A FRAMEWORK TO ENHANCE THE ADOPTION OF BUILDING INFORMATION MODELLING AMONGST SRI LANKAN QUANTITY SURVEYING ORGANISATIONS TO INCREASE THE ACCURACY OF PRE-TENDER COST ESTIMATES

ANUSHKA PRASADINI RATHNAYAKE

School of the Science, Engineering and Environment

University of Salford, Salford, UK

Submitted in Partial Fulfilment of the Requirements of the Degree of Doctor of Philosophy

2021

ABSTRACT

For decades, construction projects around the globe have been suffered to complete on budget due to ongoing cost overruns. Accordingly, both developed and developing countries have reported a number of construction projects that have resulted in increased initial project costs. As a result, several studies have been undertaken to investigate the causes of cost overruns and found that inaccurate project cost estimates are a major reason for project cost overruns. Conventional tasks, such as manual quantity take-off, the use of 2D drawings, and a lack of information that are embedded within the process when preparing cost estimates, were found to be challenging to produce accurate cost estimates. Nevertheless, through the use of Building Information Modelling (BIM) many countries, both developed and developing, have been able to prepare accurate cost estimates by overcoming the consequences of conventional cost estimation practices. Many BIM adopted countries have identified drivers and barriers as part of the BIM adoption process and been able to develop BIM frameworks to enhance its adoption.

Many studies indicate that BIM is a buzzword for the Sri Lankan construction industry and placed in BIM level 0. Majority of the quantity surveying organizations are lagging behind of adopting BIM to improve the accuracy of pre-tender cost estimates. Therefore, BIM adoption among quantity surveying organisations has often been criticised, as many have not yet adopted BIM within their practice. Although the literature indicates the importance of a nationally developed BIM framework, Sri Lanka not yet developed a BIM adoption framework by identifying national wide barriers and solutions. Accordingly, this research seeks to explore the issues behind non-BIM adoption to resolve the issue.

This research inquiries into the drivers and barriers to BIM adoption, in order to provide affordable solutions. Thus, a framework if proposed to enhance BIM adoption, by identifying the gaps in BIM adoption (drivers and barriers) and the mitigating actions required to overcome these barriers. And the selection of a specific developing country would permit an in-depth understanding of the process of BIM adoption; thus, Sri Lanka was selected for the proposed purpose of this research.

This study adopts an explanatory, sequential mixed method that applies a questionnaire survey and a semi-structured interview within a case study. The case study and survey data were collected separately in Sri Lanka from June 2017 to January 2018. The collected quantitative data was analysed descriptively and ranked using a relative important index analysis. The qualitative data were analysed using a thematic analysis technique to identify the themes and patterns.

The results show that only a few QS organisations have adopted BIM. Nevertheless, it was found that six major drivers, namely BIM benefits, client demand, professional bodies, BIM-related training, organisational pressure, and BIM education, influence organisations to adopt BIM. Moreover, the use of a BIM model, automated quantity take-off, improved visualisation, improved information management, clash detection and timesaving were the highlighted as the key BIM benefits for QS organisations. In the meantime, the findings further identified the interrelationships between major drivers. Besides, six major barriers were also identified, namely financial, organisational, unawareness, the lack of market demand, the lack of resources, regulatory issues, and sub-factors, which hinder the adoption of BIM. In the meantime, findings further revealed the root causes for each barrier and identified interrelationships between the major barriers. Moreover, mitigating actions to overcome the impact of the barriers and their root causes were also identified. The analysis further showed that some of the empirical findings replicate those in similar contexts reported in the literature for other countries.

A framework was produced and presented at the end of the thesis, which was designed to enable plausible means to overcome the impact of the barriers found. The proposed framework is expected to benefit quantity surveying organisations, architects, and other construction industry-related professionals to evaluate their strengths in BIM adoption (drivers) and to mitigate the impact of barriers that lead to the non-adoption of BIM. It is also expected to benefit construction-related professional bodies, governments, and academics by determining their role in support of BIM adoption.

DEDICATION

I dedicate this thesis to my loving father, Mahinda Rathnayake, and to my loving mother, Thamara Priyani Amarasinghe.

ACKNOWLEDGMENTS

I wish to express my sincere gratitude to all the individuals and organisations who have supported me during my PhD journey.

First of all, I am extremely grateful to my supervisor, Dr Kaushal Keraminiyage, for his continuous support of my PhD study. His patience, motivation, enthusiasm, and immense knowledge and guidance helped me throughout the research and writing of this thesis. I have been amazingly fortunate to have Kaushal as a supervisor. My deepest gratitude also goes to my co-supervisor, Dr. Paul Coates, who has always been there to listen, help, support and provide guidance.

I am indebted to my previous supervisor, Dr Udayangani Kulatunga. I realized from the very early stages that I was so lucky to have Dr Coates and Dr Udayangani as joint supervisors. Towards the middle of the PhD journey, Dr Udayangani left the University of Salford and an agreement was made with Dr Kaushal to become my main supervisor. Your brilliant supervision, encouragement and support made this research continue smoothly and enabled its successful completion. Thank-you.

Very special thanks go to all quantity surveying organisations and experts who have participated in this study by devoting their valuable time. In particular, I would like to thank Mr. Thushara Indika, Rajitha Abeywardhana, Mrs Sarojini and Mr Janaka Mawella for their enormous support during my fieldwork in Sri Lanka. I cannot thank my friends enough - Harshana Ekanayake and Malika Amarasena - who have never allowed me to feel lonely.

Last but not least, I would like to take this opportunity to thank my parents, Mr. Mahinda Rathnayake and Mrs. Thamara Priyani Amarasinghe, my sister Mrs. Samadhi Rathnayake and my brother Mr. Naveen Mullegama for their selfless love and affection at all times. Finally, I would like to thank my teachers, friends and relatives from Sri Lanka for all their love and care.

LIST OF ABBREVIATIONS

AG – Agree

AEC – Architectural Engineering and Construction

AQTO- Automate Quantity Take-off

BDS – Building Description System

BIM – Building Information Modelling

CAD - Computer-Aided Design

CAGR – Compound Annual Growth Rate

DA - Disagree

ESMM - Explanatory Sequential Mixed Method

FW - Framework

GDP – Gross Domestic Product

GLIDE - Graphical Language for Interactive Design

ICT - Information Communication Technology

IQSSL – Institute of Quantity Surveyors Sri Lanka

IT – Information Technology

LOD – Level of Detail

MQTO- Manual Quantity Take-off

NPP – National Physical Plan

PTE – Pre-Tender Estimates

QS – Quantity Surveying

QS’s- Quantity Surveyors

QTO - Quantity Take-off

RII - Relative Important Index

SA- Strongly Agree

SD – Strongly Disagree

SL – Sri Lankan

UK – United Kingdom

USA – United States of America

Contents

LIST OF ILLUSTRATIONS

LIST OF TABLES

1 INTRODUCTION

1.1 Introduction

This chapter introduces the research problem and justifies the need for this research. It outlines the research aim, key objectives, scope, and contribution of the research. Moreover, an outline of the thesis structure is also given.

1.2 Research Background

Cost overruns in construction projects have been identified as a worldwide issue for both developed and developing countries (Anigbogu et al., 2019; Cooray et al., 2018; Hutton, 2019; Malkanthi et al., 2017). Studies have been undertaken worldwide to address the problem and found that inaccurate project cost estimates represent a major reason for cost overruns (Ahady et al., 2017; Anigbogu, 2018; Kotb et al., 2019; Rahman et al., 2018; Thabani, 2019; Wong, 2019). Therefore, accurate cost estimates are fundamental for the successful completion of construction projects.

According to the RIBA Plan of Work, cost estimates are prepared during the pre-tender stage by a consultant quantity surveyor on behalf of the client (RICS, 2014). They give an approximation of the expected project cost and therefore help the client to decide on the feasibility of any construction project (Hassan, 2017). Contractors also prepare cost estimates with a good profit margin during the pre-tender stage, which help to secure the contract (ICE, 2020; Marjuk, 2006). Therefore, the need for accurate cost estimates is vital for the client and contractor. Nevertheless, it is difficult to prepare accurate pre-tender cost estimates due to the challenges associated with conventional practices, such as the lack of coordination, lack of information, inappropriate software usage (MS Excel), different cost estimating methods (unit method, floor area method), poor communication, issues with Manual Quantity Take-Off (MQTO), and the use of 2D drawings (Ghorbani, 2019; Rathnayake & Samir, 2019; Tahir et al., 2018). Thus, managing the effect of conventional practices could increase the accuracy of cost estimates.

Many countries have found the use of modern technologies, such as Building Information Modelling (BIM), improve the accuracy of pre-tender cost estimates by minimizing the impact of convectional practices (Agus et al., 2019; Rathnayake et al., 2019; Saka & Chan, 2019; Ullah et al., 2019). The use of BIM models enables the flow of rich information as it demands that all project members work on the same platform (Bui, 2019) through collaboration. Therefore, it improves the level of communication and coordination among project team members (Abanda et al., 2018). Moreover, the use of BIM models enhances Automated Quantity Take-Off (AQTO) by eliminating the most tedious task, namely MQTO (Vitasek & Zak, 2018). Through adopting AQTO, the quantity surveyor (QS) can save significant time on the typical time-consuming tasks in conventional practice. Therefore, the use of BIM in cost estimate practices has increased in both developed and developing countries.

Several case studies have been conducted in the USA (Gerges et al., 2017; Wang, 2020) Germany (Ali, 2019; Paul, 2018), Denmark (Paul 2018;), the UK (Babatunde et al., 2019; Malleson, 2018; NBS 2019), Australia (ABAB, 2020; Hook, 2019), Hong Kong (CIC, 2019; Hatmoko, 2019), Singapore (NBS, 2019; Ali, 2019) and Canada (Moreno et al., 2019). These collectively indicate that developed countries have already adopted BIM and are experiencing benefits in the field of cost estimating. Cases studies conducted in developing countries, such as India (Paul, 2018; Ahuja et al., 2018), Malaysia (Ali, 2019; Tahir et al., 2018; Ismail et al., 2019), China (Ismail et al., 2017; Song et al., 2018; Cicco, 2018), Indonesia (Hatmoko et al., 2019) and Nigeria (Babatunde et al., 2018; Hamma-Adama et al., 2019; (Onungwa & Uduma-Olugu, 2017), also indicate the use of BIM in the field of cost estimating. Nevertheless, Olawumi and Chan (2019) state that, compared to developed countries, the adoption of BIM among developing countries seems to be slow. A recent study conducted by Girginkaya and Maqsood (2019) ranked the USA in first place in terms of BIM adoption. Moreover, Europe ranked second while the Middle East was ranked third. Africa and Asia were ranked in fourth and fifth places respectively, which indicates that BIM adoption among developing countries lags compared to developed countries.

Even though many Asian countries, such as China, India, Malaysia, Indonesia, Thailand and Myanmar, have reported some BIM adoption (Ismail et al, 2019), its uptake in Sri Lanka is reported to lag far behind other Asian countries (Gunasekara & Jayasena, 2013; Ismail et al., 2019; Rathnayake et al., 2019; Rathnayake & Samir, 2019; Weddikkara, 2013). Sri Lanka has been undergoing major urbanization and economic development since the end of the civil war in 2009. As a developing South Asian country (IMF, 2012), the construction industry plays a major role in the development and achievement of the goals of its society (OBG, 2016). Construction is one of the largest industries in Sri Lanka and contributes about 8% to the Gross Domestic Product (GDP) (Trading Economics, 2017). However, the industry is complex in nature because it comprises a large number of parties, namely clients, contractors, consultants, stakeholders, shareholders, and regulators. According to the Central Bank (2019), of a total workforce of 6.2 million people, or 6.6%, are employed in the construction sector comprising 51% unskilled workers, 33% masons, 10% carpenters, and 1-2% other skilled workers; moreover, approximately 80% of the workforce is casually employed. Therefore, the performance of the construction industry is a reflection of the economic situation in Sri Lanka (Langford et al., 2008).

A recent survey report indicated that the value of the Sri Lankan construction industry increased at a compound annual growth rate (CAGR) of 8.6% between 2014 and 2018 (ConsTrack360, 2019). The President of the Chamber of the Construction Industry in Sri Lanka declared that the sector should continue to grow for the next 15 to 20 years (Wickremasinghe, 2019). Therefore, the construction industry has established plans to record a CAGR of 16.4% to thus achieve LKR 2,114.3 billion by 2023. Nevertheless, this could be an ambitious target, as the industry is suffering from inaccurate pre-tender cost estimates due to widespread adherence to ongoing conventional practices (Epasinghe et al., 2018; Fernando, 2017; Kumara et al., 2017; Rathnayake et al., 2018; Rathnayake & Samir, 2019). The late adoption of new technologies represents an issue that underpins ongoing conventional practice (Epasinghe et al., 2018; Wijeykoon et al., 2017). As BIM is capable of increasing the accuracy of cost estimates and has gained in reputation across the global context generally and the South Asian region specifically, its application would offer a solution to Sri Lankan quantity surveyors wanting to improve the accuracy of pre-tender cost estimates.

1.3 Problem Statement

Although the construction industries across many developed and developing countries have improved the accuracy of pre-tender estimates by adopting BIM, its uptake among Sri Lankan quantity surveyors remains relatively low (Fernando, 2018; Rathnasiri & Jayasena, 2019; Siriwardene et al., 2018). Ismail et al. (2017) found that, on the Bew-Richards UK BIM Maturity Model of BIM Adoption, the Sri Lankan construction industry was still at phase ‘0’. However, increased interest in the topic of BIM among professionals in Sri

Lanka has been noted, which prompted the BIM Symposium that was held in Colombo in 2017 and organized by the Institute of Quantity Surveyors Sri Lanka (IQSSL). The presentation titled '*Quantity surveyor's pathway to 5D BIM*' and the BIM-based software 'CostX' were introduced to quantity surveyors (IQSSL, 2017). Moreover, since this event, Rathnayake and Samir (2019) have found that the Sri Lankan construction industry is no longer at phase '0' in terms of BIM adoption and has since moved to level '1'. This indicates that the use of BIM has gained momentum among professionals in the industry through increased awareness.

However, a study conducted by Rathnayake et al. (2019) revealed that the majority of quantity surveyors (67%) do not use BIM, meaning that most are not employing BIM within their practice, and only a few are achieving profits through its use. Many countries have succeeded in adopting BIM after undertaking appropriate action to address the barriers. In the literature, few studies have identified barriers to the adoption of BIM industry-wise (Fernando, 2018; Jasanth, 2016; John, 2016; Siriwardene et al., 2018). However, studies to identify the factors affecting the adoption of BIM amongst QS professions have rarely been conducted in the Sri Lankan context. Therefore, the identification of factors affecting both the barriers and drivers along with the mitigating actions from a QS perspective would accelerate the adoption of BIM among Sri Lankan quantity surveying organizations. Moreover, many countries have implemented appropriate actions to overcome the impact of barriers through nationally developed frameworks. Thus, it may not be appropriate to adopt strategies, roadmaps, or even frameworks by developed economies (Gunasekara & Jayasena, 2013), as these frameworks would only be compatible with the level of their construction industries (Rogers et al., 2015). Thus, a nationally developed BIM framework would be a key requirement for the adoption of BIM amongst Sri Lankan QS organizations (Rathnayake et al., 2019; Rathnayake & Samir, 2019; Siriwardene et al., 2018). Therefore, this study intends to develop a BIM adoption framework for Sri Lankan QS organizations to improve the accuracy of their pre-tender cost estimates.

Accordingly, BIM adoption in Sri Lanka was chosen as the central theme for an in-depth study. The justification for this choice is as follows; firstly, compared with other South Asian countries, Sri Lanka is still at the lowest level of development (Gunathilake, 2019). However, the National Physical Plan – 2050 consists of plans to develop a 'Smart Nation' by 2050 (NPP, 2019). Kim (2019) indicates that BIM-based Smart construction represents the best method for Sri Lankans to achieve NPP 2050. Secondly, according to the Global Construction Report (2020), Asia reported the highest BIM adoption rate (46%) compared to other regions. Moreover, the majority of South Asian countries have already adopted BIM within their construction, including India (Amaranath, 2019; Jagadeesh, 2019; Paul, 2018), Bangladesh (Hossain & Ahmed, 2019; Rakib & Rahman, 2018; Silicon Valley, 2020), Bhutan (CDB, 2019), the Maldives (Silicon Valley, 2019; Tholhath & Ibrahim, 2019), Nepal (Dahal, 2019; Pradhan, 2018;) and Pakistan (Akdag & Maqsood 2019; Ali et al., 2018; Farooq et al., 2019). Only Afghanistan and Sri Lanka have not so far reported widespread BIM adoption. However, as Afghanistan has faced more than three decades of war, construction projects are more limited in number compared with the Sri Lankan construction industry (BBC, 2019).

1.4 Aim and Objectives

1.4.1 Aim

This research aims to develop a BIM adoption framework for Sri Lankan quantity surveying organizations to improve the accuracy of pre-tender cost estimates.

1.4.2 Objectives

1. To identify the current status of pre-tender cost estimates and the factors affecting the accuracy of pre-tender cost estimates in Sri Lanka.
2. To evaluate the development of BIM, and the use of BIM to improve the accuracy of pre-tender cost estimates.
3. To identify the BIM adoption drivers and barriers along with mitigating actions to overcome the impact of identified barriers.
4. To develop and validate a BIM adoption framework for Sri Lankan Quantity Surveying firms to improve the accuracy of pre-tender cost estimates.

1.4.3 Research Questions

The following research questions will also guide the development of the BIM adoption framework for the Sri Lankan quantity surveying industry.

1. What are the factors affecting the accuracy of pre-tender cost estimates?

2. How does the use of BIM improve the accuracy of the pre-tender cost estimate process?

3. Why is the adoption of BIM limited to a few QS organizations in Sri Lanka?

4. Why have the majority of QS firms in Sri Lanka not yet adopted BIM?

5. How could the impact of these barriers be mitigated or overcome?

1.5 Scope of the Research

This research focuses on the incorporation of BIM into quantity surveying practice. It examines the quantity surveyor's role, namely cost estimating, and the responsibilities attached to cost estimating practices. However, due to its focus on improving the accuracy of pre-tender cost estimates, it excludes other roles and responsibilities in the quantity surveying profession and other disciplines in the project team. Moreover, the project life cycle consists of two main phases, namely pre-construction and post-construction (Dietz, 2018). According to the RIBA plan of work pre-tender stage consists of preparation and design stages, where cost estimates are prepared and required before construction commences (Rhaman, 2019). According to the RIBA plan of work post tender consists of pre-construction, construction and use. In the post-construction phase, only bills are prepared but not cost estimates (Nichols, 2019). Therefore, this study will only focus on pre-tender cost estimates, so post tender activities will not be assessed. Accordingly, the traditional procurement approach will only be applicable within this study, with the definition selected for PTE in section 2.3. Both civil and building projects will be part of this study, as Sri Lanka faces significant cost overruns in both types of projects.

This research aims to promote and increase the use of BIM within quantity surveying organizations in Sri Lanka, through a developed framework with mitigating actions to overcome the impact of barriers. Therefore, it includes QS practitioners from Sri Lanka, and excludes worldwide QS practitioners, as the results will vary if participants from countries with different economics, culture, law, and political issues are included. Moreover, all mitigating actions along with the barriers are addressed from a QS perspective, which means that the perspectives of other disciplines regarding BIM adoption are excluded. Therefore, the developed framework is only appropriate to the specific usage of this country and will not generalise the practice of BIM adoption across a broad global context. If the same study is conducted with the same targeted population, different countries might have equivalent or distinctive reactions. Thus, the findings could contribute to the body of references and offer a reliable source for similar research conducted in other countries.

1.6 Structure of the Thesis

Chapter 1 introduces the context of the study by presenting the research background, problem statement, aim and objectives, and research scope. Chapter 2 reviews the state of art of cost estimates and identifies the key concepts related to objective one of this study. It provides an overview of cost overruns globally and within the Sri Lankan context. Moreover, it examines the link between pre-tender cost estimates and cost overruns, the importance of accurate cost estimates, and factors affecting the accuracy of pre-tender cost estimates. Chapter 3 reviews the state of art in BIM and identifies the key concepts related to objectives two and three of this study. It provides definitions for the key concepts, explores the link between BIM adoption and accurate cost estimates, BIM adoption in the global context, drivers, and barriers in BIM adoption and the conceptual framework. Chapter 4 describes the methods used in this study, and justifies the philosophical assumptions, methodological choices, research approach, research strategies, time horizon, data collections, and analysis techniques used.

Chapter 5 presents the questionnaire survey data, which is collected to identify the factors affecting the accuracy of cost estimates, and the BIM adoption drivers and barriers. It also describes the procedures adopted, the analysis, and the data interpretation. Chapter 6 consists of the analysis of the case studies in order to identify the factors affecting the accuracy of cost estimates and BIM adoption drivers, barriers, and mitigating actions. The case study background is presented and followed by the analysis of the cases. Chapter 7 presents the findings of the empirical study through a comparison of the results from the questionnaire survey, case studies, and literature review; moreover, it updates the conceptual framework with these findings. Chapter 8 presents the proposed BIM adoption framework to enhance its adoption in Sri Lankan quantity surveying organizations; furthermore, it validates the developed framework. Finally, Chapter 9 presents the conclusions of the study by summarizing the research context and research findings. It also identifies research contributions to the theory and practice of BIM adoption, whilst also noting the limitations of the study and future research directions.

1.7 Summary and Link

This chapter consists of an introduction to the research and has explained the background of the study, the research justification, aim and objectives, and scope. Besides, a summary of the adopted techniques is also explained. The next chapter provides the literature synthesis for objective 1 of this study.

