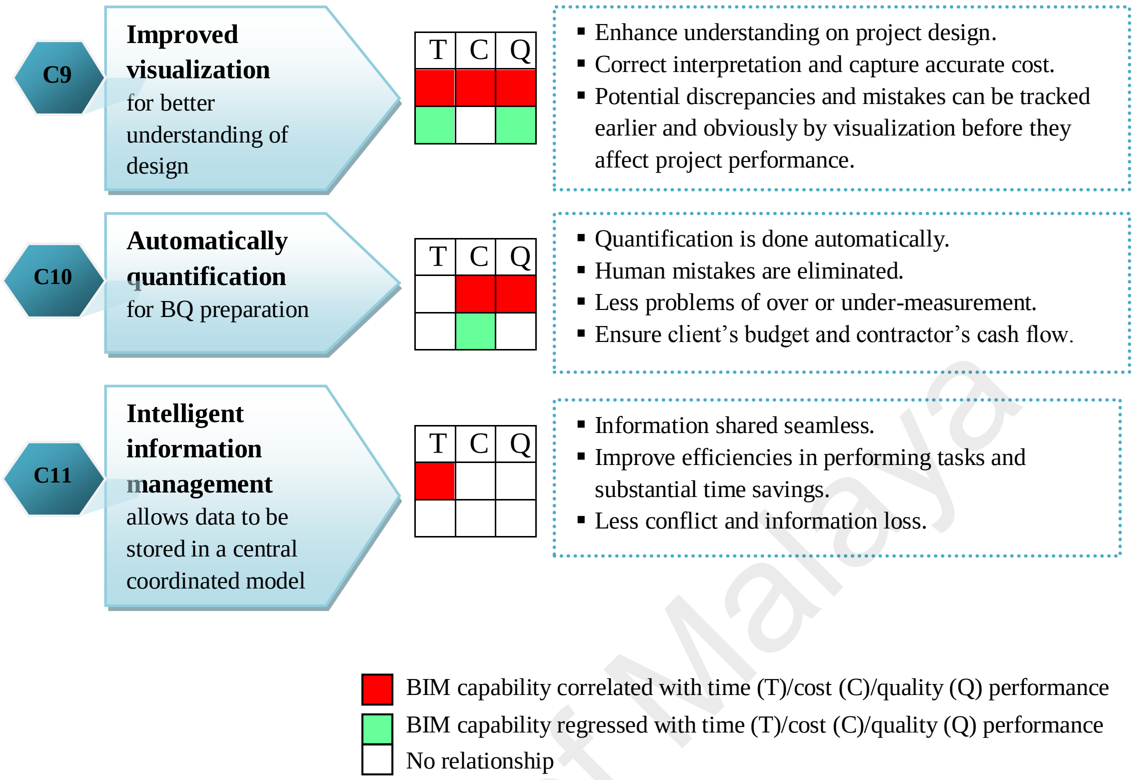

Figure 7.1: Relationship Framework of BIM Capabilities in Quantity Surveying Practice and Project Performance (continued)

In addition, a previous study by Alshanbari (2010) had identified that cost saving was achieved when BIM was adopted in a 4D aspect for planning during pre-construction stage. However in this research, it was found that project performance in terms of time, cost, and quality improved when QSs adopted BIM capabilities in their practice during the pre-construction stage. This research provided an empirical evidence of the relationship between BIM capabilities in quantity surveying practice during pre-construction stage and project performance. The results have lent support to the suggestion that by adopting BIM in quantity surveying practice during the pre-construction stage, QSs can perform efficiently, and the project performance is more likely to enhance. Hence, BIM adoption in quantity surveying practice during pre-construction stage is one key practice that is necessary to improve project performance. It is due to more effort spent during the pre-construction stage, which is critical to improve project performance in terms of time, cost, and quality (Gibson and Hamilton, 1994; Sullivan et al., 1997) than efforts undertaken after the project has begun. Moreover, it has been noted that this early stage has the major influence on the project's cost, time and quality outcomes. Many crucial decisions are made during this early stage as the impact of these decisions made early is usually greater than during later stages (Ahuja, 1994).