2 PRE-TENDER COST ESTIMATES AND FACTORS AFFECTING THEIR ACCURACY

2.1 Introduction

This chapter reviews and synthesizes literature relating to pre-tender cost estimates and factors affecting the accuracy of such estimates. The chapter is structured as follows: Firstly, pre-tender cost estimation is considered along with the importance of accurate pre-tender cost estimates; secondly, the background of cost overruns globally and within the Sri Lankan context are discussed. Thirdly, the causes of cost overruns globally and within the Sri Lankan context are outlined. Finally, factors affecting the accuracy of pre-tender cost estimates are reviewed.

2.2 Pre-Tender Estimates (PTE)

Cost estimates are prepared during the pre-tender stage and are crucial to determine whether a project is stepped back or continued (Pasco & Aibinu, 2008; AbouRizk et al., 2008; Chandraratne et al., 2019). According to RICS (2014), it is important to know the estimated project cost for two reasons;

1. Whether the client can afford the proposed project
2. It offers a basis for comparison when the tenders are returned (RICS, 2014).

Therefore, once the client has decided to construct a building, the first step is to determine how much would it cost, and this is the point at which the pre-tender cost estimate is prepared. As clients urgently want to know that how much a project would cost, a consultant carries out the final costing on behalf of the client before tenders are received (Odusami & Onukwube, 2008). Nevertheless, authors have defined pre-tender estimates from different viewpoints:

According to Seeley (1996):

> The primary role of estimated or pre-tender estimating is to produce a forecast of the probable cost of a future project before the building has been designed in detail and contract particulars prepared. In this way, the building client is made aware of his likely financial commitments before the extensive design is undertaken.

In comparison, Serpell (2005) defined pre-tender estimates as:

> … the forecasting of project costs that is performed before any significant amount of information is available from detailed design and with still incomplete work scope definition.

According to Aibinu et al. (2011) PTE forecasts the cost of a project during the planning and designing stage. Moreover, Enshassi et al. (2013) defined PTE as "final costing of the work carried out by a consultant on behalf of a client, before tenders are received.". According to the RICS (2014), at a time when a minimum of design work has been produced, pre-tender estimate has to be undertaken under the New Rules of Measurement (NRM) 1; this exists before the tender stage to avoid problematic analysis.

Accordingly, the researcher's point of view PTE is "*a process of calculating project costs at a stage of minimum data, such as the scope, design, etc, before the tender*". Therefore, the process of preparing PTE initially starts with incomplete design drawings provided by the design team.

According to Plebankiewicz et al. (2015) and Peurifoy and Oberlender (2002), the process of preparing a PTE involves going through a series of steps, such as analysing design drawings, collecting data from design documents, gathering technical specifications, quantity take-offs, manual mapping with cost assemblies, noting evaluations and modifications. Thus, the process consists of time-consuming tasks that mean it takes months to prepare a PTE. As decisions to execute projects are based on pre-tender cost estimates, this demands accurate pre-tender cost estimates in construction (Chipulu et al., 2020; Enshassi et al., 2007). Consequently, accurate PTE would benefit different parties in many aspects; thus many, authors in the literature have highlighted the importance of accurate PTE. The next section will describe the importance of accurate pre-tender cost estimates from the perspectives of the different parties involved.

2.2.1 Importance of the Accurate Pre-tender Cost Estimates

The accuracy of pre-tender cost estimates is fundamental to decision making although they are prepared within a limited timeframe and a minimum of information (Aibunu, et al., 2011; Ismail et al., 2015; Pasco & Aibinu, 2008). Many authors have defined accurate cost estimates as one that is close to the actual project cost with minimal error (Azman et al., 2013; Flanagan & Norman, 2006; Serpell, 2004; Azman, 2012). In comparison, an inaccurate estimate is defined as the degree to which a measurement or calculation varies from its actual price (Azman et al., 2013; Barzandeh, 2011; Serpell, 2004). The level of estimate accuracy can be assessed in many ways such as irrespective to the estimated cost, and the proximity of estimates to the actual value (Ashworth, 2013), the cost of the end product, the cost of an estimated item or through a comparison of the tender price figures (Barzandeh, 2011).

According to Skitmore (1991), the accuracy of PTE consists of three aspects, namely bias, consistency, and the accuracy of the estimate. Thus, Pasco and Aibinu (2008) define bias as concerned with "the average of differences between prices and forecasts", while measures of consistency are concerned with "the degree of variation around the average" and accuracy is considered the overall combination of both bias and consistency. Therefore, Morrison (1984) and Aibinu & Pasco (2008) identified bias and consistency as the two measures of the accurate cost estimate, as illustrated in Figure 2.1.

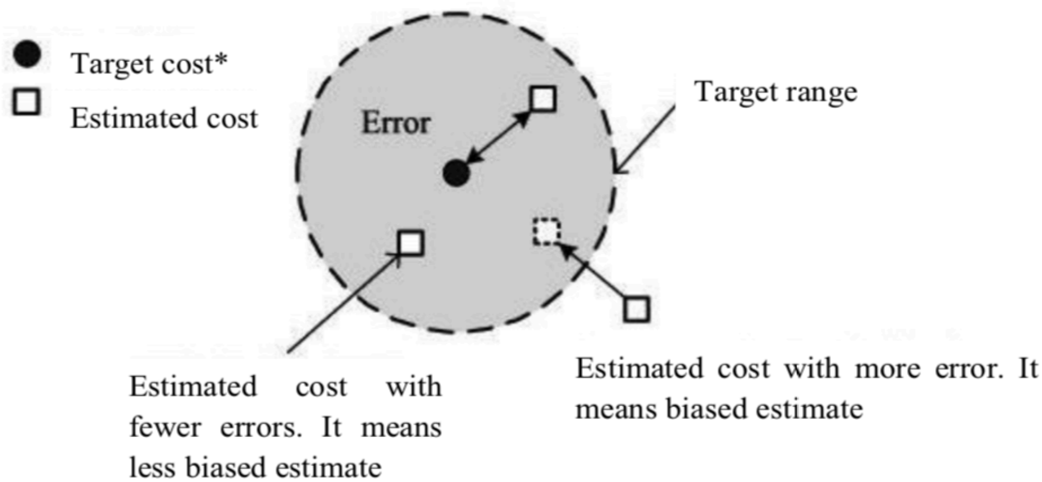


Figure 2.1: Accuracy of pre-tender cost estimates (abstracted from An, Cho, & Lee, 2011)

Therefore, this denotes associating the mean difference with the estimated and actual prices, whereas consistency is associated with the degree of variation around the mean (Aibinu & Pasco, 2008; Dysert, 2006). The smallest errors make highly accurate estimates (Flanagan & Norman, 1983). According to Odinot et al. (2012), consistency can be used as an indicator of accuracy. Correspondingly, Stanley and Benjamin (2016) identify four outcomes of accuracy and consistency, such as consistently accurate, consistently inaccurate, inconsistently accurate, and inconsistently inaccurate. Inconsistent information can produce accurate cost estimates, hence consistent reports can be inaccurate (Odinot et al., 2012). Moreover, inconsistencies are considered an indicator of inaccuracy (McNally, 2003; Talarico & Rubin, 2003). Therefore, inconsistency reports illustrate inaccurate estimates (Berman & Cutler, 1996; Brewer & Hupfield, 2004; Brewer et al., 1999; Fisher et al., 2009). Ideally, the most accurate cost estimates are those that mostly reflect the actual or tendered price of a construction project (Azman et al., 2013; Barzandeh, 2011; Serpell, 2004).

At the pre-tender stage, the accuracy level of cost estimates is one of the most critical indicators of effective estimation (Liu & Zhu, 2007). Therefore, the accuracy of the pre-tender cost estimates is vital as inaccurate figures can be unusable or risky. Faulty estimates could either be overestimates or underestimates. Underestimated pre-tender cost estimates can result in implementing an unfeasible project and means limited resources are available for the project, while overestimated pre-tender cost estimates lead to feasible projects being uncontrolled (Chipulu et al., 2020; Odusami & Onukwube, 2008). Therefore, pre-tender cost estimate forecasts for construction projects are vital to the client, contractor, and project team for different purposes (Feng et al., 2010; Oberlender & Trost, 2003).

From the client perspective, the pre-tender estimate gives the most-likely cost of construction to the client. This is important for the client who needs to determine the feasibility of the project (Alumbugu et al., 2014; Chandrarathne et al., 2019; Mahamid, 2018). Pre-tender estimates inspire the client to push forward with the design scheme of a project and to ensure that detailed working drawings are produced (Serpell, 2005). Thus, if the estimate is high/overestimated, it can mean the client reconsiders the project scope or loses the opportunity (Amoateng & Osei, 2017; De Silva at al., 2008; ICE, 2019; Odusami & Onukwube, 2008; RICS, 2014). Moreover, overestimation also discourages the client to deal with a particular company due to potential breaches of his expectations (Barzandeh, 2011; Chipulu et al., 2020). In contrast, low estimates/underestimates can result in an aborted design, wasted development, or even litigation due to client dissatisfaction (Chipulu et al., 2020; Odusami & Onukwube, 2008; Shash & Ibrahim, 2005). Moreover, underestimation could mislead the client as to the size of his investment (Barzandeh, 2011), and he may be unprepared when the tenders are drastically modified upwards. The client can also use pre-tender estimates as an indicator of probable costs from the early stages of construction; these can be used to monitor costs and the project budget (Oladokun et al., 2016; Skitmore & Picken, 2000). It can also serve as a tool to enable the client to evaluate the tender process and determine the most competitive bid. Moreover, pre-tender estimates also provide an assessment of capital costs for a specified piece of work (Liu et al., 2016; Schottlander, 2006).

From the contractor's perspective, contractors are invited to submit their bids to the project client. If the submitted tender price is overestimated, in most cases the tender will not be acceptable to the client (Akintoye, 1998). Therefore, overestimated cost estimates lead contractors to lose jobs. In a competitive contract, the contractor with the lowest bid frequently gets the job (Alumbugu et al., 2014; ICE, 2019). Nevertheless, if the bid is too low, the contractor might end up completing the work without profit (Al-Khaldi, 1990; Hendrickson, 2000). Thus, it has been observed that, in most projects, the client has to pay more at the end of the project, as the cost tends to be different from the price tendered by the contractor. Moreover, underestimated costs may lose a contract due to uncertainties associated with the project. There is, therefore, the need for estimates to be as accurate as possible (Odusami & Onukwube, 2008). According to Morrison (1984, p.58), the "Accuracy of an estimate is measured by deviation from the lowest acceptable tender received in competition for the project". Both overestimated and underestimated cost estimates have a significant impact on lost opportunities for a contractor (Alumbugu et al., 2014; ICE, 2019). Therefore, the estimator's aim should be to prepare cost estimates that follow the fine line between overestimates and underestimates.

From the project team perspective, pre-tender estimates are important for business decision making as they provide basic information, such as hours, duration, tasks, and resources, which help to prepare the project schedules (Marjuki, 2006). Apart from basic information, this will also provide general resource requirements, such as labour, material, and construction equipment. For the project team, the performance and overall success will most likely be measured and assessed on the capability of the actual costs to compare with the early cost estimate. Moreover, pre-tender estimates also provide a basis for cost planning and cost control during tendering and construction by defining the project scope of work and its associated estimated cost. Therefore, the accuracy of pre-tender estimates is important for the project team. Moreover, according to Liu et al. (2016), inaccurate cost estimates can create conflict among project team members. Besides, inaccuracies lead project stakeholders to obtain loans from financial institutions due to conflict between the cost and benefits of a project (Amoateng & Osei, 2017). Therefore, inaccuracies in early estimates can point to lost opportunities, inefficient development effort, and reduced expectations on returns (Mwikali & Kavale, 2012).

Table 2.1: Summary of the importance of accurate pre-tender estimates for each project member

Project party	Importance of the accuracy of pre-tender estimates	References
Client	To determine the economic feasibility of a project To give the client an idea about the entire project To monitor costs and the project's budget To secure opportunity Not to breach the contract and expectations with relevant companies To avoid aborted design, wasted development, or even litigation due to client dissatisfaction To evaluate the tender process and determine the most competitive bid To provide an assessment of capital costs for a specified piece of work	Skitmore & Picken, 2000; Serpell, 2005; Shash & Ibrahim, 2005; Schottlander, 2006; De Silva at al. 2008; Odusami and Onukwube 2008; Barzandeh, 2011; RICS 2014; Alumbugu et al 2014; Liu, Wang and Wilkinson 2016; Oladokun, Oladokun and Odesola, 2016; Amoateng and Osei 2017; Mahamid, 2018; Chandrarathne et al 2019; ICE 2019; Chipulu et al, 2020.
Contractor	Not to lose the contract To complete the job with a good profit margin	Morrison, 1984; Al-Khaldi, 1990; Akintoye, 1998; Hendrickson, 2000; Alumbugu et al 2014; ICE 2019.
Project Team	To get basic information, such as hours, duration, tasks, and resources To prepare project schedules To provide the basis for cost planning and cost control To avoid lost opportunities, inefficient development efforts, and lower expected returns To provide rovides financial input needed for preparing cash flow curves.	(Marjuki, 2006); Mwikali and Kavale, 2012; Liu et al (2016); Amoateng and Osei 2017.

According to Table 2.1, the accuracy of pre-tender cost estimates is not just important to a single party but rather to the entire project team. Therefore, it can be concluded that accurate pre-tender cost estimates are one of the parameters that can assure a project's success. As such, the preparation of accurate cost estimates, especially at the initial stage, is critical (ICE, 2019; Ismail et al., 2015; Thadsagini & Waidyasekara, 2018) due to various factors associated with the estimation process and project phases. According to Aibinu et al. (2011), an inaccurate pre-tender cost estimate is the underlying cause of cost overruns. Thus, Ali and Kamaruzzaman (2001) identified inaccurate pre-tender cost estimates as the biggest factor contributing to cost overruns in construction projects. Therefore, it can be concluded that there is a close and strong relationship between the accuracy of initial cost estimates and cost overruns. Therefore, in the next section, a detailed discussion has been presented on cost overruns.

2.3 Construction Cost Overruns

Completion within the established project budget is one of the important criteria for the successful completion of construction projects (Ramabhadran, 2018). However, project completion within an exact budget seems more crucial within the construction industry due to cost overruns (Kotb et al, 2019; Murali & Kumar, 2019; Oluyemi-Ayibiowu et al, 2019). Shehu, Endut & Akintoye (2014) defined cost overruns as "*the difference between final project cost and the cost agreed within the project contract*". The impact of cost overruns is not specific to one country or one region, but rather a global issue.

2.3.1 Construction Costs Overruns in A Global Context

Even though the general goal of the construction industry is to achieve successful project completions within the specified budget (Thabani, 2019), cost overruns mean they represent unrealistic targets on many occasions. Previous and recent studies offer evidence that elaborates on the global situation of cost overruns.

In Germany, Hamburg's Elbphilharmonie concert hall was able to open to the public six years late and more than €700 million over budget (McCarthy, 2018). Moreover, Berlin's brand-new airport was meant to open in October 2011 but was under construction and opened in Autumn (October) 2020 with an excessively over budget (Forbes, 2020). Figure 2.2 illustrates how projects can become expensive if costs are not under control. According to this figure, projects undertaken to provide venues for the Athens Olympics cost an extra $7 billion, which was almost 95% of the actual budget (Podio, 2019).

Furthermore, the FIFA world cup in Brazil cost $2.5 billion more than the planned budget, whilst Franca and Haddad (2018) revealed that 71% of 231 contracts exceeded their budget by 14%. Moreover, Callegari and Schaeffer's (2018) results indicate that construction project costs were, on average, 97.53% above the initial estimates.

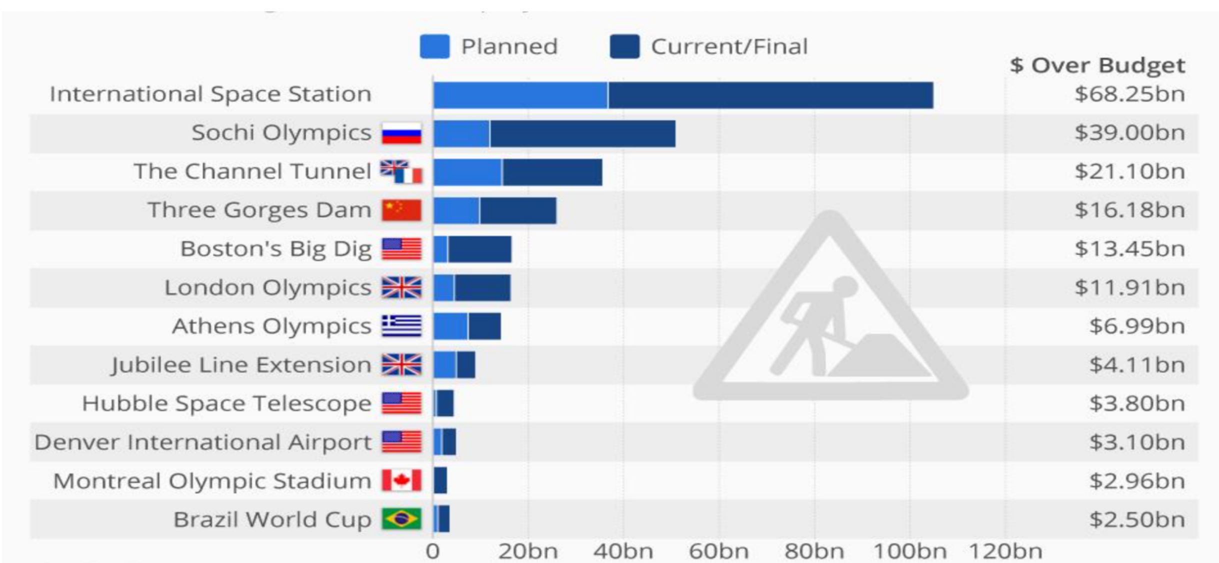


Figure 2.2: Over-budget construction projects worldwide (Forbes, 2020)

In 2005, the 2012 London Olympics bid was awarded at around £2.4 billion. After substantial variation, in 2007 it was changed to £9.3 billion, and by the end of the project in 2010, it cost £8.9 billion (Cf. National Audit Office 2012). The Edinburgh trams project started with an initial cost of £375 million. However, due to substantial scope changes it was completed at a cost of £776 million three years later (City of Edinburgh Council, 2014; Economist, 2018). Moreover, the Humber bridge in the UK experienced a 175% cost overrun following completion. Also, the Channel Tunnel costs - one of the most famous projects overruns - changed from £2600 million to £4650 million (80% higher than the forecasted costs) (Flyvbjerg et al., 2017). The Crossrail project has exceeded the established project budget of more than £400m, which increased to £650m, and the opening date have been set for October 2021 (Price, 2019). Similarly, the 2019 London Thameslink network cost overrun was £5.5 billion, which was significantly more than the initial budget of £5.0 billion (National Audit Office, 2017). The Great Western Railway modernization exceeded its original budget of £1 billion, by increasing to £5.58 billion 2019 and it is still under construction (Haylen et al., 2019). The replacement of Britain's three invincible- class 'light' aircraft carriers by two larger 'super' carriers started in 2016 with an initial estimated cost of £3.65 billion. However, at the moment, cost has increased to £6.8 billion with a revised completion date of 2023 (MOD, 2019). The recent study conducted by Hutton (2019) found that average cost overruns in the UK totalled almost 80%. Moreover, according to Locatelli and Brookes (2018), mega scale projects in the UK are significantly affected by cost overruns.

Furthermore, there are plenty of examples of project cost overrun in different countries around the world, such as The Great Belt link in Denmark (54% overrun), and the Paris Nord TGV in France (25% overrun) (Flyvbjerg et al., 2017). Another project that started in 2007 in western France that constructed a new reactor increased its initial costs through delaying the initial completion date from 2012 to 2019 (Goldsmith, 2019). According to RFI (2019), France's EDF exceeded its initial costs by 400 million euros, increasing from 10.5 to 10.9 billion euros, which was more than three times the initial budget. Nuclear plant construction was scheduled for the end of 2019 with commercial activity starting in 2020 and costs revised again from €10.5bn to €10.9bn (Keohane, 2019). Germany, Europe's largest economy holder, also struggled with construction cost overruns (Kostka & Fiedler, 2016). Accordingly, the average cost overruns for energy projects ranged from 85% to 91%, whereas in the transport and building sector they ranged from 32% to 51% in terms of the average cost overruns (Kostka & Anzinger, 2016).

According to a study by Heon et al. (2009), the average final completion cost of seven megaprojects increased by 122.4% in Korea. Moreover, in the same study, they also found that the average cost overrun for 29 medium-sized projects was 32.5%. In the USA, the City of Boston's Central Artery project was expected to complete at a cost of US$2.6 billion. However, it was completed in 2006 at US$14.8 billion after 7 years (Gelinas 2007). A report prepared by the General Accounting Office USA pointed out that 77% of construction projects in the USA incurred cost overruns that exceeded 200% from their actual budgets (General Accounting Office, 1997). In addition, Pickrell (1990, 1992) identified 61% as the average cost overrun in US rail projects. Moreover, Cantarelli et al. (2012), noticed an average cost overrun of 16.5% for 78 projects, including road (37 projects), rail (26 projects), tunnel (8 projects), and bridges (7 projects).

In Australia, the Sydney Opera house exceeded its construction costs by 1357% by the time its construction was completed (Podio, 2019). It was also reported that for projects conducted in Western Australia (Auditor General of Western Australia 2017), out of 20 projects, 15 exceeded their original budget and four exceeded their approved budget by more than 200%. Recent figures indicated that Australian project cost overruns varied from 20% to 131% between the smallest and largest projects (Petheram & McMahon, 2019). Moreover, studies also indicated that cost overruns were inevitable in Australian road construction projects (Andrić et al., 2019; Love et al., 2017; Petheram & McMahon, 2019; Terrill & Danks, 2016).

In Canada, the Spadina subway extension exceeded its initial estimated cost of $400M in 2015 (Siemiatycki, 2015). As reported by Toronto Star (2015), construction of the Canadian city hall and union station also exceeded its initial estimated cost. Moreover, due to the cost overruns of mega-scale projects, Niagara Falls Parks and the Recreation Department in Toronto, two project managers were fired (City News, 2017). In 2015, the world's largest synthetic crude producer declared the new expansion would subsequently cost $8.1 million, which was $4 billion over the estimated cost (Economist, 2017). In the USA, it was reported that most construction projects were affected by cost overruns in the highest percentages. Recent findings indicated that 66% of megaprojects exceeded their initial estimated budget (James, 2017). Moreover, in New York, the Metropolitan Transportation Authority sued contractors for cost overruns across several projects (Associated Press, 2019).

A study published by Flyvbjerg et al. (2017) indicated that, in 20 different developed countries 90% of 258 infrastructure projects have experienced cost overruns and that infrastructure projects, in particular, had an 86% risk of exceeding their initial estimates. Moreover, a study undertaken by Alex et al. (2017) noted that over 800 water and sewer projects had an 86% risk of exceeding their initial estimates. In Hong Kong, it was reported that more than 40% of railway projects experienced cost overruns (Huo et al., 2018). Moreover, the recent mega project - Hong Kong-Zhuhai-Macao Bridge - was opened after nine years of construction with a final cost of 120 billion yuan instead of the estimated 70-billion-yuan; this increase represented the cost of building almost two bridges (HK, 2018). Senouci et al. (2016) revealed an increase in terms and cost in 122 construction contracts in Qatar and found that 54% incurred increased costs and 72% saw their deadlines increase. The famous Burj Khalifa was constructed with the latest technologies, the project cost increased by 71% than initially estimated (Dubai- Architecture, 2014). The above examples offer clear evidence that construction projects in developed countries have an adverse effect on cost overruns.

The impact of cost overruns seems to be more severe compared in developing countries than developed countries (Rajkumar, 2016; Vaardini et al, 2016). Several studies conducted in the Jordanian construction industry (Al-Hazim & Abu Salem, 2015; Al-Hazim et al., 2017; Tadewos & Patel, 2018) indicated that project cost overruns varied from 101% to 600%. Nigeria reported 54.62% as an average cost overrun in road construction projects (Anigbogu et al., 2019). In Ethiopia cost overrun rates varied from 4.11% to 135.06% of the total cost (Tadewos & Patel, 2018). The Nuevo international airport in Mexico started its construction at an estimated cost of US$9.5 billion (Navarro, 2017). This was the largest project undertaken by the Mexican government in 50 years and was expected to open in the year 2020. However, by postponing its opening to the year 2020, Hernández (2017) stated that the project cost increased from its original to US$10.5 billion. In Nigeria, construction projects incur high-cost overruns rates that range from a minimum of 50% to a maximum of 216.08%. Moreover, projects with a high completion percentage and low-cost overruns ranged from a minimum of 44.75% (in terms of cost overrun), at 17% completion to a maximum of 216.08% cost overrun at 5% completion. However, the projects with a high percentage of completion time and low-cost overruns ranged from a minimum of 5.56% cost overrun, with 90% completion to a maximum of 19.27% cost overrun, with 95% completion (Saidu & Shakantu, 2017). In Ghana, a vast number of projects (95.9%) experienced cost overruns (Coffie, 2019). Moreover, the largest cost overrun at 100% occurred in the Central Region and the Upper East Region, whereas the Upper West Region experienced the lowest number (87.5%) of project cost overruns (Aigbavboa, 2019). Furthermore, countries in the Asian region also suffering from severe cost overruns.

In the Chinese construction industry, 75% of projects suffer from cost overruns (CIOB, 2017; HK, 2018). According to Kaming et al. (1997), Indonesian construction suffers from more than 90% cost overruns. Meanwhile, according to Shehu et al. (2014), Malaysian construction projects experience cost overruns of more than 55%. Moreover, a study conducted by Karunakaran et al. (2018) also found similar supporting factors. These figures indicated that cost overruns are a common worldwide phenomenon in construction projects but can be more severe in developing countries (Angelo & Reina, 2002; Durdyev et al., 2012).

South Asian countries also report the same issues in the construction industry. Accordingly, studies conducted in India (Murali & Kumar, 2019; Shanmugapriya & Subramanian, 2018; Wanjari & Dobariya, 2016) indicated that 60% of construction projects suffer from cost overruns with a loss of around US$200 billion. Moreover, by November 2017, there were 11 operational metros in ten cities across India (Kolkata, Delhi, Bangalore, Gurgaon, Mumbai, Jaipur, Chennai, Kochi, Lucknow, and Hyderabad) with 324 km of operational metro lines (Metrorailnews, 2018). Existing metros, those under construction and, many of the metro rail projects are facing cost overruns, schedule delays and safety incidents (Indo-Asian News Service, 2017; Menezes, 2018; Mevada & Devkar, 2018; Rawal, 2018; Senthilvel et al., 2018; Staff Reporter, 2017). According to the Indian Express (2019), 361 infrastructure projects showed cost overruns of Rs 3.77 lakh crore.

In Pakistan, cost overruns in building and infrastructure projects were found to pose a major issue for construction projects (Sohu et al., 2017; Sohu et al., 2018). Figures indicated that the Lowari tunnel was supposed to completed by 2015 but was completed in 2017 at Rs. 27 billion as opposed to the initial cost of Rs 7 billion (Business Recorder, 2017). Moreover, the Karachi Hyderabad Motorway was completed by October 2017 (although it was due for completion in 2015) at a revised cost of Rs 36 billion from the initial estimated cost of Rs 24.93 billion (Business Recorder, 2017). According to Rana (2017), over 1000 projects have faced cost overruns; for example, the total cost of housing schemes was Rs7.9 trillion, although Rs2.231 trillion of which had already been spent. The Planning Ministry needed another Rs5.7 trillion to complete the work as against Rs.1 trillion allocated this year 2017.

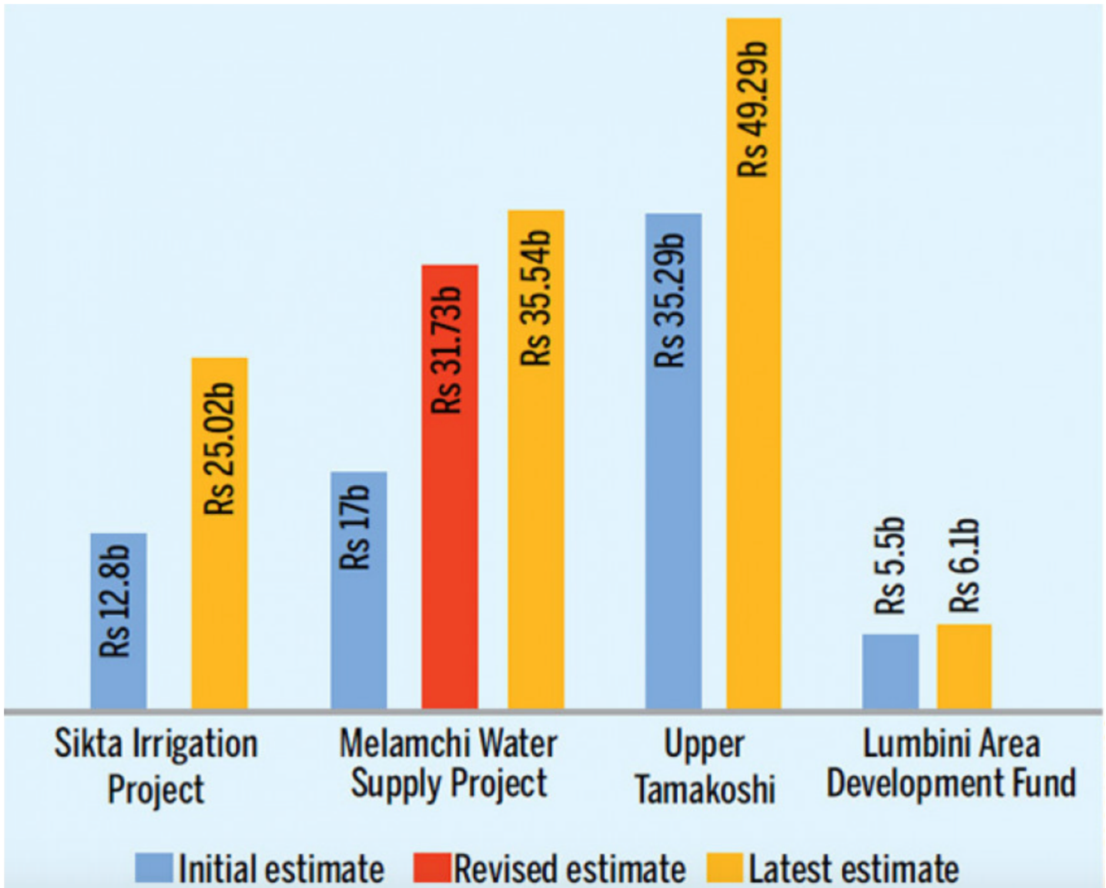


Figure 2.3: Cost overruns in Nepal construction projects (Kathmandu, 2020)

In Bhutan, cost overruns in construction projects are a common news headline. Millions of Ngultrum and months of delays are experienced within bigger projects. For example, Bhutan Electricity Authority (2017) reported that hydropower projects had cost overruns of 39.92%, 166%, and 93% of the initial costs. As illustrated in the Kuensel report (2019), for projects executed between 2014 and 2018 the cost overrun percentage increased significantly, with the highest recorded in the financial year 2016-2017, where time had elapsed in 64.53% of the works and the cost had increased from the contract price in 585 of the 719 executed works. In Nepal, the latest figures indicated (Figure 2.3) that costs dramatically increased in major construction projects. Accordingly, the Sikta Irrigation Project was initiated in 2005-06, and was supposed to be completed by 2014-15 at an estimated cost of Rs12.8 billion. Officials further projected that the project would not be complete before 2019-20, and by the time it is fully operational, the project is expected to cost Rs25.02 billion (Shrestha, 2018). Melamchi Water Supply Project is another example of a cost overrun (according to Figure 2.3); when it started, in 2001-02, the initial estimated cost was Rs17 billion. In 2008, the cost was readjusted to Rs31.73 billion before it was increased again to Rs 35.54 billion in 2014, (Commission's Report, 2017).

Nepal Electric Authority (NEA) developed Chameliya Hydropower Project (CHP). Construction of the project began in mid-January 2008 and the project was scheduled for completion by mid-June 2011 at a cost of NRs 8 billion; however, but the cost of the project has since reached NRs 15.6 billion. The cost overrun in this project is almost 100% of the initial estimated cost. Normally, the cost of 1 MW capacity costs around NRs 150 million but in the case of Chameliya, the cost per MW has now reached NRs 540 million and it is still under construction (Bhandari, 2017).

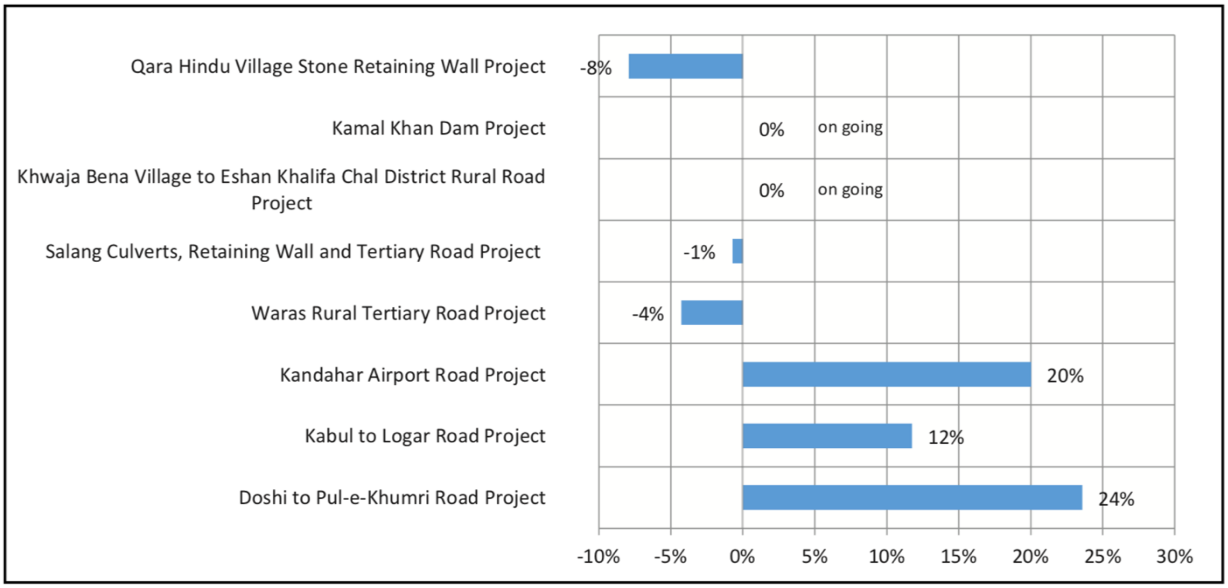


Figure 2.4: Project cost overruns in Afghanistan construction projects (Minister of Economy and Cost Afghanistan MSG, 2019).

The Afghanistan construction industry also faces significant cost overruns (Minister of Economy and Cost Afghanistan [MSG], 2019). Malik et al. (2017) reported that the final project cost of the Kabul Power Plant had risen to approximately $300 million, which had originally been estimated at $40 million. Moreover, the headquarters of the Afghan Ministry of Defence in Kabul actually cost three times more than originally estimated, increasing from $48.7 million to 154.7$ million (SIGAR, 2016). According to Figure 2.4, three projects have experienced cost overruns and the Doshi to Pul-e-Khumri Road project has the highest cost overrun percentage at 24%. Kandahar Airport Road has the second-highest cost overrun percentage (Niazi & Painting, 2017). Moreover, the rural road project in the Chal District of Takhar province is not yet completed and no variation order has been approved to date. Similarly, the Kamal Khan Dam project is now at the beginning stage and no cost variation has been approved to date; therefore, the cost overrun is showing as 0% (Mastoor, 2019).

The above figures indicate that the impact of cost overruns is not just limited to one region or one country; instead, it an overall issue for both developed and developing counties as well as Asian and South Asian regions, in which Sri Lanka is located as a developing country. The next section discusses the cost overruns in the Sri Lankan context.

2.3.2 Construction Cost Overruns in The Sri Lankan Context

As a developing country in the South Asian region, the contribution of the Sri Lankan construction industry amounted to USD 6.23 Bn in 2018, which was the highest recorded Gross Domestic Product (GDP) at 7.2% (Balachandra, 2019; Central Bank of Sri Lanka, 2019). By the year 2018, more than 7% of the total workforce were directly employed in the Sri Lankan construction industry (CCI, 2019). The aim of the National Physical Plan – 2050 is to plan towards a smart nation by 2050, with the intention to move from a developing to a developed country with a per capita income of 12000 USD (NPP, 2019). This requires an annual growth rate of 7.5% in the Gross Domestic Product (GDP) (Munasinghe, 2019). Like most countries, the construction industry is the backbone of the Sri Lankan economy (Wijeratne, 2019). Therefore, the productivity of the construction industry is a fundamental element of the journey towards becoming a developed nation.

According to the Oxford Business Group (2018), a vast number of construction projects are underway across the island. Both local and major foreign investors, such as the Chinese, state-owned China Communications Construction Company, China Merchant Holdings International, a Hong Kong-based conglomerate and Indian state-owned company, National Thermal Power Corporation, etc, have already invested millions in many projects, such as buildings, apartments, hotels, and ports (Finex, 2017). Among the number of joint venture contracts, some are performed with local contractors, providing an opportunity for local construction companies to gain experience in different areas, such as technologies (Jayakody, 2017). Nevertheless, according to Gunathilake (2019), most of the projects have exceeded their costs by 75% to 80% of the estimated value.

Construction of the lotus tower, South Asia's tallest self-standing structure (Figure 2.5) started in 2012 and was expected to be complete by May 2015 at an estimated cost of Rs.19 billion (Daily News, 2019). It was one of the mega projects conducted by the Sri Lankan government with Chinese funding and consists of restaurants, an auditorium, a television tower, a telecommunications museum, a shopping mall, and a conference room (Abeyratne, 2019). Although it was opened in 2019, it was not fully completed and cost an extra Rs.5,475 million to the Sri Lankan government (Mudalige, 2019).

Figure 2.5: Colombo Lotus Tower (Daily News, 2019)

Colombo port city is another foreign-funded on-going project that started in 2012 and is expected to complete its first phase by 2021(PWC, 2020). The first phase expectations are to reclaim 233 hectares for US$ 1.4 million (Colombo Telegraph, 2015). However, the estimated cost has currently increased to US$ 1.9 billion (Sirimane, 2019) and further cost overruns are expected (Samaranayake, 2020).

Hotel project Shangri-La Colombo was started in 2012 with an estimated project cost of $550 million; it was due to complete no later than 2015. However, the project finished in 2017, having exceeded its project costs by 10% of the total cost (De Alwis, 2017). A study conducted by Silva (2016) identified cost overruns as a major challenge for building projects in Sri Lanka. Nevertheless, cost overruns are not just limited to Sri Lankan building projects, as other projects have also encountered the same issue. Southern Expressway was constructed to connect Colombo and Hambantota in less than an hour and a half having previously taken four hours and began with an estimated cost of $348.75m. By the time it was constructed, the cost had escalated to $741.1m, which was more than double the initial estimate (Oxford Business Group, 2019).

Moreover, the expressway from Kadawatha to Meerigama started at $1.1 billion; it was due to begin in 2017 and expected to complete by 2020. However, at the moment, the project has exceeded its cost by an additional $5.86 billion with extended timelines. Railway construction is also under pressure as many projects have exceeded their estimated costs (LKR 7.7bn by $50.3m in 2015 and LKR 6.8bn by $44.4m in 2016). Mattala International Airport started to construct in two phases in 2009. The first phase was estimated at US$209 million but was completed at $285.88 million in 2012. Moreover, the second phase was estimated at US$190 million but ended up costing $259.89 million (Attanayake, 2018).

The above projects indicate that majority of projects ended up with cost overruns; therefore, it is hard to accurately estimate the maximum contribution to the economic development from the construction industry. Most importantly, the majority of the projects are foreign-funded, and the government has to pay long term debts, including excessive project costs. In the Daily News (2019), it was reported that in 2018, the Sri Lankan government paid loan instalments of Rs.2400 million and needed to continue paying the same amount for the next 10 years. Nevertheless, the Sri Lankan government was expecting to execute several foreign-funded projects, such as the Western Region Megapolis, which is a 15-year, $40bn development plan for the Greater Colombo area that aims to transform the capital and raise the western region's GDP to $230bn by 2030, through $300m worth of 64km long electrified railway. Colombo's Bandaranaike International Airport expansion is worth $550m and funded by the Japanese International Cooperation Agency; however, this is yet to commence (CCI, 2019). Nevertheless, at a time when a massive number of projects have been launched and have incurred cost overruns, future projects will increase the debt rate rather than benefit the growth of the country's economy. Besides, cost overruns also result in the following impacts:

- From the client's perspective, the extra cost added to the initially agreed budget will reduce any returns on investment.
- From an end-user's perspective excessive costs will mean they will pay higher rental/lease costs or prices.
- From a professional perspective, cost overruns indicate a lack of capability's in a job role and create a black mark for their reputation resulting in a loss of confidence and fewer new jobs in the future.
- From the contractor's perspective, this indicates a loss of profit and threatens his future career by minimizing the chances of winning further jobs.

- For the industry as a whole, cost overruns could bring about project abandonment and a drop-in building activity, poor reputations, an inability to secure project finance or securing it at higher costs due to added risks (Mbahu & Nkado, 2004).

Therefore, cost overruns have been a topic discussed in both previous and recent literature, as it represents a significant problem for construction projects. It is claimed that addressing the root causes of this issue could help to identify appropriate solutions (Ali & Kamaruzzaman, 2010; Durdyev et al., 2017). Therefore, it is an opportune time for the Sri Lankan construction industry to identify the root causes for cost overruns and take appropriate action to minimise the impact of such.

2.3.3 The Causes of Construction Cost Overruns Globally

As cost overruns in construction projects are a global issue, over the past decade many researchers have explored the causes behind this phenomenon (Shah, 2016). However, the issue of cost overruns is still sufficiently important to attract many researchers to examine the causes. Across North America, an extensive range of research has been conducted over the years to identify the major causes behind cost overruns. Canada indicates that inaccurate cost estimates have resulted in cost overruns amongst the majority of construction projects since the 1970s (Flyvbjerg et al.2002; Gehring & Narula, 1986; Hall, 1982; Merewitz, 1973; Nijkamp & Ubbels, 1999; Pickrell,1992; Tihanski, 1976). However, recent studies have also reported similar findings, which indicate that the impact of inaccurate cost estimates still exists in the Canadian construction sector. In addition, as project cost estimates continued to inaccurate over the period, most projects, but especially megaprojects, suffer from cost overruns (Siemiatycki, 2015, 2016). According to IMFG (2016) scope changes, changed orders, handover problems, incomplete studies before project approval: inflation in labour and material costs, inaccurate forecasting (estimates), project delays, and unforeseen events were reported as the main causes behind cost overruns. A study undertaken by Bhutan to investigate cost overruns in hydropower projects found unreasonable cost estimates and gaps in management were the major causes behind cost overruns in the Muskrat Falls hydroelectric project in Canada (BEA, 2017).