When QSs adopt BIM for practice, many decisions can be made at the early stage based on their professional advice, which ultimately have significant impact on the project outcome. Thus, it is essential to adopt BIM among QSs during this early stage. QSs gain efficiency in performing their work with BIM during the early stage, and it has an effect on the project performance. This leads to a more efficient project that stays on budget and schedule. This aligns with Aibinu and Venkatesh (2012) who asserted that BIM enhances the accuracy in quantity takeoff that would influence cost estimating and also other services performed by the QSs, which in turn have positive implications for a project as a whole. Thus, a relationship framework was established to present the relationships between BIM capabilities in quantity surveying practice during pre-construction stage and project performance for time, cost, and quality aspects. QSs should focus on these identified BIM capabilities to further streamline their roles. Furthermore, it creates better overall project outcomes for the project.

7.4 Summary of Chapter

Semi-structured interviews were conducted and analyzed to validate the results of questionnaire survey. Overall, the results for ranking, correlation, and regression analyses were validated through interviews. The relationships between BIM capabilities in quantity surveying practice and project performance had been confirmed by the interviewees who adopted BIM in their projects. Therefore, the results were deemed valid and reliable. The relationships between BIM capabilities and project performance were further developed into a relationship framework. The conclusion of the research is discussed in the next chapter.

CHAPTER 8

CONCLUSION AND RECOMMENDATIONS

8.1 Introduction

This final chapter concludes the overall findings and summary of the study to achieve the research aim and objectives. The chapter begins with a summary of the overall research chapters to discuss the overall research findings in meeting the research objectives. Contributions to the knowledge are highlighted and are recommended to be applied in the industry. In the later part of this chapter, limitations of the research are highlighted and recommendations for future research are suggested.

8.2 Overall Chapters Summary

The fragmented nature of the construction industry has resulted in poor performance of the project in the construction industry, especially in the cost aspect. Poor cost performance in the construction industry has been documented in numerous studies (Puspasari, 2005; Baloi and Price, 2003; Olatunji et al., 2010a). Quantity surveyor (QS) is the key person who provides cost management services in the construction industry. However, their method of performing tasks by using manual method or relying on 2D-based documents is fraught with human error and often leads to inaccuracies in costing which affect project performance. As stressed by several authors (Aibinu and Pasco, 2008; Peeters and Maduss, 2008), one of the factors for project failures in the construction industry is due to inaccurate estimates. Hassan (2010) suggested that quantity surveyors (QSs) should move away from old methods to gain competitive advantage in their professions.

The application of BIM has been identified as a potential solution to eliminate such poor performance resulting from the traditional manual practice. As discussed in **Chapter 2**, there are some unique features of BIM that differ from the traditional 2D CAD and manual method. It has a set of features that provide many capabilities for the project participants during the project life cycle. By using BIM in the construction industry, it is believed to rectify the inefficiency of the traditional paper-based system and to improve project productivity. The benefit of using BIM has been dominated in the phases of design, construction, and maintenance. However, the capability of BIM in quantity surveying practice is limited and scarcely discussed which result in low adoption among this profession.

This research was initiated with the review of literature that revealed the low adoption of BIM, especially in the quantity surveying practice as discussed in **Chapter 3**. Although BIM application has proliferated in the construction industry, relatively little attention has so far been drawn to its capabilities in the quantity surveying practice. Most of the existing studies have focused on BIM application in design perspective. How BIM application can assist the QSs in a project have not been investigated yet (Wang et al., 2014). Furthermore, reviewing the literature revealed that limited study had focused on BIM capabilities in quantity surveying practice and also on project performance. The effect of BIM adoption by QSs during pre-construction stage on project performance has not been investigated. This has resulted in low awareness among QSs which causes slow adoption. Hence, this research focused on studying the relationship between BIM capabilities in quantity surveying practice during pre-construction stage and project performance in time, cost, and quality aspects. Understanding how BIM adoption in quantity surveying practice affects the project performance is important. With regard to this, the relationships between the BIM capabilities and project performance had been developed into a relationship framework to facilitate understanding and awareness among QSs.