In the USA Flyvbjerg (2016) identified four dimensions as the main causes for cost overruns, namely: technical, economic, political, and psychological. He further identified six key causes for technical dimensions; among them were inaccurate cost estimates, design changes, and uncertainties. Nine factors were identified as the causes of economic issues, and among them were, inaccurate cost estimates, a lack of resources, and the inefficient use of resources. Psychology is affected by three causes, namely optimism bias, cognitive bias, and cautious attitudes. Inaccurate cost estimates, the manipulation of forecasts, and private information were found to be the main causes of the political dimension. These findings indicate that, apart from the phycological factor, the remaining three factors were mainly caused by inaccurate cost estimates. Chibuikem (2018) analysed 29 construction projects in the USA and found design issues, poor site management, contract disputes, fund shortages, poor weather, and government issues as the main causes for cost overruns. However, Ghorbani (2019) analysed 20 major construction projects that experienced cost overruns in 2018 and noted that for the majority of projects, 32% of the cost overruns were due to estimation errors (see Figure 2.6).

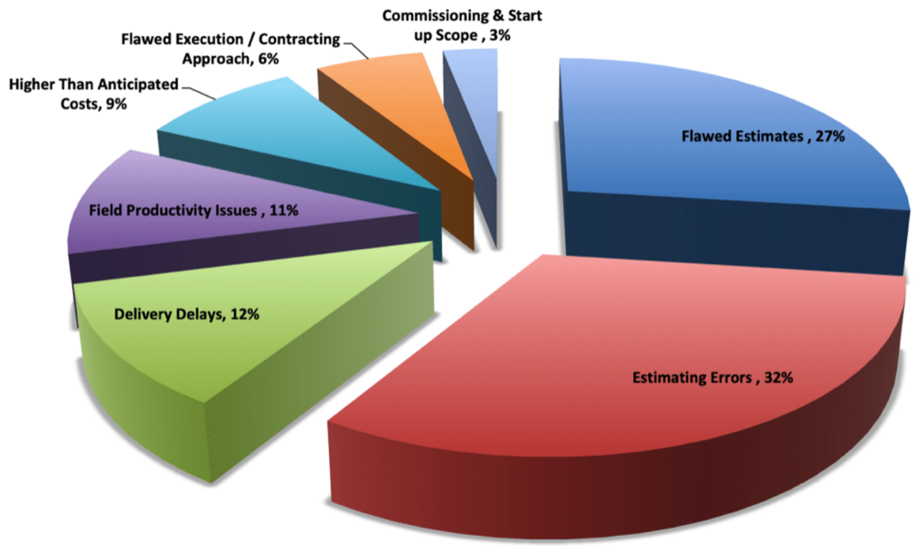


Figure 2.6: Reasons for cost overruns in major USA construction projects (Ghorbani, 2019)

In South America, Brazil has conducted many types of research on the causes of cost overruns. Accordingly, a study conducted by Franca and Haddad (2018) found that such causes could be attributed to groups, namely directors, project managers, and area managers. The study results indicate that unrealistic initial cost estimates were a common cause for the three groups. Moreover, a change of scope, a lack of design detail during budgeting, and high indirect costs in a period of low productivity was also found to be the main causes of cost overrun. Moreover, Callegari and Schaeffer (2018) identified reliable cost estimates as the main solution to ongoing project cost overruns. In the Venezuelan construction industry, errors in cost estimates, design errors, changes in project scope, owners or contractor's interferences, contractor's performance, failures in quality performance and controls, delays in approval by owners and work permits, a lack of skilled workers, and coordination and communication problems were identified as the main causes behind project cost overruns (de Dikdan & Odríguez-Monroy, 2018; Love et al., 2018; Pietrosemoli et al., 2016)

In Australia**,** cost overruns were found to be an ongoing challenge in the majority of constriction projects. As a result, several studies have been conducted to investigate the causes of these overruns. A study conducted by Allahaim and Liu (2012), identified market volatility, pressure to alter estimation due to less accurate initial estimates, novelty, complexity, and time pressure as main causes behind cost overruns. Although Newton et al. (2014), argued that it is understandable that designs change, clients vacillate, productivity varies, delays occur, economies cycle, and markets fluctuate; they argued that inaccurate cost estimates are unacceptable as there is a particular flow to preparing cost estimates. A study conducted by Terril et al. (2016) found that overly optimistic cost estimates and poor project management and contracting practices cause projects to be more expensive than they should be moreover, scope changes were the main causes of cost overruns. Nevertheless, according to Terrill and Danks (2016), scope change has only a minor impact on cost overruns in Australian construction projects. A recent study conducted by Petheram and McMahon (2019) to investigate the causes behind dam cost overruns Australia, reported unrealistic cost estimates systematically misled entire project teams on cost overruns.

Previous studies in Africa found that several causes resulted in cost overruns. In South Africa, a study conducted by Baloyi and Bekker (2011) revealed that project complexity; increased labour costs; inaccurate cost estimates; differences between the selected bid and consultants' estimates; variations to orders by clients during construction, and manpower shortages as the main causes behind the 2010 FIFA World Cup stadium cost overruns. Studies conducted by Flyvbjerg et. al. (2003) and Ahiaga-Dagbui et. al. (2015) revealed that inefficiencies in project cost estimations and forecasting during the project planning phase were the main causes behind cost overruns. A study conducted by Gbahabo and Ajuwon (2017), found the main cost overrun causes were: inaccurate project costs and schedule estimations; a weak institutional governance environment ranging from delays in the government approval process to poor enforcement of contracts obligations, and the prevalence of corruption and kickbacks in infrastructure procurement.

In Nigeria, studies have been undertaken to investigate the causes of cost overruns for decades. Accordingly, a study conducted by Okpala and Aniekwu (1988) found that price fluctuations, additional works, delays, inaccurate estimates, fraudulent practices and kickbacks, shortening of the contract period, and insurance were the main causes behind cost overruns. Studies conducted between 1990 and 2000 reported inaccurate estimates/tender sums, issues with contractors, improper contract knowledge, poor management of construction programs, poor cost/financial management, inadequate planning and a contractor's lack of ability in risk/uncertainty management as main causes behind cost overruns (Elinwa & Buba, 1994; Odeyinka & Yusif, 1997; Mbachu, 1998; Mbachu & Olaoye, 1999; Ishaya, 2000). Research conducted between 2001 and 2010, also revealed similar causes, such as inaccurate estimates, poor management, inadequate planning and scheduling, ineffective resource coordination, and a lack of relevant tools and equipment (Elinwa & Joshua, 2001; Omoregie & Radford, 2006; Oseghale & Olugbenga, 2008; Ameh et al., 2010). This indicates, throughout 10 years, inaccurate cost estimates were the main cause behind cost overruns. Moreover, recent studies similarly identified inaccurate cost estimates as the main cause for cost overruns as well as from price fluctuations, costly materials, high-interest rates charged by banks on loans received by contractors, high labour costs, and high machinery costs (Aghimien et al., 2017; Aljohani et al., 2017; Kadiri & Shittu 2015; Kasimu, 2012; Saidu & Shakantu, 2017). A recent study conducted by Ohiomah (2019), identified that payment delays to sub-contractors and suppliers, payment delays to the main contractor, contract information delay, inadequate prime costs, and provisional sums, price fluctuation/inflation and inaccurate cost estimate as main causes of cost overruns. Therefore, it can be concluded that inaccurate cost estimates have been the main cause behind cost overruns in Nigeria for decades.

Studies conducted in Ghana over different decades have reported various causes of cost overruns. A study conducted by Kaming et al. (1997) found that unpredictable weather conditions, inaccurate cost estimates, inaccurate production rate predictions by craftsmen, inaccurate predictions of equipment production rates and material shortages as the main causes. A study by Agyakwah-Baah and Fugar (2010) reported that delays in payment certificates, underestimated project costs, underestimated project complexity, difficulty in accessing bank credit, and poor supervision as the main causes of cost overruns. Nevertheless, the recent studies also have captured similar causes, such as the underestimation of project costs by consultants, poorly defined project scopes, client-initiated variations and underestimated project complexity (Amoa-Abban & Allotey, 2017; Amoatey & Ankrah, 2017; Coffie and & Aigbavboa, 2019; Famiyeh, et al., 2017; Shah 2016). Therefore, even though some causal factors have changed over time, it is clear that the impact of inaccurate cost estimates has been a continuous cause for cost overruns in Ghana. Many more countries in Africa have reported the impact of inaccurate cost estimates on construction cost overruns, including: Egypt

(Elbashbishy et al., 2019; Khoderi & Ghandour, 2019; Kotb 2019), Zimbabwe (Aljohani et al., 2019; Maxwel, 2019; Sampson et al., 2020; Shah 2016; Taruvinga, 2019; Thabani, 2019), Ethiopia (Ashebir et al., 2017; Belachew et al., 2017; Gadisa & Zhou, 2019; Kassa, 2020; Nigussie & Chandrasekar, 2020), Tanzania (Jongo et al., 2019; Shabani et al., 2018). Therefore, it can be concluded that the impact of inaccurate cost estimates has been a key ongoing cause of cost overruns on the African continent.

Section 2.3.1 indicated that cost overruns in Europe were significant. Accordingly, several types of research have been conducted in Europe and the specifically UK to investigate the causes of cost overruns over the past decades. Studies conducted by Wachs (1990), Jackson (2002), Siemiatycki (2009) and Flyvbjerg (2009) found that an uncertain future, difficulties delivering large complex projects, poor forecasting models, incomplete designs and cost estimates, poor cost estimate reliability, and scope changes (whether mandated by circumstance or requested by the client) as the main causes of cost overruns. Nicolos (2004) pointed out that the majority of construction projects cost overruns were due to incomplete cost estimates and highlighted the use of historical cost data to increase the level of accuracy. Thus, the studies conducted between 2010 and 2015 also illustrated similar facts, such as cost estimate reliability, scope changes (whether mandated by circumstances or requested by the client); managerial and technical difficulties, risk and uncertainty as the major causes of cost overruns (Ahiaga-Dagbui et al., 2013; Ahiaga-Dagbu & Smith, 2014; Okmen & Öztas, 2010; Jennings, 2012; Love et al., 2011). Surprisingly, recent studies also illustrate similar findings at a time of widespread use of advanced technology. Accordingly, the failure to produce accurate cost estimates, a shortage of skilled labour, uncertain weather, planning problems, changes to design, poor management, skimping on quality, project complexity and high staff turnover were reported as the main causes behind UK cost overruns (Hutton, 2019; Scott, 2017; UK Construction, 2017, Zinmagazine, 2020). Although there are other causes to consider, the failure to produce accurate cost estimates still rank as the most significant in many studies. Nevertheless, Dahl et al. (2017) found inaccurate cost estimate as the main reason behind Norwegian petroleum project cost overruns. This was further supported by the study conducted by Lorentzen et al. (2017) who concluded that cost overruns were driven by unrealistic cost estimates as well as poor weather conditions, high material prices, and large project sizes. In Italy, recent study results indicate that the size of a project, underestimations, and risks relating to conditions on-site as the most common root causes of cost overruns (Mangialardo et al., 2018; Torrieri & Oppio, 2019).

Like most of the continents, countries on the Asian continent also suffer from severe cost overruns (see section 2.3.1). In the United Arab Emirates (UAE) plenty of research has been undertaken over the years to investigate causes of cost overruns. A study conducted by Alghonamy (2015) found that underestimates, frequent changes in design, improper planning, long periods between design and implementation, and payment delays as the major causes. According to Johnson and Babu (2018), design variation, poor cost estimations, delays in the client's decision-making process, the financial constraints of clients, and inappropriate procurement methods as the main causes of cost overruns. Moreover, Ramabhadran (2018) found that improvements to productivity, efficient estimation processes, value management, change management, and procurement management are also crucial to minimize cost overruns in construction projects. Besides, Seddeeq et al. (2019) surveyed the Saudi Arabian oil and gas construction industry and found out changes to the design and scope by the client during construction, poor project planning and scheduling, design errors, inadequate comprehension of the scope of work at the bidding stage, cost and schedules underestimations were the main drivers of cost overruns.

In Qatar, a study conducted by Kasimu (2012) found that awarding contracts to the lowest bidder, site conditions, incompetent subcontractors, poor site management, inaccurate estimates, and client-led changed orders were the major reasons for cost overruns. However, the same study also identified that market conditions, personal experience in contract work, insufficient estimated time for construction items, material fluctuations, and political situations also resulted in cost overruns. However, Maki (2016) identified schedule delays, improper planning and scheduling, frequent design changes, inaccurate time and cost estimates for the project, unrealistic contract durations, and imposed requirements were the main driving factors of cost overruns.

In Kuwait, design changes, inadequate planning, unpredictable weather conditions, and fluctuations in the cost of building materials were found to be the major causes of cost overruns (Chimwaso, 2000; Kaming et al., 1997). However, a study conducted by Kouski et al. (2005) identified that contractor elide, material related problems, and owners' financial constraints were the three most important causes of cost overruns. In Turkey, a study conducted by Arditi et al. (1985) identified that increased material prices and rapid inflation caused contractors to produce products at an agreed price, Delays caused by changes to design specifications and financial problems and the underestimation of project costs when setting the project budget were the main causes of cost overruns. Studies conducted in Bahrain reported that design changes, mistakes during construction, schedule delays, inadequate supervision and site management, mistakes in time and cost estimates, delays in the making and approval of different design and drawings, and poor design as the main causative factors of cost overruns (Abusafiya & Suliman, 2017; Huo et al., 2018).

In Malaysia**,** a study conducted by Memon et al. (2010) revealed 15 causative factors of cost overruns; among them were financial problems experienced by contractors, inadequate site management, a lack of monitoring of work progress by the contractor, incapable contractors, a lack of site labour, indelicate planning and arrangement by the contractors, unstable construction material costs, and underestimation. Ramanathan et al. (2012) identified 18 major causes, among them were time extensions, fluctuations in the cost of raw materials, design changes, unpredictable weather conditions, insufficient project preparations, and poor cost estimates. Rahman et al. (2013) reported that cost overruns stemmed from variations to the cost of raw materials, ineffective site management and supervision by the contractor, a lack of contractor experience in handling large construction projects, construction mistakes resulting schedule delays, inaccurate cost estimates, and underestimated project durations. Ahiaga-Dagbui et. al, (2015) reported that inefficiencies in project cost estimations and forecasting during the project planning phase were the major reasons for Malaysian construction cost overruns. The Department of Statistics (DOSM, 2016) reported that delays in the preparation of design documents, ineffective communication between stakeholders, changes in law and regulations, low labour productivity and inaccurate estimates were the main causes of cost overruns. Several studies conducted by different authors in 2017 found that: inaccurate estimations, a lack of communication on-site, a lack of skilled workforce, poor project management and unsuitable construction methods were the major causes of cost overruns (Ghani & Ismail 2017; Khan et al., 2017; Tahir et al., 2017). Moreover, a recent study conducted by Albtoush and Doh (2019) classified factors into 10 main groups, namely design and contract related factors, estimation related factors, planning and schedule related factors, project management related factors, labour-related factors, financial related factors, material and machinery related factors, construction phase related factors, communication-related factors and external related factors.

Moreover, Kaming et al. (1997) found increases to the price of materials due to inflation, errors in the estimation of materials, and project complexity as the main causes of cost overruns in the Indonesian construction industry. A study conducted by Rauzana (2016) found similar causes that supported the above study findings, such as poorly estimated costs, problematic implementation and working relationships, material cost increases due to inflation, inaccurate material estimation, and the degree of complexity. Similarly, many more researchers conducted studies in Asian countries and discovered incorrect/poor estimates of the original cost as a major cause behind construction cost overruns (Durdyev et al., 2017; Le-Hoai et al., 2008; Malik et al., 2017; Sriprasert, 2000).

Section 2.3.1 revealed that countries in the South Asian context have also suffered from cost overruns for decades; for example, India suffers from cost overruns. As a result, many researchers have conducted several studies to address the causes of the issue. Accordingly, a study conducted by Subramani et al. (2014) examined the causes of cost overruns, and the results indicated that the major causes were slow decision-making at the planning stage of a project; poor project schedules and management; increases in the prices of materials and machines; poor contract management; poor design/delays in producing designs; rework due to mistakes; land-acquisition problems; poor estimation or estimation techniques, and

long periods of time between the design and time to bid/tender. Moreover, a study on road construction projects investigated the causes of cost overruns and found inadequate project formulation, poor field investigation, bad cost estimates, poor planning during the execution stage, inadequate equipment supply plans, a lack of project management during the stage of execution, insufficient working, changes in the scope of work, changes to law and order were the major contributing factors for cost overruns (Raphael & Priyanka, 2014). According to the findings of Kumar (2016), delays to the preliminary handing over of projects, wrong/inappropriate choices of site, inadequate cost estimates, increases to material prices, price resources constraints, unpredictable weather conditions, fluctuations in the cost of materials, equipment allocation problems, a lack of cost reports and design changes were the major factors affecting cost overruns. However, a study conducted by Patil and Pankaj (2016), found different factors such as high transportation costs, changes to material specifications, the escalation of material prices, and the frequent breakdown of construction plants, equipment, and rework. The findings of Ahady et al., (2017) indicated that poor management, changed material prices, inaccurate material estimates, and the financial status of the contractor as the main causes. Sha et al. (2017) reported inadequate contractor experience, inappropriate construction methods, inaccurate time estimations, inaccurate cost estimations, poor site management and supervision, improper project planning and scheduling, incompetent project teams, unreliable subcontractors and obsolete technologies as the main reasons for cost overruns in the Indian construction sector. Besides, Tadewos and Patel (2018) found that financial problems, improper planning, land acquisition and construction delays, design changes, fewer materials and equipment supply issues by contractors, incomplete cost estimates and incomplete design as the major reason for cost overruns. A recent study conducted by Prasad et al. (2019) analysed cost overrun factors in India and concluded that delays in payment for extra work, delays in settlement claims by owners, contractor's financial difficulties, and late payments from contractors to subcontractors were the main cost overrun factors.

In Pakistan, a study conducted by Azhar et al. (2008) found that cost data, inappropriate contractual procedures, additional works, wrong cost estimation methods, poor relationships between management and labour, stealing and waste on-site, and labour/skill availability were the major issues behind cost overruns. According to Choudhry et al. (2012), inappropriate government policies and priorities, improper planning, price increases on major construction materials, and/or price adjustments, land acquisition and resettlement, inconsistent cash flows, delayed decision by the employer, design errors and changes, inaccurate estimations, and the relocation of services and utilities were the main issues for cost overruns. A study conducted by Zafar et al. (2016) found different factors to Choudhry et al. (2012); instead, their findings revealed that the major factors of cost overruns were a shortage of experienced contractors, the project site location, security problems, low productivity, and mistakes in the estimation of costs for the project. Moreover, Akram et al. (2017) found that inadequate planning and scheduling, fluctuations in the price of materials, insufficient fund provisions by the client, inaccurate cost estimates, delays in payment by the client, financial difficulties faced by the constructor, financial difficulties faced by the client, additional works, poor financial control on-site, delays in decision making by the client, and frequent design changes were the most significant impacts on cost overruns. A recent study conducted by Sohu et al. (2018) revealed that financial difficulties faced by the client, slow information between parties, changes in the price of materials, design delays, poor site management, poor cost estimation, cash, and payment problems faced by contractor, and delays in decision making were more recent reasons for cost overruns.

In Afghanistan, a study conducted by Niazi and Painting (2017) identified that corruption, delays in progress of payments by the owner, difficulties in financing projects by contractors, security, changes to the order by the owner during construction, and market inflation as the major causes of cost overruns. However, in the same year Ahady et al. (2017) found that market inflation/deflation, corruption, shortages in the supply of construction materials, fluctuations to the cost of building and other materials, delays to the subcontractor's work, a lack of pre-contract project ordination, a lack of skilled labour, improvements to standard drawings during the construction stage, labour unrest, inadequate cost estimates and insufficiently skilled labour as the causal factors of cost overrun. Besides, the latest report published by the Minister of Economy and Cost Afghanistan (2019) revealed that inaccurate design and cost estimates, inflation (exchange rate/escalation), local communities, the demand for change as the major causes of cost overruns in Afghan construction. In Bhutan**,** it was revealed that the poor development of technical and cost estimates and supervision by sponsors, technical problems that arose during construction, poor implementation by suppliers and contractors, and changes to external conditions (economic and regulatory) as the major causes of cost overruns (BEA, 2017). Moreover, the same study revealed that poor project cost estimates, flaws in technical design, and a lack of detailed study on geological aspects as the most common causes of cost overruns in the Bhutan construction sector.

Although some authors have concluded that none of the countries can have similar factors affecting cost overruns (Jarfas, 2010; Wanjari & Dobariya, 2016), the above discussion demonstrates that different countries face various root causes behind such overruns. Thus, it could also be seen that common factors, such as inaccurate cost estimates, material costs, weather conditions, appear in most studies on cost overruns. According to Ahady et al. (2017), inaccurate cost estimates were identified as the most common root causes of cost overruns in developing countries. However, according to the above discussion, this is not limited to developing countries but also includes developed countries, such as Canada, the USA and the UK. Thus, it can be concluded that inaccurate cost estimates are an ongoing common root cause that results in cost overruns in both developed and developing countries. Therefore, regardless of the category of the construction, whatever the type of operation, either in a developed or developing country, inaccurate cost estimates have an adverse effect on cost overruns in almost all the continents around the world.