In order to examine the relationship between BIM capabilities in quantity surveying practice during the pre-construction stage and project performance, a sequential mixed method of quantitative questionnaire survey and qualitative interview approach was used to achieve the research aim and objectives. For this research, a four-phased research approach was designed, as described in **Chapter 4** to guide the data collection and analyses. In the first phase, literature review was conducted to identify the BIM capabilities in quantity surveying practice. In order to identify the capabilities of BIM in quantity surveying practice, RIBA Plan of Work 2013 was used as a template to understand the tasks provided by the QSs and also to identify the BIM capabilities following the plan of work. Through literature review, 11 BIM capabilities were found to be associated with project performance and a conceptual framework was formed, as demonstrated in **Chapter 3**. Moving to the second phase of the research, a preliminary interview was conducted with 8 QSs. All the 11 BIM capabilities obtained from the literature were confirmed by the interviewees. Findings for the preliminary interview were reported in **Chapter 5**. Ultimately, a list of BIM capabilities was complied through a combination of literature review and preliminary interviews.

Meanwhile, in the third phase of the research, questionnaire survey was designed and was pre-tested by conducting content validity, face validity, and pilot study. Subsequently, the questionnaire survey was refined. Sampling determination is important as not all quantity surveying organizations adopt BIM for practice. Thus, phone calls were made to 318 quantity surveying organizations and also BIM vendors to identify the organizations that adopted BIM into practice. The final questionnaire survey was then distributed to 131 quantity surveying organizations after sampling determination. A total of 64 responses were received which generated a response rate of 48.9%. Besides, several tests were performed via SPSS. BIM capabilities were ranked using RII. Correlation between BIM capabilities and project performance was determined by using Spearman correlation. The results showed that 7 BIM capabilities were correlated significantly with time performance; 7 BIM capabilities correlated significantly with cost performance; and 9 BIM capabilities correlated significantly with quality performance. On the other hand, the results of logistic regression demonstrated that 2 capabilities affected the project performance for time, cost, and quality aspects respectively. **Chapter 6** presented the findings of the survey.

In **Chapter 7**, semi-structured interview was carried out at the last phase of the research to validate the results retrieved from the questionnaire. 15 QSs who adopted BIM in their practices were interviewed. The interviews were conducted to discuss the interviewees' experience of using BIM capabilities in their practice and project. The discussion focused on the impact of BIM capabilities in quantity surveying practice on project performance for time, cost, and quality aspects by ascertaining the views of the interviewees. Their experiences and views of using these BIM capabilities in project were then compared with the quantitative results for validation purpose. Findings from the interviews revealed that all the relationships identified through quantitative results were validated. A relationship framework was developed to indicate the relationship between the BIM capabilities and the project performance. In conclusion, BIM capabilities in quantity surveying practice during pre-construction stage had significantly influenced the project performance. This is because planning can be performed earlier and changes or mistakes can be identified earlier in the model as those changes are cheaper to effect on a BIM model than on the construction site. By adopting BIM in quantity surveying practice at the early stage, the project performance is enhanced. Hence, as mentioned by Yin and Kun (2013), BIM application in cost management aspect is an important tool due to increasingly complex projects, tightening budgets, and constraining duration of a project.

Next, the conclusions from the research related to the research objectives are discussed in the following subsections.

8.2.1 Objective 1: To identify the BIM capabilities in quantity surveying practice

It had been observed that BIM application brings tremendous benefits to the QSs in their practice. It has the capability to take away the tedious and the laborious works of QSs. The identification of BIM capabilities was completed through a detailed review of literature. Overall, there were 11 BIM capabilities in quantity surveying practice during the pre-construction stage. The 11 BIM capabilities as follows:

i. Cost appraisal can be prepared quickly at feasibility stage (C1).

ii. Preliminary cost plan can be prepared by extracting quantities directly from the model (C2).

iii. Easily update cost plan more details as design is developed (C3).

iv. Easily generate accurate cost estimate for various design alternatives (C4).

v. Design changes are reflected consistently in all drawings views (C5).

vi. Cost implication of design changes can be generated easily without manually re-measurement (C6).

vii. Clash detection reduces design errors and cost estimates revisions (C7).

viii. Cost checking can be performed quickly to ensure all items are captured (C8).

ix. Improved visualization for better understanding of design (C9).

x. Automatically quantification for BQ preparation (C10).

xi. Intelligent information management allows data to be stored in a central coordinated model (C11).

BIM capabilities in quantity surveying practice that were found from the literatures were then required to be confirmed to reveal the capability of BIM for QSs by conducting a preliminary interview. 8 QSs were involved in the preliminary interview. Each capability is discussed in detail with interviewees for the purpose of validation. Overall, all capabilities were confirmed by the interviewees as BIM capabilities in quantity surveying practice.

8.2.2 Objective 2: To examine the extent to which these BIM capabilities in quantity surveying practice have an impact on project performance

130 questionnaires were sent out to the quantity surveying organization after sample determination and the return rate was 48.9%. SPSS software was used to examine the relationship between BIM capabilities and project performance for time, cost, and quality aspects.

Meanwhile, the BIM capabilities were ranked using RII and the order is: C10 (automatic BQ quantification), C4 (cost estimate for alternatives), C1 (cost appraisal at feasibility), C8 (cost checking), C3 (update cost plan), both C6 (cost implication) and C7 (clash detection) were ranked similar at six, then C2 (preliminary cost plan), C5 (design changes reflected consistently), and both C9 (visualization) and C11 (intelligent information management) were ranked similar at last. Based on the results of correlation analysis as shown in Table 8.1, it was found that 7 BIM capabilities correlated significantly to time performance, which were *C1* (cost appraisal at feasibility), *C2* (preliminary cost plan), *C3* (update cost plan), *C4* (cost estimate for alternatives), *C8* (cost checking), *C9* (visualization), *and C11* (intelligent information management); 7 BIM capabilities correlated significantly to cost performance, which were *C2* (preliminary cost plan), *C4* (cost estimate for alternatives), *C5* (design changes reflected consistently), *C6* (cost implication), *C7* (clash detection), *C9* (visualization), *and C10* (automatic BQ quantification); and 9 BIM capabilities correlated significantly to quality performance, which were *C1* (cost appraisal at feasibility), *C2* (preliminary cost plan), *C3* (update cost plan), *C4* (cost estimate for alternatives), *C6* (cost implication), *C7* (clash detection), *C8* (cost checking), *C9* (visualization), *and C10* (automatic BQ quantification).

Table 8.1: Summary of Correlation Results between Capability of BIM and Project Performance in Time, Cost and Quality Aspect

BIM Capability		Project Performance		
		Time	Cost	Quality
C1	Cost appraisal can be prepared quickly at feasibility stage	✓		✓
C2	Preliminary cost plan can be prepared by extracting quantities directly from the model	✓	✓	✓
C3	Easily update cost plan more details as design is developed	✓		✓
C4	Easily generate accurate cost estimate for various design alternatives	✓	✓	✓
C5	Design changes are reflected consistently in all drawings views		✓	
C6	Cost implication of design changes can be generated easily without manually re-measurement		✓	✓
C7	Clash detection reduces design errors and cost estimates revisions		✓	✓
C8	Cost checking can be performed quickly to ensure all items are captured	✓		✓
C9	Improved visualization for better understanding of design	✓	✓	✓
C10	Automatically quantification for BQ preparation		✓	✓
C11	Intelligent information management allows data to be stored in a central coordinated model	✓		

Meanwhile, three logistic regression models were produced in this study, as depicted in the following:

P [time]: Z = -10.015 + 2.761 (C8 - cost checking) + 1.609 (C9 - visualization)

P [cost]: Z = -16.305 + 1.987 (C4 - cost estimate for alternatives) + 3.985 (C10 - automatic BQ quantification)

P [quality]: Z = -6.804 + 1.381 (C7 - clash detection) + 1.786 (C9 - visualization)

These regression models show the linkages of the BIM capabilities and project performance which can be used to predict the likelihood of project performance (good or poor) when QSs adopted BIM in their practices. The results demonstrated that BIM capabilities of C4 (cost estimate for alternatives), C7 (clash detection), C8 cost checking), C9 (visualization), and C10 (automatic BQ quantification) affected the project performance for time, cost, and quality aspects.