2.3.4 Causes of Construction Cost Overruns in The Sri Lankan Context

In the Sri Lankan context, a plethora of studies have been undertaken over decades to investigate the causes of cost overruns, as these have a significant impact on construction projects (see section 2.3.2). Many studies have been undertaken on road construction projects and, as a result, they have found that design changes, defects in design, an incorrect assessment of the brief, defects in cost estimates, inadequate site investigations, improper specifications as the main causes of cost overruns (Huiwe et al., 2003; Nishanth, 2005; Wickramasinghe, 2006). Moreover, a study conducted by Wijeykoon (2011) concluded that inaccurate cost estimates, payment delays, delays in shifting existing utilities, cost escalations, design changes during construction, issues in land acquisition as the most predominant factors for cost overruns in Sri Lankan road construction projects. In the same year, a study conducted by Karunasena (2011) identified design changes and defects in cost estimates as the frequent causes of cost overruns. Moreover, Jeykanthan and Jayawardene (2012) carried out a study to examine the cost overrun causes of donor-funded road projects in Sri Lanka. The results were based on 24 road projects and concluded that inadequate feasibility studies, errors, omissions in the cost estimates, scope changes, and land acquisition were the main causes for cost overruns. Halwathura (2013) investigated eleven road construction projects and found that poor estimation was the most significant cause of cost overruns as illustrated in Figure 2.7.

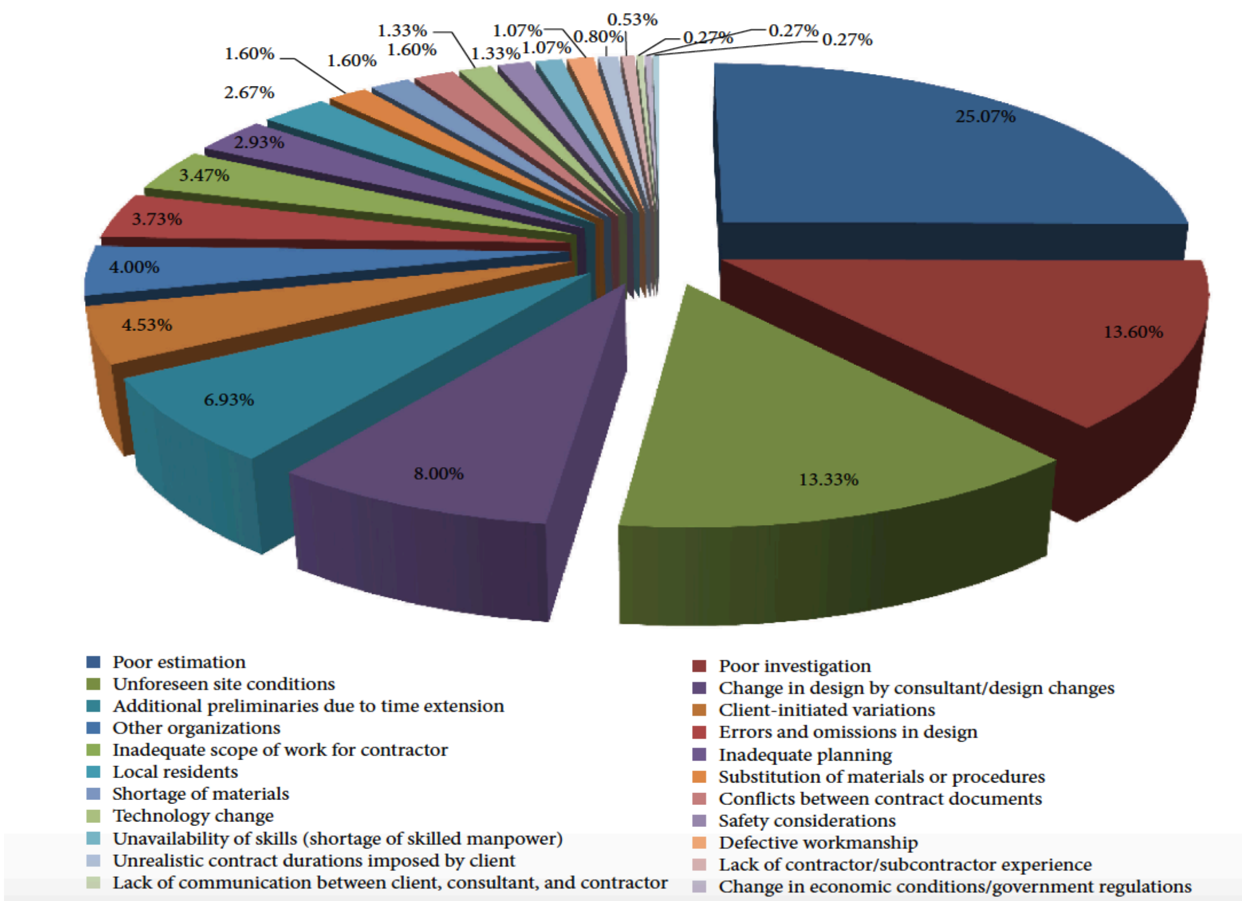


Figure 2.7: Major causes of cost overruns in Sri Lankan construction projects (Halwatura, 2013)

Kumarage (2016) found inaccurate cost estimates, design changes, defects in the feasibility report, and political corruption as the major causes behind cost overrun in the Southern Expressway. A study conducted by Cooray (2017) investigated design changes, exceptional weather, high material costs, deficiencies in cost estimates, and defects in the feasibility report found to be the main causes behind cost overruns in the Colombo-Katunayake expressway. Dissanayake (2019) reported poor planning, poor design, poor estimation and cost control, poor or non-existent competitive procurement process, lender-nominated contractors or negotiated contracts, and corruption as the main causes behind the Northern Expressway-Central Expressway cost overrun. These findings - from both past and recent studies - indicate inaccurate cost estimates or defects in cost estimates as a major reason behind the cost overruns. Therefore, it can be concluded that inaccurate cost estimates are an on-going major reason behind cost overruns in road construction projects in Sri Lanka.

A study conducted by Shanmugam et al. (2006) illustrated that variation, extra works, discrepancies in cost estimates, day works, and price fluctuations were the main causes of building cost overruns in the Sri Lankan construction industry. Dolage and Rathnamali's (2013) findings revealed insufficient/inaccurate initial cost estimates, a shortage of material in the market, delays in approving extra work, variations by the consultant, rainy weather, and contractor labour shortage resulted in cost overruns in Sri Lankan building projects. A recent study conducted by Perera (2016) determined that mistakes and discrepancies involving initial cost estimates, drawbacks in design drawings, a lack of consultant experience, delays in providing the necessary approvals and instructions, and the attitude of consultant persons were the main causes of cost overruns. Moreover, Perera (2017) revealed discrepancies in initial cost estimates resulted in cost overruns in the construction of Peradeniya Medical Faculty in 2014. As reported by De Alwis (2017), the Shangri-La hotel construction project exceeded its budget mainly due to last-minute design changes and issues in the initial cost estimates. These occurred not only in building projects, according to Gamage (2019), but it was found that exchange rate variations, project scope changes, material price escalations, unforeseen ground changes, design changes, inaccurate cost estimates, and inaccurate project planning were the main causes of cost overruns.

Even though the above studies indicate that cost overruns are caused by different factors, inaccurate cost estimates were highlighted as a common cause in all sectors, such as road, building, and hydropower. Moreover, the Sri Lankan government decided to form a special Cost Estimate Review Committee, to avoid cost overruns due to inaccuracies in cost estimates. Harshana (2018) indicates that the impact of inaccurate cost estimates is more severe than other factors. Besides, the former Finance and Media Minister, Mangala Samaraweera (2018), stated that a large number of contracts were awarded over and above the engineer's cost estimates, and the upward revision of cost regularly occurred during the implementation stage. Thus, the accuracy of initial/pre-tender cost estimates are highly important in overcoming the cost overruns in construction projects (Hedaya, 2016). According to Perera et al. (2018) and Rathnayake et al. (2018), conventional practices in preparing cost estimates hinder their accuracy in Sri Lanka. A number of factors have been identified in the literature by various researchers; thus, the identification of these factors helps to increase the accuracy of PTE by minimizing or eliminating their effect. Therefore, the next section will identify the factors specific to the Sri Lankan context.

2.4 Factors Affecting the Accuracy of Pre-Tender Cost Estimates

Inaccurate pre-tender cost estimates are produced due to various factors. At the early stage of the estimates, these factors should be taken into account to minimize the inaccuracies of pre-tender cost estimates. Several studies have been conducted to identify the factors that impact the accuracy of pre-tender cost estimates around the globe. Researchers such as Ji et al. (2014) and Enshassi et al. (2013), have labelled the identified factors under some key categories, such as project characteristics, client characteristics, contractor characteristics, tendering situation, consultant and design, external factors and market conditions. A study conducted by Lim et al. (2016), categorized the factors under different key categories, such as consultants, design parameters, and information. Moreover, Shabani et al. (2018) categorized his findings under technical factors, external factors, management factors, and personal factors. A recent study conducted by Chipulu et al. (2020) identified project information, clarity, and details of the drawings and specifications as the main categories. Nevertheless, as Liu & Zhu (2007) and Enshassi et al. (2015) noted, most factors can also be categorized under two main categories namely control factors and idiosyncratic factors. The factors such as quality information, experience and skill level of the estimator, and quality of the assumptions can be labelled under controlled factors as an estimator can control them to improve the accuracy of pre-tender cost estimates. These factors influence the accuracy of cost estimates, but are out of the estimator's control, such as market conditions, project complexity, weather, contract size, site constraints, resource availability, type of procurement system and contract work type; these can be labelled idiosyncratic factors (Liu & Zhu, 2007). This research aims to improve the accuracy of pre-tender cost estimates through the adoption of BIM. In other words, it aims to improve the efficiency and effectiveness of the estimation process while improving the performance of the estimator. Therefore, considering the nature of this research, only control factors will be considered and factors within the idiosyncratic category will be excluded (see Table 2.2).

This section has evidenced that a plethora of international studies have been conducted to identify factors affecting the accuracy of pre-tender cost estimates. However, it is important to review the factors affecting the Sri Lankan context due to the differences in economic policies, project characteristics, practical problems, and resource availability. In terms of the Sri Lankan context, factors identified in the global literature could be the same or completely different. However, many researchers have conducted studies to identify the factors particular to Sri Lanka's construction environment. For example, a study conducted by Jeykanthan and Jayawardena (2012) found that the following factors affects the accuracy of cost estimates: error and omission in detail designs, extreme weather, poor documentation, failures in manual quantity take-off, and the double counting of quantities.

A survey conducted by Wijekoon and Attanayake (2013) to identify the factors affecting the accuracy of cost estimates in Sri Lankan road projects identified design errors, project complexity, inaccurate quantities, insufficient time, errors in the original measures, poor document management and adverse weather as the major factors. Moreover, unforeseen site conditions, design changes, errors and omissions, a lack of communication, poor weather conditions, inexperienced estimators, insufficient time for the preparation of estimates, and inaccuracies in quantity take-offs were the main factors found by Haluwithrana and Ranasinghe (2013). According to Britto et al. (2013), the accuracy and reliability of cost information, material prices, clear and detailed drawings, estimator experience, quality information, applicable information, the availability of historical cost data were the main factors identified. Dolage and Rathnamali (2013) found the rainy weather, inexperienced estimators, insufficient time, unclear design drawings, insufficient information, poor coordination, a lack of communication, rework and poor site investigation had a considerable impact on the accuracy of cost estimates.

Perera et al. (2014) conducted a Delphi survey with 33 Sri Lankan construction experts. Although one finding indicated that design errors were the most critical factor, Perera et al. highlighted poor information management, insufficient time, estimator inexperience, poor quality information, and unrealistic measures as similarly critical factors. Hiroshan and Hadiwattage (2014) reported 44 factors, and among them the cost of materials, size of the project, project planning, and project complexity were identified as the most significant factors. According to a survey conducted by the World Bank Group (WBG, 2014) to identify factors of inaccurate cost estimates in Sri Lanka, inadequate time, shortfalls inexperience, incomplete design drawings, major changes in quantity, inadequate site investigations, and errors and omissions in the design drawings were the major factors impacting the estimate. Dolage and Pathmarajah (2015) found 24 factors that affect the accuracy of estimates, and among them were, poor coordination among staff members, poor skill development poor communication with other parties, and poor information management.

According to Lalitha and Malkanthi (2017), 21 factors affect the accuracy of pre-tender cost estimates. Of these 21 factors the following are noted as significant: design changes, unpredictable weather conditions, fluctuations in the cost of building materials, a lack of coordination at the design phase, the inadequate review of drawings and contract documents, incomplete design at the time of tender, re-measurements of provisional works, delays in issuing information, improvements to standard drawings, omissions, and errors in the BOQ, inaccurate quantity take-off, and lack of experienced project team members. According to Risath et al. (2017), the major factors affecting the accuracy of cost estimates in the eastern province of Sri Lanka are: poor communication and coordination, mistakes in design drawings, inadequate estimator experience, insufficient information at the initial stage, rework due to errors, the lack of use of advanced technologies, and poor site investigations.

After proposing to set up a Committee to review initial estimates, the Finance and Mass Media Minister, Mangala Samaraweera (2018), explained several reasons for unrealistic cost estimates, such as a lack of consideration given to the initial project preparatory works, incomplete and inaccurate project design drawings and plans, errors and omissions in the engineers' cost estimates, faulty tender documents, discrepancies among documents, and lack of proper feasibility studies. As Chandraratne et al. (2019) identified, the experience and skills of the estimator, the lack of reliable cost estimation, and incomplete project details are the main factors affecting of the accuracy of PTE. According to Perera et al. (2019), the type of work, project duration, and location of the project are the main factors that determine the accuracy of the PTE.

In Table 2.2 these factors are grouped under main headings, such as design, coordination, quantity take-off, and information. However, according to an argument made during the discussion, weather, market conditions, and project characteristics are identified as idiosyncratic factors. Therefore, these three categories will not form part of this research. Apart from that, other factors will be discussed in detail in the next section.

Table 2.2: Summary of factors affecting the accuracy of pre-tender cost estimates in Sri Lanka.

Category	Factors	
2D Design Drawings	Design changes	Control Factor
	Inadequate review for drawings	Control Factor
	Incomplete design	Control Factor
	Improvements to standard drawings	Control Factor
	Absence of clear and detail drawings	Control Factor
	Mistakes in design drawings	Control Factor
	Rework due to errors in drawings	Control Factor
	Errors and omissions in drawings	Control Factor
Coordination	Lack of coordination	Control Factor
	Poor coordination among staff members	Control Factor
Manual Quantity Take-off (QTO)	Re-measurements	Control Factor
	Omissions and errors in the BOQ	Control Factor
	Inaccurate quantity take-off	Control Factor
	Double counting's of quantities.	Control Factor
	Errors in original measures	Control Factor
	Major changes in quantities	Control Factor
Information	Delays in issuing information	Control Factor
	Poor information management	Control Factor
	Accuracy and reliability of cost information	Control Factor
	Lack of Quality information	Control Factor
	Lack of Applicable information,	Control Factor
	Availability of historical cost data	Control Factor
	Poor documentation	Control Factor
Experience and knowledge	Estimators Lack of experience	Control Factor
	Poor skills	Control Factor
Weather	Unpredictable weather conditions	Idiosyncratic Factor
Market condition	Fluctuations in the cost of building materials	Idiosyncratic Factor
Communication	Poor communication with other parties	Control Factor
Use of technology	Un-use advanced technologies	Control Factor
Site investigations	Lack of conducting site investigations	Control Factor
	Inadequate site investigations	Control Factor
Time constraints	Insufficient time	Control Factor
Project characteristics	Project complexity	Idiosyncratic Factor

2.4.1 The Use Of 2D Design Drawings

The history of design drawings can be traced back to Ancient Egypt (Babič & Rebolj, 2016; Pratyush, 2007). In the modern construction industry, different types of drawings are available, such as 2D CAD drawings, 3D drawings and BIM models. However, for this research, the term 'design drawings' will refer only to '2D CAD Drawings'. After the era of pen and pencil paper drawings, Computer-Aided Design (CAD) evolved for drafting, modelling, and measurement purposes (Olatunji et al., 2010). Moreover, due to the increasingly complex nature of construction projects, the use of 2D drawings has become very problematic. Nevertheless, the majority of construction firms solely depend on outdated methods, such as the use of 2D drawings (CIC, 2019; Thilmany, 2018). A recent study conducted by Kumara et al. (2017) found the majority of Sri Lankan construction projects dealt with 2D CAD drawings, having had more than two decades of history in using such drawings.

2D drawings provide limited visualization to the consumers, who have to spend a significant amount of time visualizing the drawings to get a clear picture (Sunil et al., N.D). According to Thilmany (2018), different people involved in a project visualize the look of a completed building in their minds but not on the screen. This has become more challenging with the increasingly complex nature of projects. Not only do non-technical people find it hard to understand 2D drawings but also QS's encounter difficulties in reading drawings (BIP, 2020; Jayawardene et al., 2019). A clear picture of the design drawings reduces conflicts, which could occur during the estimation (Viklund, 2011). However, limited visualization in 2D drawings increases misunderstanding amongst QS's about the details provided in the drawings. This can lead to the wrong assumptions e.g., about material and finishes to be used, and the taking of incorrect measurements, such as the wrong heights in calculations (Toostep, 2010). Thus, this can lead to inaccurate cost estimates at the initial project stage (Wong et al., 2014).

Limited visualization does not allow for early clash detection or the identification of drawing errors at the early stage of the project (Mattsson & Rodny, 2013), which results in design changes. In 2D drawings, this review process is carried out manually, or by combining 2D CAD drawings digitally. Therefore, there is a strong relationship between visualization and clash detection, as increased visualizations results in early clash detection. Thus, clash detection in 2D drawings is extremely error-prone due to the lack of visualization provided by 2D drawings. Moreover, design changes can also occur due to the lack of visualization and the failure to conduct early clash detection (Ali & Kamaruzzaman, 2010). In construction, design changes are considered a factor for changing the entire project cost (Isan, n.d; Ridmika & Dissanayake, 2017; Madushanka et al., 2017). Therefore, in 2D drawings design changes are inevitable. In addition, 2D designs lead to errors and omissions, not only in early design stages but also throughout the construction process, which ultimately mean the production of inaccurate pre-tender cost estimates (Abeykoon et al., 2019; Monteiro & Martins, 2013). Research undertaken by Senaratne and Wijesiri (2008), found that 88% of design errors and 88% of rework were due to design changes and caused frequent waste in the Sri Lankan construction industry. For example, in a road project when designing the pavement of the road and strengthening the pavement with aggregate base coarse which is replaced by binder coarse leads for cost overruns. When curve widening on a road is taken up during construction, if this was not included in the original design, this invariably increases the cost of the project (Isan, n.d) as it would not have been included in the pre-tender cost estimate. Moreover, Perera et al. (2009) identified that most of the design changes happen in road construction projects in Sri Lanka due to increasing road widths, changes to the road surface from Double Bituminous Surface Treatment (DBST) to asphalt paving, the addition of a binder course layer and the introduction of a hard shoulder instead of an earth shoulder. Therefore, Dolage and Rathnamali (2013) recommended that a sufficient number of sessions should be undertaken for the design review process before finalizing the design.

Nevertheless, once the changes are made in 2D drawings, e.g. the editing of plans, sections or elevations, QS has to carry out manual revisions (Robinson et al; 2015; Mahamid, 2017) to identify these changes and to incorporate them within the existing measures in the estimate. This is a very time-consuming task involving the entire estimation process. Moreover, views of 2D drawings do not accurately reflect the design (SolidWorks Corporation, 2017) as lines, circles and curves do not allow any relationship between the components of the drawing, e.g. window and wall (Weygant, 2011). Therefore, 2D drawings are less interactive and changes in one view will not automatically be reflected in other views (Reinholdt, 2014).

As PTEs are prepared at a time of limited information, all available information is fundamental for an accurate PTE. However, 2D drawings consist of lines, circles, and curves, which only provide a graphical representation of geometric data (Eastman et al., 2011; Thilmany, 2018). They do not provide any non-geometrical information, such as quantities and measurements for the estimator. Therefore, 2D drawings are limited with less information available in the drawings, and sections that have to be produced (Bawail, 2018; Gebrehiwet & Luo, 2017; Mattsson & Rodny, 2013). This results in the estimator making unrealistic assumptions, which decreases the accuracy of the pre-tender cost estimates (Hussain et al., 2018). Therefore, a question arises as to why most construction firms still adopt outdated error-prone 2D drawings at a time of complex construction works.

2.4.2 Poor Communication

Poor communication is found to be one of the main challenges behind inaccurate cost estimates especially in the initial stages of the project (Olanrewaju et al 2017; Shanmugam et al, 2006; Sherman 2018). According to Hussain et al. (2018), communication is the medium of transferring information between the sender and receiver. Therefore, there is a strong relationship between information and communication, as rich, high quality information can be received through effective communication. The preparation of accurate estimates requires the transmission of high-quality information to several parties (Cherkaoui, 2018; Olanrewaju et al, 2017; Sunil et al, 2015). Even though Jelle (2013) explained that stakeholders should stick together to yield an accurate cost estimate, cultural differences in the different professions in many cases mean it is hard to maintain a proper information flow (Dainty et al., 2006; Eastman et al., 2011; Gamil et al., 2018; Gómez-Ferrer, 2017).

According to Epasinghe et al. (2018), in most cases, papers are used as the medium of sharing information among stakeholders, which also results in poor communication. Most of the time, QS's request information through extensive paperwork (Bhat, 2019; Sunil et al, 2015). Vulcanss (2015) identified this as a 'wall syndrome, as shown in Figure 2.8. Thus, it avoids the chances of clashing with other parties and ensures the consistency and accuracy of information when undertaking accurate estimates (Ling & Boo, 2001). Therefore, paper-based information sharing among project team members offer less effective communication.