In conclusion, BIM capabilities had been significantly associated to the performance outcome for time, cost, and quality aspects. Taking into cognizance the significant relationship, QSs must consider these capabilities when implementing BIM into their practices. Consequently, the performance outcomes can be optimized and improved.

8.2.3 Objective 3: To establish the relationship between BIM capabilities in quantity surveying practice and project performance.

The relationships were then validated through semi-structured interviews, involving 15 QSs who adopted BIM into their practices. The results of ranking, correlations, and regressions between BIM capabilities in quantity surveying practice and project performance for time, cost, and quality aspects are discussed in detail during the semi-structured interviews by ascertaining the views of the interviewees. In short, all the results were confirmed and were validated by the interviewees. The validation had been made based on the majority experiences encountered by the interviewees during BIM adoption in their practice on a project. According to the interviewees, they have successfully graphed the capabilities of BIM which were enabled in their practice during early stage and the project performance was enhanced. Hence, the relationships between BIM capabilities and project performance were validated and were established in a relationship framework. The linkages between BIM capabilities in quantity surveying practice and project performance indicated that implication of BIM adoption by QSs at the pre-construction stage improved the project performance.

8.3 Contributions to the Knowledge

The benefits of adopting BIM are widely discussed in the construction industry especially in design practice by previous studies. Nevertheless, this research studied the BIM capabilities in quantity surveying practice by focusing on QSs. This research had filled the current knowledge gap of BIM application in quantity surveying practice due to limited studies. As urged by several scholars on the essential of increasing the awareness of BIM application among QSs, hence creating awareness is clearly a pre-requisite for the development of BIM adoption in quantity surveying practice.

This research has identified the capabilities in quantity surveying practice. It provides empirical evidence on the capabilities that were brought by BIM in quantity surveying practice. This research has brought attention in the BIM research field and also the construction industry on the importance of adopting BIM in quantity surveying practice to raise awareness. A list of 11 BIM capabilities in quantity surveying practice during the pre-construction stage was identified. This research has listed it to show the capabilities that could be obtained through the BIM application in quantity surveying practice. The application of BIM during the pre-construction stage is abundant for QSs if compared to the traditional methods. Thus, it is critical that QSs should understand how BIM applications can enable competitive advantages and allow them to perform excellently in their practices. Besides, QSs can leverage the results of the study to better understand BIM capabilities in their practice and adopt them to gain the benefits of BIM capabilities. Ultimately, this research recommends the QSs to be involved themselves in the implementation of BIM by focusing on these capabilities.

Furthermore, the main intention of the research had been to show how the project performance can be related and affected by the BIM capabilities in quantity surveying practice during the pre-construction stage. Statistically significant relationships between BIM capabilities and project performance for time, cost, and quality aspects were identified and validated through the experience of QSs on BIM adoption in their practice. The findings from this study contribute to the empirical research on the relationship between BIM capabilities in quantity surveying practice and project performance by consolidating them in a relationship framework. It adds to the recent literature by linking BIM capabilities in quantity surveying practice and project performance. By referring to the relationship framework, it can be a deciding factor for QSs to get involved in BIM application for better project performance. Thus, this research brought up the insight that by considering the BIM capabilities in the early stage, most of the problems affecting the performance can be identified and solved before the construction stage begins. This in turn ensures a smoother run of the project and fewer obstacles after the start of the construction. The contribution of the research is related to whereby adopting BIM and taking into account the identified BIM capabilities in quantity surveying practice at the early stage is way more effective to optimize the project outcome. Thus, the relationship framework is useful in governing project performance by contributing a practical approach to QSs by focusing on BIM capabilities in quantity surveying practice and the relationships to facilitate implementation.