Figure 2.8: Poor communication over the wall syndrome (Vulcanss, 2015)

During the time of President Premadasa (1978-1989), advanced communication tools, such as the Internet, were not available in Sri Lanka (Silva, 2015). So, communication occurred through letter writing. Hence, it is disappointing to note that, although advanced technologies like the Internet, email, and many electronic applications are available, there is very poor linkage between project stakeholders.

Once changes are made, formal feedback from project participants, such as the design team and the estimating team is essential (Ling & Boo, 2001) to clarify and update estimates. In the Sri Lankan context, if someone sends an email requesting feedback you will neither get an acknowledgment nor a communication on what you expect (Silva, 2015; Synder, 2019). Therefore, unresponsiveness has resulted in a poor feedback system that increases conflicts in design information and results in less accurate cost estimates (Akintoye & Fitzgerald, 2000). Moreover, the failure to use modern applications, such as email and smartphones, has also resulted in unresponsiveness and poor communication (Smith, 2019).

Besides competition, a lack of trust, selfishness, and short-term relationships have also resulted in poor communication which decreases the accuracy of initial cost estimates (Eastman et al., 2011; Hatmoko et al., 2019). Moreover, unclear responsibilities also result in poor communication as most QS's lack knowledge and a solid understanding of their project role (Gamil et al., 2018; Olanrewaju et al., 2017). Similarly, failures in the identification of stakeholders might result in information transmitted to the wrong party, or relevant parties might not receive any information, which can also lead to miscommunication (Azrai, 2012; Gómez-Ferrer, 2017; Löfgren & Wikforss, 2007).

It was also found that the use of different languages could also result in poor communications due to difficulties in understanding by the receiver (Emmitt & Gorse, 2006; Emuze, & James, 2013; Gómez-Ferrer, 2017; Hussain et al., 2018; Lunenberg, 2010). Moreover, according to Olanrewaju et al. (2017) and Gamil et al. (2018) poor coordination among project stakeholders was found to be another reason for poor communication. Therefore, it can be concluded that there is a strong relationship between poor communication and poor coordination. Nevertheless, Gamil and Rahman (2017) state that effective communication is key to the production of accurate cost estimates. Thus, based on the above discussion poor communication can be concluded as one of the main reasons behind inaccurate cost estimates.

2.4.3 Lack of Information

The accuracy of a PTE depends on the amount and quality of available information (Azrai, 2012; Constructiontuts, 2017; Enhassi et al., 2013). Therefore, the accuracy of the pre-tender cost estimates is positively correlated with the amount of information available (Kim et al., 2004). However, the use of 2D drawings only gives the QS access to a limited amount of information with less accuracy (Bawail, 2018; Gebrehiwet & Luo, 2017; ICE, 2019; Lim et al., 2016; Oladokun, 2009; Mattsson & Rodny, 2013). Therefore, on most occasions, gaps of missing information are filled by the assumptions made by a QS which leads to cost miscalculations (Akintoye & Fitzgerald, 2000; Alumbugu et al 2014; Azrai, 2012; Hussain et al., 2018; Ling & Boo, 2001; Liu & Zhu, 2007; Sunil et al, 2015). Unrealistic assumptions increase the inaccuracy of pre-tender cost estimates (Dell' Isola, 2002; Ling & Boo, 2010).

Moreover, as discussed in section 2.3.2, poor communication also results in less information due to paper-based information sharing, the failure to use modern technologies, cultural differences, and poor feedback (Epasinghe et al., 2018; Gamil et al., 2018; Smith, 2019). According to Senaratne and Wijesiri (2008), late information was found to be the main waste in pre-tender cost estimation in Sri Lankan building projects, alongside defective information, and unclear information, as shown in Figure 2.9. These types of information help to establish unreliable information flow throughout the project life cycle, which increases the inaccuracy of cost estimates.

Britto et al. (2015) stated that the common practice of producing pre-tender cost estimates in the Sri Lankan context means using historical cost data and adjusting to the current market rates (Britto et al., 2015; Shanmugam et al., 2006). However, the level of accuracy of this information is uncertain. Besides, a lack of coordination among project stakeholders also leads to difficulties in information sharing (Li et al., 2017). According to Gutierrez (2017), one-sided data ownership has resulted in limited access to project information for other stakeholders. Therefore, the relationship between the project stakeholders is highly significant for the receipt of timely sufficient information and the avoidance of repetitive work. It can be concluded that the lack of information has a strong effect on reducing the accuracy of the PTE.

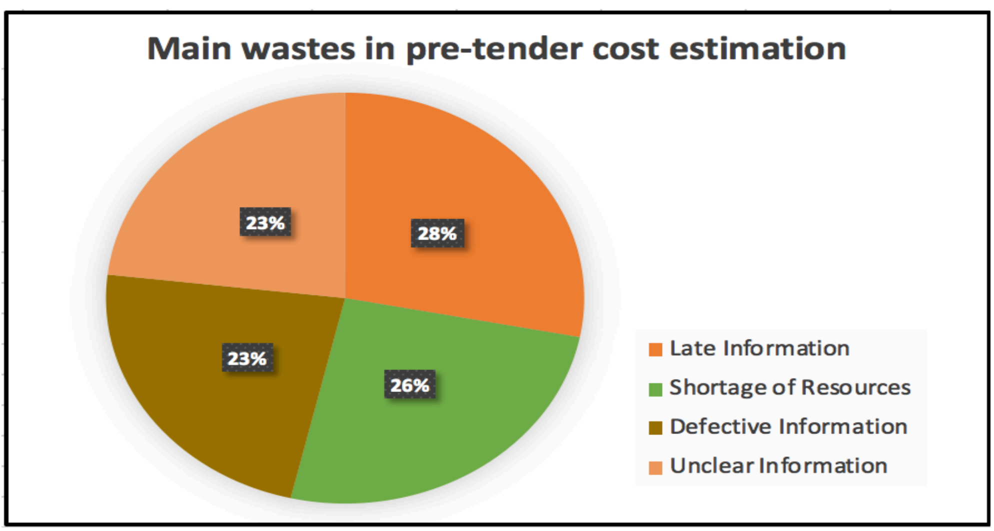


Figure 2.9 Main waste in pre-tender cost estimates in Sri Lanka (Senaratne & Wijesiri, 2008)

2.4.4 Lack of Coordination

According to Gunaratne et al. (2018) and Sunil et al., (2015), the lack of coordination was noted as another issue behind the inaccurate PTE. As discussed in 2.3.2, coordination positively correlated with communication. Therefore, poor communication results in a lack of coordination (Gamil et al., 2018; Olanrewaju et al., 2017). According to Wanjari and Dobariya (2016), a lack of coordination creates a communication gap among project parties, including the client, consultant, and contractor. Project parties have to deal with a large amount of data derived from different stakeholders; therefore, the relationship among stakeholders is vital for accessing this information at the right time and for the correct location (Alaloul et al., 2016). However, a poor relationship among project stakeholders also affects the level of coordination and has led to conflict and misunderstanding during construction and difficulties in obtaining information from the different parties involved (ICE, 2019; Jeyakanthan & Jayarajah, 2016). For example, Figure 2.10 shows that the entrance stairs area to avoid was not provided in the design itself. Thus, during a heavy shower, rainwater accumulates in the corridors through a void area. If there had been effective coordination at the beginning of the project, this would have been identified, and included in the initial cost estimates. The isolated working culture among professionals was found to be another reason that has resulted in a lack of coordination (World Bank, 2017). Therefore, coordination issues might also impact on the accuracy of the PTE.

Figure 2.1 Lack of coordination

2.4.5 Lack of Proper Site Investigations

Herath et al. (2017) identified that delays in receiving the site investigation report represented another issue for inaccurate PTEs. Britto et al. (2015) further supported this in confirming that a lack of proper site investigation could result in an inaccurate PTE. Inadequate site investigations can result in ignoring important site conditions, such as slopes, natural drainage, access restrictions, and obstructions, which can help to determine the volume of enabling works and the selection of machinery and plants (Cunningham, 2017). Moreover, if these conditions are not properly included in the estimates, they can lead to cost overruns due to inaccurate figures in pre-tender cost estimates (Park & Papadopoulou, 2012). For example, narrow roads to access the site prevent the use of large-scale machinery. If a QS neglects this issue in his estimate, the cost ultimately increases either through the preparation of wider roads for access or by changing the type of machinery. Therefore, conducting a proper site investigation is fundamentally important when preparing the PTE.

Nevertheless, QS's have tended to conduct no or limited site visits prior to preparing a PTE. This is due to the limited available time (Towey, 2012). Moreover, time-consuming activities, such as MQTO (see section 2.3.7), have also limited QS site visit (Jeyakanthan & Jayarajah, 2016). Similarly, projects situated in different geographical locations have also prevented QSs from visiting the site before preparing PTE due to travel difficulties (Central Bank of Sri Lanka, 2016). According to Halwathura, (2013) a lack of site visit also influences the hiring of unprofessional staff to prepare PTE. Therefore, it can be concluded that a smaller number of site visits also results in increasing PTE inaccuracies.

2.4.6 Lack of Experience and Knowledge of Quantity Surveyor

As discussed in sections 2.4.1, 2.4.2 and 2.4.3, the QS has to make assumptions, especially during the pre-tender stage. Accordingly, when sufficient information is not available when preparing the pre-tender estimates, the QS has to fill the gaps based on their knowledge or experience (Akintoye & Fitzgerald, 2000). The reliability of these assumptions is based on the knowledge and experience of the QS. The quality of their assumptions can be determined by identifying the trend in estimating (Lowe & Skitmore, 1994). In the previous literature, it has been cited that the accuracy of cost estimates highly depends on the level of knowledge and experience of the QS (Aibinu & Pasco, 2008; Aljohani et al., 2017; Arain et al., 2006; Clough & Sears, 1994; Madi, 2003; Trost & Oberlender, 2003;).

Moreover, experienced QSs are capable of determining the quality of the information provided before making any decision (Oberlender & Trost, 2001). The experience and knowledge of the QS is required, not only to identify quality information, but also to determine the client's needs and the different aspects of a contract (Azrai, 2012). A lack of experience can also lead to reworks during the project, which decreases the accuracy of initial cost estimates (Aljohani et al., 2017). According to Sunil et al. (2015), a lack of ability to apply modern techniques in cost estimation also result of a lack of knowledge and experience, and thereby decreases the accuracy of cost estimates. The ability to manage critical timelines, and physical and mental work overload also depends upon the knowledge and experience of the QS (Eastman et al., 2011; Jackson, 2002). An experienced and knowledgeable QS can manage these effectively without being nervous. Therefore, a lack of experience and knowledge is one of the main factors to affect the accuracy of cost estimates (Aljohani et al., 2017; Odusami & Onukwube, 2008). Therefore, in Sri Lanka, the accuracy of a PTE is based on experience and skills of the QS (Chandrathne et al., 2019).

Halwathura and Ranasinghe (2013) identified that the lack of available professional staff to prepare pre-tender estimates for Sri Lankan clients have resulted in a lack of QS experience and knowledge. This is mainly due to the client's financial consideration, which may mean they hire a less experienced QS, which will reduce the cost of the job. However, in the long term, this will affect the success of the entire project. Moreover, a lack of available professional QS's in the country (due to the large number of SL QS's working abroad) has also resulted in a lack of QS experience and knowledge to prepare PTE (EDB, 2018). As most senior QS's have direct involvement with the project, young QS's learn through observation. Even if it is easy to catch up with technical skills, it is harder to transfer soft skills, such as decision making, to a young practitioner due to the level of experience. Therefore, it can be concluded that a lack of estimator experience and knowledge is another reason for inaccurate cost estimates.

2.4.7 Manual Quantity Take-off (MQTO)

Shen and Issa (2010) defined take-off as "the process of calculating the amount, type and installation method of all elements in the object, made before the construction process". Thus, manual quantity take-off and calculations are the most time-consuming tasks in the entire estimation process (Ashworth et al., 2013; Cartlidge, 2011; Monterio & Martins, 2013; Sabol, 2008). This was further supported by Mitchell (2012) and Wong et al. (2014) who stated that 50% to 90% of the time is just spent on counting the elements from the total allocated time for the preparation of cost estimates. As quantities are determined manually, extra care is needed when detailing every material type and quantity specified on the construction drawings (Trivedi, 2019). Nevertheless, human errors in MQTO are inevitable due to various reasons.

According to Jayawardene et al. (2019) and BIP (2020), a QS can take considerable time to read and understand drawings due to discrepancies in 2D drawings. Moreover, as discussed in section 2.3.1, the project complexity, limited visualization and design changes are time-consuming tasks that demand repetitive work (Hanid et al., 2011). A lack of visualization leads QS's to take the wrong measurements and dimensions, for example 42 metres taken off as 24 metres which are combined with the wrong unit of measurements (Bečvarovska & Matějka, 2014; Toostep, 2010;). According to Nigam et al. (2016), errors are associated with moving data between files (e.g. inserting data from 2D drawings in Excel to produce estimates) and can similarly lead to the wrong measurements. Moreover, the risk of double counting is more likely to happen during a manual QTO (Cartlidge, 2013), which adds extra measurements and costs to the estimate. Once design changes have occurred, QS's have to track the design changes manually and update quantities manually accordingly during the estimation (Wong et al., 2014). Manual re-measures are a tedious time-consuming task that adds extra workload to a QS. Unable to detect all the changes and update them in all drawings leads to missing elements, which can affect the accuracy of the cost estimates (Olsen & Taylor, 2017; Sabol, 2008). Also, extra work increases the stress level of the QS and can mean that inaccurate measurements are taken (Leung, et al., 2008, 2010).

Some clients expect to have accurate cost estimates in order to verify the design alternatives, identify the ideal design, and apply the best construction method. Hence, MQTO does not produce various accurate cost estimates for different design alternatives (Ashworth et al., 2013). Moreover, MQTO requires an experienced quantity surveyor to conduct a QTO; thus, an MQTO estimator's knowledge of materials, rates, experience in estimating, and skill in taking off material quantities are essential to ensure an accurate estimate (Haider et al., 2020). However, it is difficult to perform an accurate QTO manually even for experienced quantity surveyors. Besides, the estimator's ability to deal with Excel is also compulsory for MQTO, as it requires the development of formulas for the quantity calculations (Gołaszewska & Salamak, 2017), and inaccurate formulas result in inaccurate measurements. Therefore, it can be concluded that MQTO can also negatively impact the accuracy of PTE.

2.4.8 Time Constraints

In the initial project phases, the client provides a limited time period for the QS to prepare a pre-tender cost estimate. According to An et al. (2011), the most important factor for increasing the accuracy of the pre-tender cost estimate is to allocate an appropriate time. However, time-consuming tasks, such as the MQTO (see section 2.3.7) make this more challenging as the process requires considerable time. Moreover, the use of 2D drawings also takes considerable time, as the QS has to properly understand the drawing. At the pre-tender stage, and due to limited information, the QS might need to chase project stakeholders to get relevant project information.

Thus, due to the lack of time, in most cases, a QS is unable to collect proper information (Azrai, 2012). This increases the inaccuracy of pre-tender cost estimates due to missing items, which especially affects complex projects (Magnussen & Olsson, 2006). Moreover, limited time means a QS has to make many assumptions that increase the number of mistakes during the pre-tender cost estimation (McGinnis, 2016). Besides, limited time also encourages a QS to take shortcuts, such as 'guess estimations', to complete cost estimates during the given time (Toostep, 2010); for example, working out a metre square rate for the roof of another project and multiplying that rate by the area of the proposed project. Also, a QS may take the overall floor area of building to price the screed, floor finish, and ceilings. The walls make up about 10% of the floor area and could cause serious price deviation if the floor finish and ceiling are expensive.

According to McGinnis, (2016), the lack of time also effects the building of stakeholder relationships. Limited time leads them to fulfill individual goals rather than to work as a team. Therefore, it reduces coordination among the project team. Allocation of sufficient time would support the preparation of accurate pre-tender cost estimates at the initial stage of the project (Attanayake & Wijekoon, 2013; Oberlender & Trost, 2000; Sinclair, et al., 2002). Therefore, it can be concluded that time constraints are another factor to affect the accuracy of the PTE.

2.4.9 Inefficiencies in Existing Cost Estimating Software

Karlsen and Lereim (2005) identified the use of sophisticated technology as a major reason for time-consuming tasks in pre-tender cost estimations. According to Kumara et al. (2017), MS Excel was found to be the most popular software among Sri Lankan QS's when conducting cost estimations. This was further supported by Epasinghe et al. (2018) who indicated that 76% of Sri Lankan construction industry practitioners utilise Microsoft Excel to perform cost estimates. According to Akintoye and Fitzgerald (2000), the use of generic systems, such as Microsoft Excel, represented a major reason for the low reliability of estimates. This is because Excel is a general spreadsheet program that does not consist of estimator-specific functions; therefore, it could be hard to maintain a consistent approach to estimating when using Excel (Hook, 2018). Moreover, Excel has limited compatibility with take-off programs but requires the input of all information manually, which is prone human error, such as missing information or double counting (Goaszewska & Salamak, 2017).

Although Excel is effective in its calculations, it leaves plenty of room for human error, especially when creating formulas (Lee, 2016). With the improvements in estimation techniques, formulas have become more complex and spreadsheet errors have become more frequent (Caulkins et al., 2008; Chandraratne et al., 2019). Therefore, this requires QS's with specific knowledge and experience related to Excel, and particularly with an ability to define formulas (Torp & Klakegg, 2016). Nevertheless, these formulas can be easily altered either on purpose or by mistake (Hook, 2018). Moreover, in most cases formulas require manual adjustment based on the different tax rates as these do not automatically update (Lee, 2016). Mistakes in formulas lead to miscalculations and it would be hard to determine where such errors are located (Construction Software Review, 2017). For example, external works may not be accounted due to failures to check the formulas applied in all the relevant cells across the entire calculation. Besides, multiple people are involved in a spreadsheet, who can end up restoring issues, which is very time-consuming, and means more work is created (Hook, 2018). Therefore, choosing the right software is important at the beginning of a cost estimation (Goaszewska & Salamak, 2017). Moreover, the use of inappropriate software risks increasing inaccuracy amongst pre-tender cost estimates. To summarise, the above discussion was able to identify the most significant factors and their root causes, which affect the accuracy of PTEs; these are summarised in Figure 2.11.

2.5 Summary and Link

This chapter explained the state of the art of the phenomenon related to objective 1. Firstly, the chapter explored the status of pre-tender cost estimates, its definitions, and the importance of having an accurate PTE. Subsequently, the chapter describes the status of global and Sri Lankan cost overruns and identified the major causes for cost overruns both globally and in Sri Lanka. Moreover, the chapter identified the use of 2D design drawings, poor communication, a lack of information, poor site investigations, a lack of QS knowledge and experience, Manual Quantity Take-off (MQTO), a lack of coordination, time constraints and inefficiencies in existing cost estimating software as the significant factors which affect the accuracy of PTEs.

To mitigate or overcome the impact of the above-identified factors, it is clear that there is a need to introduce a new estimating practice that is capable of improving the accuracy of pre-tender cost estimates in Sri Lanka (Britto et al., 2015). In many countries, the BIM-based estimating process has become popular due to its capabilities for improving the accuracy of cost estimates. Therefore, chapter three describes how BIM helps to improve the accuracy of pre-tender cost estimates by overcoming the factors identified in this chapter.

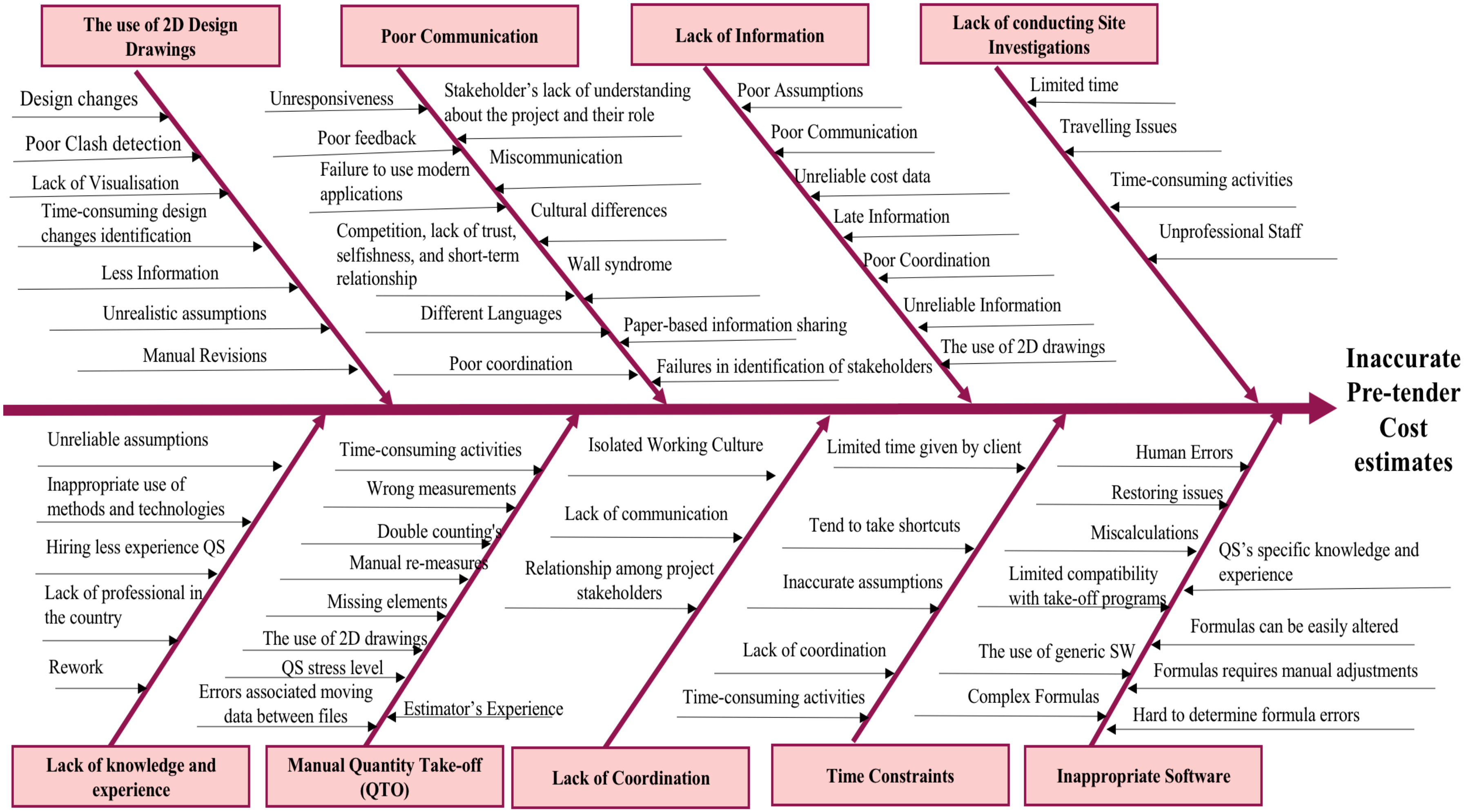


Figure 2.2: Fishbone diagram of the factors affecting the accuracy of the pre-tender cost estimate

3 BUILDING INFORMATION MODELLING AND BIM ADOPTION

3.1 Introduction

This chapter reviews state of art BIM and BIM adoption. The chapter structure is presented as follows: Firstly, it addresses the evolution of BIM, BIM definitions, and dimensions of BIM is reviewed. Secondly, it reviews how BIM helps to improve the accuracy of pre-tender cost estimates. Thirdly, the chapter considers BIM adoption trends in both developed and developing countries, and finally, the drivers and barriers to BIM adoption are discussed.