In practical fields, the relationship framework that had been developed in this study can assist the professional body, government or software vendor to promote the BIM capabilities in quantity surveying practice, which in turn increase its adoption among QSs for better project performance. It provides evidence that application of BIM in quantity surveying practice does matter in the quest for project performance improvement through the experience of interviewees. Nevertheless, BIM application cannot completely offer its benefits by sole commitment of other project participants without the involvement of QS in its implementation. It requires participation of QSs in the application to enhance project outcome. Thus, the relationship framework developed can be utilized to be disseminated in the construction industry to gain understanding of BIM capabilities and the impact of BIM application among QSs on the project performance. In fact, the relationship framework in this research has been requested by a few 5D BIM vendors for knowledge sharing to promote the application of BIM in quantity surveying practice.

8.4 Research Limitation

Several limitations were encountered while conducting this research, which may influence the result of this research. They were:

i. Capability 11 is not practice yet in the Malaysian construction industry. The industry is still lacking in experience concerning this capability. Most of the quantity surveying organizations have adopted BIM-based software, but not to the extent of sharing information in a common platform between the project participants.

ii. BIM is in its early stages of implementation. Hence, BIM application is not widely used to the full extent in the Malaysian construction industry. A single BIM model that contains all information from different project participants is not apparent within the Malaysian construction industry; instead, project participants use their own proprietary modeling software to create the model for their purpose in an isolated way. There is lack of using a single BIM model in Malaysia, but instead, different types of models are utilized. The adoption of BIM is considered semi-BIM; as the interoperability is still absent in the Malaysian construction industry. Hence, this research is limited to discuss the BIM capability in this approach.

iii. For many projects that involved using BIM as discussed by the interviewees, 3D BIM model was not developed by designers; instead, QSs built up the 3D model by using BIM software for automatic quantity extraction and other capabilities. There are limited BIM-based project that fully utilize BIM by every project parties (architects, engineers, contractors, etc.) in one project to its full extent. Therefore, this research is limited to discuss the BIM projects in this approach.

8.5 Recommendations for Future Research

The research recommends further study in the following areas:

i. BIM capability in quantity surveying by focusing the post construction stage. Further researches can be carried out in identifying the relationships between the BIM capabilities during post construction stage and project performance.

ii. A comparison between BIM practice and traditional practice in case studies will be ideal to measure the job performance of QSs. The relationship between BIM application and job performance can be further studied to better understand how BIM adoption enhances job performance of a QS.

iii. Further researches such as case studies can be undertaken for BIM adoption on individual projects to discover the extent to which capabilities of BIM in quantity surveying practice are contingent upon specific project characteristics, such as project type, size, value, and complexity to refine the relationship framework.

iv. A similar study can be carried out in other geographical area as BIM application in Malaysia is still in its developing stage. Comparative study is suggested to further refine and improve the relationship framework. However, it is noted that the research outcomes might be varied due to the contrasts in terms of culture, practice, environment, and other factors.

v. The logistic regression models developed can be used for further research for prediction purpose to predict the project performance in time, cost and quality. Further testing and investigations are envisaged following the collection and analysis of data from more completed BIM building projects to increase the sample size. The purpose of the case study is to test the applicability of the developed regression model in practical.

vi. A similar research to cover different scopes of study, such as architects, engineers, contractors, and facility managers can be carried out.

8.6 Summary of Chapter

This chapter presents the overall chapter summary to achieve the aim and the objectives of the study. Contributions of the research have been highlighted. At the end of this chapter, this research highlights the limitations pertaining to conduct of this research, and then, it provides several suggestions for further researches in the future.

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LIST OF PUBLICATIONS AND PAPERS PRESENTED

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2. Wong, P. F., Salleh, H. & Rahim, F. A. (2014). Capability of Building Information Modeling Application in Quantity Surveying Practice. *Journal of Surveying, Construction & Property, 5* (1), 1-13.

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