3.2 Evolution of Building Information Modelling (BIM) in the Construction Industry

BIM is the latest technological development within the construction industry and operates in a collaborative 3D environment (MagiCAD, 2020). However, the development of the concept can be traced more than six decades (Andersen, 2020). During the late 1970's, Eastman experienced difficulties in working with construction drawings due to the limitations to visualizations and late updates (Crotty, 2012; Eastman et al., 1975). Many countries, such as the USA, Finland, and Japan, have undertaken experiments to develop computer programs to solve issues in construction drawings (Goubau, 2017).

According to Reddy (2012) and Ahmad-Latiffi et al. (2013), the concept of BIM originated in the late 1970s from Professor Charles Eastman at the Georgia Tech School of Architecture. The development of BIM does not just reflect one aspect of the construction industry; hence, it has broadened to a wide range of perspectives, such as design, estimation, construction process, building life cycle, performance, and technology (Latiffi, 2014). Overall, BIM could be applied to the overall construction life cycle starting from pre-construction, construction, and through to post-construction (Azhar et al., 2008; Latiffi, 2014). Figure 3.1 illustrates the development of BIM since 1975.

As illustrated in Figure 3.1, BIM has evolved gradually from a period that started with Building Description Systems (BDS) that were introduced by Eastman in 1975. BDS was used to detect clashes in complex projects during design development (Eastman, 1976). However, within a short time, BDS was rejected by many architects who did not have the opportunity to develop it (Dobelis, 2013). As a result, the Graphical Language for Interactive Design (GLIDE) was introduced in 1977, which is an improved version of BDS. GLIDE was used to detect certain elements while ensuring the accuracy of data in cost estimating and structural design (Eastman, 1997). Nevertheless, BDS and GLIDE limited the construction stakeholder's involvement to the design stage; therefore, they needed more advanced programs to offer more collaboration during the construction phase. As a result, in 1989, Building Product Model (BPM) was invented which covered design application, estimation, construction process, and involvement of construction players (Bjork, 1989; Hatti, 1996).

BPM also is known as RATAS in Finland, which was used as a national framework and conceptual model to program IT in construction (Hatti, 1996). Compared to BDS and GLIDE, BPM acted as a database consisting of project information throughout its project lifecycle. Therefore, it improved interpretable communication for Computer-Aided Design (CAD) in construction (Luiten et al., 1998). With time, AEC required the integration of information and knowledge for design and construction management; hence, BPM was focused only on product information. Therefore, in 1995, BPM was further developed as a Generic Building Model (GBM) to capture AEC industry needs (Eastman & Siabiris 1995). GBM was capable of managing project information by incorporating construction activities. Nevertheless, as the complexity of the construction industry gradually increased, there was a need for the wider adoption of ICT to accomplish project expectations and higher productivity (Lattiffi, 2014).

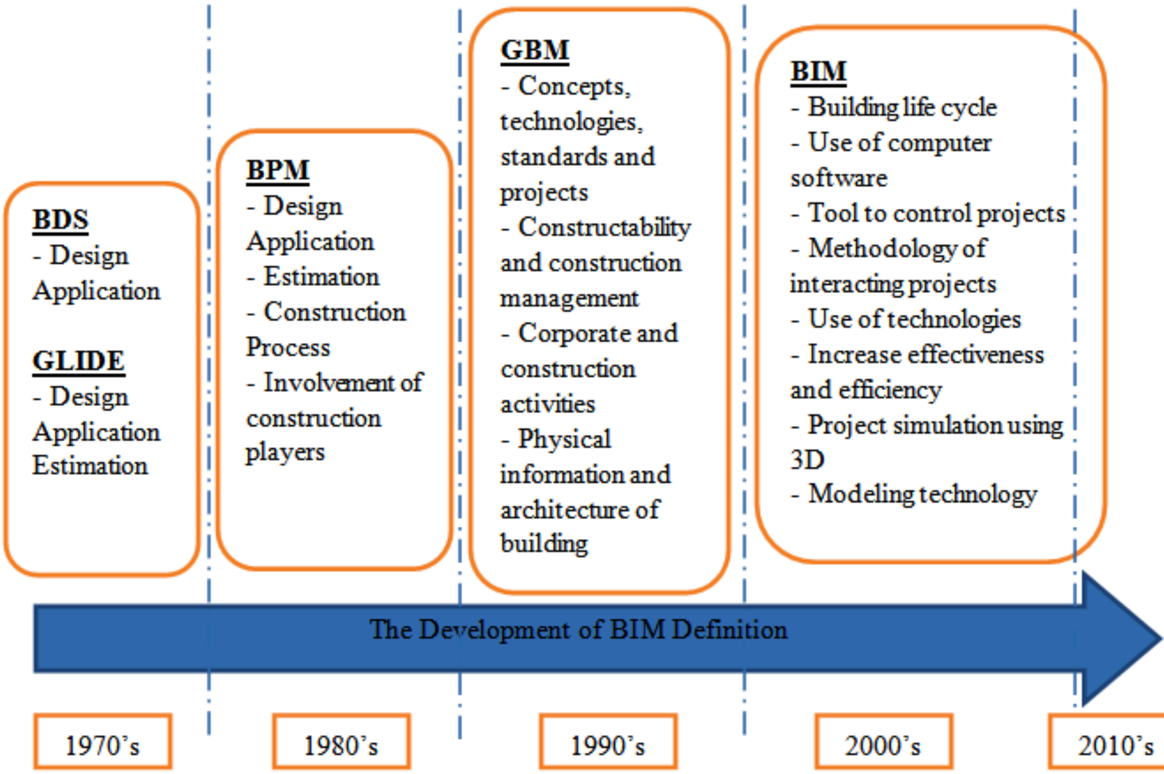


Figure 3.1: Development of the definition of BIM from 1975 to 2013 (Latiffi, 2014)

It was clear that technology was developed to accomplish the needs of the industry over different periods. Likewise, BIM was utilized to fulfill the AEC industry needs. However, BIM cannot be considered a newly developed concept, but rather a more advanced version of previous technologies. Therefore, the introduction of the concept "BIM" cannot be traced back to one person, but instead to many (Hanratty, 2018).

As BIM evolves to provide more sophisticated BIM services, different dimension levels are introduced to professional roles in the construction industry (Smith, 2014). These dimensions provide a widespread understanding of the construction project, how it should be delivered, how much it would cost, and the way it should be maintained (NBS, 2017). Therefore, these dimensions - namely 3D, 4D, 5D, 6D, 7D, and 8D – are linked to an information model with a particular set of data (McPartland, 2017).

As illustrated in Figure 3.2, 3D BIM or the shared information model is the most familiar dimension to develop a three-dimensional object via 3D modelling software, such as Revit and a LOD definition (Warsaw, 2016). These objects consist of geometric (such as volume of concrete, length, width, height) and non-geometric (labour hours) information; these are fundamental for QSs in the preparation of accurate cost estimates (Kjartansdóttir et al., 2017). Moreover, this information becomes richer and is updated promptly as the project progresses (Celauro et al., 2019). Moreover, improved visualization, improved coordination, and rich information are the key benefits that a QS could experience with the use of a 3D model (McPartland, 2017).

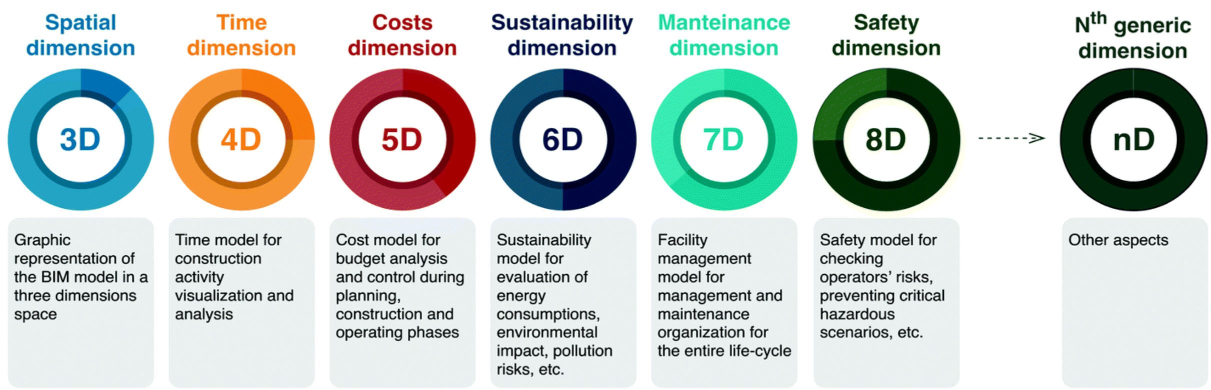


Figure 3.2: BIM dimensions (Celauro et al., 2019)

In comparison, 4D or Construction Sequencing is the fourth dimension, according to Figure 3.2, which adds scheduling data to the project information in the 3D model (NBS, 2017). This will provide accurate programme information and an overview of how the project develops sequentially (McPartland, 2017). For example, a QS can obtain a clear picture of a certain element and how long it takes to construct or install, the time required for it to become operational, and the order in which the components should be installed (Kjartansdóttir et al., 2017). Thereby, a QS can accurately determine labour hours, machinery, most time-consuming tasks, and so forth. Moreover, the ability to get early feedback can minimize the amount of rework for the QS. Besides, this improves the QS's confidence level in preparing accurate cost estimates as it allows communication between team members by assessing project plans in detail (HKGBC, 2017). Indeed, by being closer to the project team and assessing feedback before preparing cost estimates, QS can add significantly more value to the cost estimates. Nevertheless, according to Lee et al. (2016) 4D scheduling is incomplete without the integration of the 5D cost dimension.

The 5th dimension represents the project's cost information, where the QS can extract accurate cost information to prepare accurate cost estimates (Vijayeta, 2019). QS can calculate the costs associated with purchase and installation of a component and the running costs based on the information linked with a particular object in the model (McPartland, 2017). Therefore, it allows QS to easily extract quantities and apply rates to generate the overall cost for the development (NBS, 2017). Moreover, information linked with the model provides notifications to a QS when changes are made and thus to automatically count them (Hengsberger, 2019). Besides, a QS can inquire about model data at any time during a project which regularly updates cost reports (Lee et al., 2016). Nevertheless, a QS can only prepare accurate cost estimates if the given information is accurate. Therefore, in 5D based cost estimation, the QS has to play an important role by not only checking the accuracy of the information but also in helping to interpret and fill information 'gaps' (NBS, 2017). Moreover, a clear understanding of how things are classified in the model is also fundamental for the QS to prepare accurate cost estimates (Kjartansdóttir et al., 2017). The preparation of accurate cost estimates does not just rely upon 5D. According to the researcher's perspective, the preparation of accurate pre-tender cost estimates depends upon the integration of 3D, 4D, and 5D.

In addition, 6D represents the sustainability dimension, and consists of information that reduces the capital costs of projects through a better understanding of the whole life costs of assets (NBS, 2017). Therefore, in some cases, 6D BIM models are also referred to as Asset Information Models (AIM) (Kjartansdóttir et al., 2017). According to McPartland, (2017) 6D mainly helps facilities managers to pre-plan maintenance activities over the lifetime of building assets. According to Figure 3.2, 7D represents the operational and maintenance information throughout the lifecycle of the project, which managers can use for management and maintenance organisation (Kumar, 2019). 8D is the most recent developed dimension and represents information to maintain health and safety by identifying risks and preventing critical hazardous events during construction (Celauro et al., 2019). In future, new dimensions will evolve under the Nth generic dimension to enable more accurate decision making throughout the project lifecycle. However, in the current context, QSs can make reliable decision-making through the 3D, 4D, and 5D early stages of the project to prepare accurate pre-tender cost estimates (see section 3.4 for more detail).

Within the AEC industry, BIM contributes to tackle issues while increasing overall productivity (Walaseka & Barszcz, 2017). Even though architects and engineers were the foremost consumers of CAD (Tulenheimo, 2015), BIM offers a next-generation solution for all stakeholders in the construction industry and the effective management of their roles. The AEC industry started using BIM from mid 2000 (Ahmad-Latiffi et al., 2013; Azhar et al., 2008). Thereafter, BIM has been implemented in many countries, such as the USA, Finland, UK, and Australia. In 2000, BIM was defined as a structured model representing building elements (Ameziane, 2000). However, over time BIM was defined in different perspectives. Therefore, the next section will discuss BIM definitions developed over time.

3.3 BIM Definitions

The abbreviation of BIM stands for three common translations, namely Building Information Model, Building Information Modelling, and Building Information Management (Lindstrom, 2013). BIM has been defined through various aspects and from different perspectives; Table 3.1 illustrates some of the definitions over time.

According to Table 3.1, BIM is defined as a: process, technology, digital form, collaborative way of working, process of combining information and technology, and a system shaping traditional roles. The majority outline BIM as a digital model to be shared among practitioners for reliable decision making. Hence, no universally accepted BIM definition exists, which is due to the rapid evolvement of BIM technology (BCA, 2016; Burr, 2016). Moreover, another reason for existence of different definitions is the way different professionals feel it is based on their role in the construction sector. For example, the majority of definitions reflect the architect's role over the rest of the professions. This study attempts to improve the accuracy of pre-tender cost estimates through BIM adoption, which reflects the role of QS. Therefore, a definition derived from the QS perspective would be ideal for this study. However, a limited number of BIM definitions exist from a QS perspective, such as AIQS, NZIQS, and NIQS (2018).

Table 3.1: BIM definitions

Organization/ Researcher	BIM definition
BIM handbook, 2011	BIM is one of the most promising developments that allows the creation of one or **more accurate virtual digitally constructed models** of a **building** to support **design, construction, fabrication, and procurement** activities through which the building is realized.
NBS, 2011	BIM is the process of **creating and using electronic data models** of buildings to facilitate a co-ordinated understanding of a broad range of **real-world building issues,** both as a design/specification tool and as an analytical tool for achieving statutory approvals or client driven performance requirements.
NIBS, 2012	A digital representation of physical and functional characteristics of a facility and a shared knowledge resource for information **about a facility forming a reliable** basis for decisions during its life cycle.
HM Government 2012	A **collaborative way of working,** underpinned by digital technologies which **unlock more efficient methods of designing, creating and maintaining** assets.
UK BIM Task group, 2013	BIM is essentially **value creating collaboration** through the entire lifecycle of an **asset**, underpinned by the creation, collation and exchange of **shared three- dimensional (3D) models** and **intelligent, structured data** attached to them.
RICS, 2014	BIM **gets people and information working together** effectively and efficiently **through defined processes and technology**.
National BIM standard, 2014	BIM is a digital representation of physical and functional characteristics of a **facility** creating a shared knowledge resource for information about it and **forming a reliable basis for decisions** during its life cycle, from earliest conception to demolition.
Mordue et al, 2015	A **process of combining information and technology** to digitalize a project which integrates data and information about the project from several sources and that **model evolves with the complete timeline** of the actual project.
Liu *et al.*, 2017	A socio-technical system since it contains technical components such as 3D modelling and social components such as process re-engineering.

Liu *et al.*, 2017	A **system shaped the traditional role of construction professionals** which was shaped by the traditional construction procedures.
Ghaffarianhoseini *et al.* (2017)	BIM enhance the collaboration within construction organizations which will **increase the productivity** while improving the design, construction and maintenance of construction projects.
Autodesk, 2018	An intelligent **3D model-based process** that gives architecture, engineering, and construction (AEC) professionals the insight and tools to more efficiently **plan, design, construct, and manage** buildings and infrastructure.
EU BIM Taskgroup Handbook, 2018	BIM is a **digital form of construction and asset operations**. It brings together technology process improvements and digital information to **radically improve client and project outcomes and asset operations.** BIM is a strategic enabler for improving decision making for both buildings and public infrastructure assets across the whole lifecycle. It applies to new build projects and crucially, BIM supports the renovation, refurbishment and maintenance of the built environment – the largest share of the sector.
NZIQS, 2018 AIQS, 2018	BIM supports more effective management of *information* through the lifecycle of a project, from initial design to construction, operations, and finally decommissioning. **BIM is a tool** that facilitates greater collaboration between engineers, owners, architects, quantity surveyors, and contractors in a virtual environment (common data environment), enabling efficient sharing of information across these disciplines. **BIM is a process** that leverages technology to facilitate collaboration amongst all parties during the project lifecycle. BIM is not software, nor is it solely a 3D model. BIM can be used, in various forms, on all sizes and types of projects.
NIQS, 2018	The **short comings of physical representation** without parametric characteristics have been addressed by BIM, the interoperability of BIM made it receptive to all software based on its model. BIM is amenable; evolved significantly to make it applicable for all professionals in the built environment as **its adoption and use would not only enhance profit and productivity but also increase efficiency and effectiveness**.
BSI, 2019	BIM is a **collaborative way of working underpinned by digital technologies**, which allow for **more efficient methods of designing, delivering and maintaining physical built** assets throughout their entire lifecycle. Greater efficiencies can be realized due to significant pre-planning during the design and construction phases, providing comprehensive information at handover stage.

Nevertheless, most of these definitions reflect collaboration rather than the role of the QS. As BIM adoption enhances QS beyond traditional boundaries and increases the efficiency and effectiveness of the QS role, for this research the term BIM was understood to combine the following two definitions. Firstly, "A system shaped [by] the traditional role of construction professionals which was shaped by the traditional construction procedures" (Liu et al., 2017), and secondly, "BIM is amenable; [it] evolved significantly to make it applicable for all professionals in the built environment as its adoption and use would not only enhance profit and productivity but also increase efficiency and effectiveness" (NIQS, 2018)

Therefore, considering the context of this research, the definition of BIM has been understood as, 'A system that enhances QS to the increase efficiency and effectiveness of the traditional role through the effective use of BIM'. As BIM is capable of addressing most of the challenging aspects of cost estimates identified in chapter 2, the above definition is aligned with the research focus. Therefore, the next section discusses how effectively BIM could improve the accuracy of pre-tender cost estimates.

3.4 The Use Of BIM to Enable Accurate Pre-Tender Cost Estimating

The literature findings in section 2.3 revealed that practices, such as the use of 2D drawings, a lack of information, a lack of communication, and manual quantity take-off, are associated with conventional cost estimating practices and result in the preparation of inaccurate cost estimates. Nevertheless, the amount of research on BIM use in cost estimation revealed that, BIM-based cost estimation is more efficient and accurate as it can address many of the weaknesses associated with conventional cost estimating practices (Abanda et al., 2015; Azar, 2011; Tokla & Subsomboon, 2020). Therefore, this section discusses whether BIM can improve the accuracy of pre-tender cost estimates.

3.4.1 The Use of BIM 3D Models

According to Wu et al. (2018), the use of BIM models provides several solutions to overcome the drawbacks associated with 2D drawings. Haider et al. (2020) defines a BIM model as "richly describe[ing] buildings through classes of objects that contain their 3D geometry and other characteristics". Therefore, the model allows QS to see the final product of the construction including all elements at a stage where decisions have not been made to execute the project (Gołaszewska & Salamak, 2017). In other words, it provides improved visualization. Improved visualization was found to be a key benefit that the BIM model offers to QS (Tokla & Subsomboon, 2020). It enables QS's to develop a clear picture through a proper understanding of the concept and design details quickly and efficiently (Stojanovic et al., 2018), without any extra effort.

Moreover, as it easy to read and understand the BIM model due to improved visualization, a simple model check significantly reduces design changes in both drawings and construction (Shin et al., 2018). Even though design changes occur, the BIM model is capable of identifying these changes in all drawing views and updating sections automatically (Ahn et al., 2016; Ganbat et al., 2018; Trivedi, 2019;). This prevents QS's from identifying time-consuming design changes and manual revisions. Improved BIM visualization also offers design alternatives for stakeholders, which avoids rework and conflict when a design changes (Arnav, 2015; Li et al, 2015).

Moreover, visualization helps the QS to absorb and realize project information without any assistance from an extra party (Nigam et al. 2016). This reduces unrealistic assumptions made by the QS due to a lack of visualization and confusion when reading drawings. Besides, improved visualization also aids in early clash detection (Tahir et al., 2018). Clashes occur when constructed components are not spatially co-ordinated and thus conflict (CIOB, 2018). Technically, two types of clashes could occur: a ‘hard clash' is very time-consuming to identify, e.g. a column running through a wall or pipework through a steel beam (Richard, 2016). Once an element does not have the required spatial or geometric tolerances, “soft clashes” occur (for example, an air conditioning unit may require certain clearances to allow for maintenance, access, or safety that a steel beam would negate) (NBS, 2016). However, the BIM model allows designers to detect these clashes easily in vibrant colours (Silicon Consultants, 2018; Wu et al., 2018), as illustrated in Figure 3.3. Moreover, a study conducted by McGraw Hill (2017) found that BIM was the most practical platform to identify clashes. Even though clash detection helps designers to overcome design issues (McPartland, 2016), it also reduces the amount of revision needed by the QS due to design changes (Patel, 2018) and costly variations (Fung et al., 2014; Wong et al., 2014). Therefore, early clash detection does not only assist designers but also QS’s by saving time on revisions.

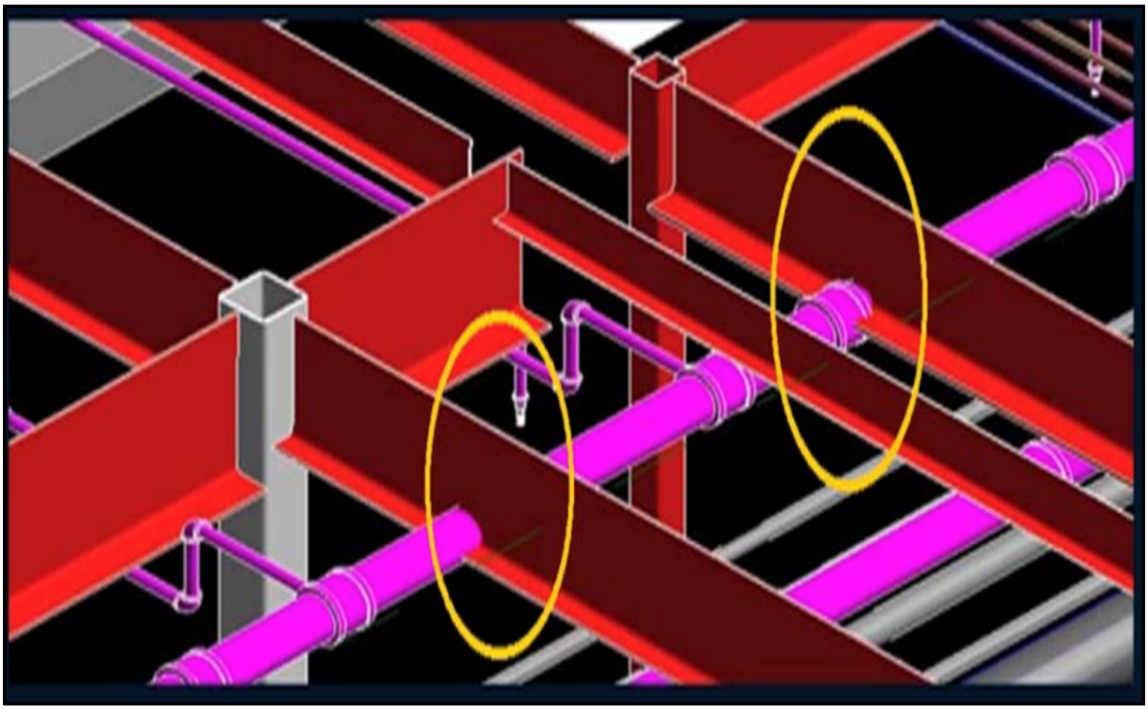


Figure 3.3: BIM Clash Detection (Silicon Consultants, 2018)

3.4.2 Improved Information Management

Another highlighted benefit of using BIM models is improved information management (Mollasalehi et al., 2017). The preparation of cost estimates is based on two types of data, such as geometric (tangible, such as the volume of concrete) and non-geometric (intangible, such as labour hours) (Tah et al., 2017). Thus, the beauty of the emerging BIM model is that it consists of non-geometric data, which the 2D version missed (Hongling et al., 2019). Moreover, the object-oriented concept of BIM helps to store information that belongs to each building item and connects it to the cost items (Wu et al., 2018). Therefore, BIM produces a digital database that could be shared among project stakeholders, rather than producing a series of separate drawings (Haider et al., 2020; Ismail et al., 2016; Lee et al., 2018; Tokla, & Subsomboon, 2020). Moreover, it provides multiple aspects of accurate information, which is required by QS's when preparing accurate cost estimates (Abanda et al., 2017; JD et al., 2017). It enables the QS to gain a greater understanding of the relationship among the objects and identify pre-existing information concerning such objects that is not available in documentary format (Chen et al., 2018). Consequently, it enhances the QS's understanding of the project information and improves their decision making by reducing the number of unreliable assumptions (Chen et al., 2018; Wang et al., 2019; Wu et al., 2019). Any change to the model automatically updates database with project documents (Haider et al., 2020).

BIM allows access to updated information on any project stakeholder at any given stage of the project (Haide et al., 2020). As a QS can easily access information at any time and extract the information needed to provide a reliable basis for decision-making rather use unreliable information (Haider et al., 2020; NZIQS, 2018). The use of the BIM model operates a collaborative working atmosphere for project stakeholders in order to more effectively share information and ideas over conventional practice (Ahn et al., 2016; Dubasa & Pasławskia 2017; Lee, et al., 2019). As a result, project stakeholders tend to insert, extract, update and modify information, which allows the QS to deal with the most recent and thus more reliable information (Zhang et al., 2015). A robust database was developed through the information gathered from different stakeholders, which ultimately improves communication between project stakeholders and thus simultaneously contributes to effective information management (Kjartansdóttir et al., 2017; Lee et al., 2018; Namil et al., 2019). Therefore, the QS does not need to depend upon unreliable cost data when preparing cost estimates. Furthermore, the BIM database can be compatible with the Industry Foundation Classes (IFC) format, which also improves information sharing across teams (Ismail et al., 2016). This reduces requests for information (RFI) from the QS as well as coordination problems (Smith, 2017). Nevertheless, Mayouf et al. (2019) found that QS's encountered a lack of information within the BIM models.

This is mainly due to the failure of architects and other designers to provide full details on their BIM model due to liability issues (Olsen & Taylor 2017; Smith, 2016). The RICS has also highlighted the importance of accessing accurate and rich information and suggested that the QS needs to improve their collaboration with designers and other stakeholders to build a reliable relationship and avoid sharing limited versions of the designer's BIM model (RICS, 2016; Smith, 2016). Gaining trust between the QS and designers add values not just for the QS but also for designers, as the QS could report errors/omissions/clashes to the designer for rectification. In return, QS could explain to designers the data/information needed, in which format and how the model could be improved (Mayouf et al., 2019). Therefore, this is a win-win situation for both parties. Moreover, Wu et al. (2018) suggested that linking the model to different professional software, such as ETABS, could also enhance accurate information from the BIM-based model. Therefore, the use of a BIM model provides a reliable cost database for the QS to prepare accurate cost estimates.

3.4.3 Automated Quantity Take-Off (AQTO)

AQTO was found to be a key benefit of BIM for QS's by enabling more accurate quantities over a short period compared to conventional QTO (Kehily & Underwood, 2017; Khosakitchalert et al., 2020). As the BIM model comprises computable graphics and data, quantities, counts, and measurements, these can be extracted directly from objects in the model (Sacks et al., 2018; Whang & Min, 2016). This saves 80% of the QS's time by eliminating the most time-consuming task in the preparation of cost estimates (Gadekar, 2018). Moreover, many BIM users claim that BIM-based QTO could be done three to five-time faster than manual methods (Trivedi, 2019). Therefore, it provides extra time for a QS's that can be spent on other cost-related tasks and reduces individual stress levels during the preparation of cost estimates (JD & Taylor, 2017). Furthermore, Whang and Min (2016) noted that 95% of accuracy could be achieved through BIM-based cost estimation.

As Valentine (2019) explains, BIM-based QTO starts with uploading the BIM model to cost support software. Thereafter, the program will fix the model by identifying information gaps in order to produce more accurate take-offs. Then, it automatically takes off the quantities and a QS can check measurements by using a 3D ruler or with the use of technologies, such as Virtual Reality (VR) to ensure every item has been measured (Trivedi, 2019). Finally, quantities can be exported into an Excel spreadsheet to create faster estimates, which Gołaszewska and Salamak (2017) claimed would eliminate cost miscalculations, double counting, and missing elements as quantities are done through automation. Moreover, according to Mattsson (2013), cost miscalculations also reduce through the use of BIM as BIM-enabled software can download the model into measuring devices to calculate the quantities, rather than manually entering the data. In addition, the accuracy of quantities also improved as rounding errors can be eliminated and omissions are minimized (Olsen & Taylor, 2017). Besides, the BIM model generates quantities together with external third-party cost estimating software, such as CostX, Vico Take-off, Zuzia BIM, and Revit, specifically to develop cost estimating (Smith 2017).

Among them, the CostX program was found to be the most widely used software for quantity take-off in more than 40 countries around the world (Exactal, 2017). As this software is customized for the use of QTO without any limitations, QS does not require any human interference to develop formulas to determine the quantities (Exactal, 2018; Signma, 2019). Therefore, it eliminates the errors associated with the use of Excel, such as altering, manual adjustments, restoring issues, and tracking errors, in formulas due to unavoidable human errors. Furthermore, with the use of BIM-based software, once the design or quantity is altered, changes are automatically updated in the costs, which saves the QSs time for manual re-measures and the identification of changes (Marsh, 2017). According to Trivedi (2019), many QSs believed that BIM-based platforms, like CostX and Revits eliminate the need for a thorough study of drawings before undertaking the MQTO, which increases the overall efficiency. Thereby, it reduces the number of inaccurate assumptions made by a QS due to difficulties in reading and understanding the set of 2D drawings (Marsh, 2017). In addition, the QS has to deal with one model, instead of referring many drawings, such as MEP, which reduces errors due to the need to move data between files (Matejka & Vitasek, 2018). Therefore, QSs are more confident when undertaking QTO in a BIM platform rather than doing it manually.

According to Kocakaya et al. (2019), accurate automated quantity generation also reduces the risk of human error and taking the wrong measurements due to the level of QS experience and knowledge. Nevertheless, Bettemir (2018) and Mohammad et al. (2019) stated that the benefits of AQTO have been partially achieved as quantity extraction happens according to the parameters set by software vendors rather than by following the method of measurement or standards operated by countries. For example, most Autodesk cost estimating products have American and North American measurement standards and not New Rules of Measurement (NRM). Smith (2017) also stated that the absence of a global standard prevents the efficient use of BIM-enable cost estimation. However, as different countries have their standards it is difficult to come up with a global standard. As a result, many countries are currently developing or already have developed their national standards, which cater to BIM-based cost estimation (MPO, 2017). In the UK, NRM have been updated to support 5D BIM-based cost estimation (RICS, 2017). The main objectives of this guidance note are to:

> Assist the QS/cost manager in deriving benefits from delivering cost consultancy services in a BIM environment, by utilizing model data rather than traditional manual measurement in the production of quantities, and ii) Inform the team in the

> needs of the QS/cost manager in performing their measurement role in a BIM environment. (RICS, 2015, p.3).

Moreover, International Construction Measurement Standards (ICMS) have also been introduced to support BIM-based cost estimation as ICMS presents costs in a consistent format to classify, define, measure, record, analyze, and present construction and other life-cycle costs (ICMS, 2015). Moreover, according to Smith (2016), firms are also capable of developing in-house BIM supported software compatible with their standards.

Moreover, Elbeltagi (2016), noted that AQTO can only generate accurate quantities if the model consists of quality information. If the details in the model are incomplete, the extracted quantities will not be accurate (Andersson et al., 2016). Therefore, Oslen and Tyler (2017) suggested that the developed model should be carefully inspected before starting quantity extraction. Moreover, Firat et al. (2016) suggested the development of the BIM model should follow appropriate modelling guidelines for the quantity take-off. Therefore, the BIM-based QTO has reduced and eliminated most of the negative aspects of MQTO (Whang & Min, 2016). However, effectively addressing the above shortcomings of AQTO will further improve the accuracy of cost estimates by generating more accurate quantities.

3.4.4 Improved Coordination and Communication

The use of BIM also provides better solutions to improve communication and coordination compared to conventional methods (Autodesk, 2018; Koacakaya et al., 2019). The use of a centralized BIM model creates strong communication among project stakeholders, thereby increasing mutual trust among the client, architect, and quantity surveyor from the beginning of the project (Goh et al., 2017). According to Figure 3.4, in conventional practice, communication goes through selected parties; therefore, in most cases QS's face difficulties in obtaining accurate information. However, model-based communication enhances communication between all stakeholders rather than within a certain party. This provides opportunities for all stakeholders to identify their project team, role, and responsibilities within the project by sharing ideas and experiences (Zulu, 2017).

Besides, according to Simmonds (2020), working on a shared BIM model promotes team working by minimizing the isolated working culture and enabling effective discussion, accelerated processes, and the ability to easily executed identified changes, thereby improving coordination. Moreover, the team working culture minimizes competition, the lack of trust, and short-term relationships among team members through the development of strong relationships (Mattson, 2017). Furthermore, this increases coordination among stakeholders from different cultural backgrounds. The shared BIM model also offers immediate feedback through BIM revisioning (Exactal, 2018). As Wileman (1993) describes, visual communication is more effective than verbal communication. Thus, as the BIM model provides improved visualization, Kopsaftis (2018) believed that improved visualization in the BIM model increased the team member's communication capacity through a thorough understanding of the building to be constructed, rather than dealing with a non-technical group of people. Moreover, BIM can enable trades to understand each other by moulding different jargon into a common form so they can see their respective interpretations of the model (Svalestuen et al., 2017).

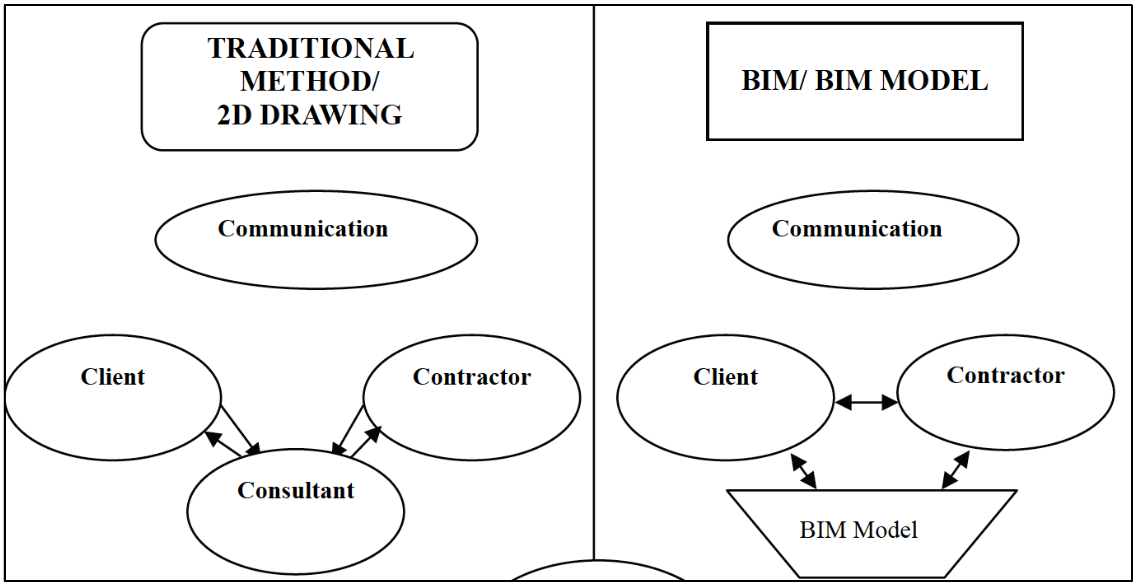


Figure 3.4: BIM-based communication method (Goh et al., 2017)

On the other hand, the use of digital applications and mobile devices in BIM-based practice enables two-way communication, which means it is easy to report errors and progress them with other parties without any hassle (Sacks et al., 2013; MagiCAD, 2018). For example, videoconferences establish reliable communication between stakeholders even over long distances (Svalestuen et al., 2017). Moreover, Harstad et al. (2015) found that the use of tablets increases access to information and understanding while developing a new way of communication. Besides, the combined use of BIM and AR (Augmented Realities) helps to minimize poor feedback and unresponsiveness through effective communication (Kapasa, 2016). As information is shared through BIM-based digital applications, the entire construction industry is heading towards a paperless but verbose communication system (Zainon et al., 2018) eliminating communication through the wall syndrome and miscommunication. As discussed in section 3.3.2, a robust database is developed comprising information gathered from different stakeholders; this ultimately improves communication between project stakeholders by sharing information and simultaneously contributes to effective information management (Lee et al., 2018; Namil et al., 2019). Nevertheless, the use of BIM does not facilitate any solutions to overcome difficulties in using the different languages identified in section 2.3.2, unless it comes from an organisational background to utilize common language in the working environment.

3.4.5 Improved Site Investigations

As discussed in section 2.3.5, in conventional practice the QS finds difficulties in conducting proper site investigations when preparing cost estimates. It was revealed that this is mainly due to the limited time given by the client, the need for time-consuming activities, such as MQTO, and the use of 2D drawings. However, the use of BIM helps to eliminate time-consuming activities by replacing 3D models and AQTO (see sections 3.3.1 and 3.3.3); thus, the QS can better manage their time by conducting full, effective site investigations before preparing cost estimates. Moreover, with the use of advanced technologies, such as costings in the Cloud, the QS can get on-site information remotely, which means saving travelling time (Exactal, 2018; PSR, 2020). The Point Cloud is another regular feature of BIM that is popular among industry practitioners when obtaining site information (BDC, 2020). This allows the QS to conduct virtual site visits without setting foot on site (Graham, 2020).

Moreover, Graham (2020) stated that the use of Point Cloud enabled QS's to cut down on physical site visits by 70% to 80%. Also, some countries, such as Poland, use BIM 360 Field from Autodesk to facilitate site-to-site collaboration, which saves the QS time usually spent wandering around the construction site (Dubasa & Pasławskia, 2017). This is also improving the quality of site information as a group can work on it rather depending on an unprofessional individual perspective. Geographic Information System (GIS) can also be used in site inspections to evaluate site location and building position (Rojas et al., 2019). According to Natwilai (2019), the use of drones is another BIM tendency in construction site inspections before construction begins. Nevertheless, even though these methods seem to be costly, they save both cost and time as ordinary site visits require time to travel to sites, for checks, in measuring dimensions, taking pictures, and travelling back to the office. Moreover, this would be a solution for projects aboard, as the QS can exact site information without travelling far. Notwithstanding, BIM-based site inspections help the QS to measure inaccessible spaces, such as crawl spaces through scanning (Graham, 2020). Besides, it improves a worker's safety as inspections are conducted remotely (Wesel, 2020).

3.4.6 Time Savings

According to Lu (2018), every stakeholder in the construction industry is working under time pressures and QS's are often under significant time pressures. Discussion in section 2.3.8 revealed that, once the design is approved, the QS has a limited time frame stipulated by the client to prepare cost estimates. However, through using BIM, the QS can save time, especially from time-consuming tasks such as MQTO (see section 3.3.3) and the use of 2D drawings (3.3.1). Moreover, as the model consists of more information, it requires improved information management (see section 3.3.2). Thereby, QSs often make inaccurate assumptions and take shortcuts during the preparation of cost estimates. However, some QS's believe that the creation of a BIM model is more time-consuming than preparing 2D drawings (Skanska, 2016). Nevertheless, even if it takes more time at the beginning of the project, in the long-term BIM models add more value to the entire estimation process by reducing the time for re-work, re-measurements, and changes detection. Moreover, due to improved communication and collaboration (see section 3.3.4), the QS can obtain relevant information without any waiting which also saves time. Lastly, remote site inspections (see section 3.4.5) also enhance timesaving rather travelling long distances for inspections.

Even though BIM is a solution to reduce unreliable assumptions (Chen et al., 2018; Tahir et al., 2018; Wang et al., 2019; Wu et al., 2019) and rework (Arnav, 2015; Li et al., 2015), it is not capable of addressing QSs' lack of knowledge and experience, of hiring less experienced QS and the lack of professionals (Gledson et al., 2016). This indicates the importance of hiring experienced QS's. Therefore, even with the use of BIM, training is required for QSs to enable the effective use of BIM-based software and obtain the best results for BIM-based cost estimation. As BIM saves the QSs time from different time-consuming tasks it is arguably not be an issue to find time to learn BIM-based cost estimation. However, this discussion illustrates that BIM is capable of addressing the majority of weaknesses in conventional cost estimation practices and thereby improve the accuracy of cost estimates. As a result, QSs can prepare more accurate cost estimates within a shorter period. Therefore, BIM has become more popular among QS's in recent years and is fundamentally transforming the digital construction era (Smith, 2017; NIQS, 2018). Many countries - both developed and developing – are in a race to adopt BIM within their practices. Therefore, the next section will discuss BIM adoption by different countries.

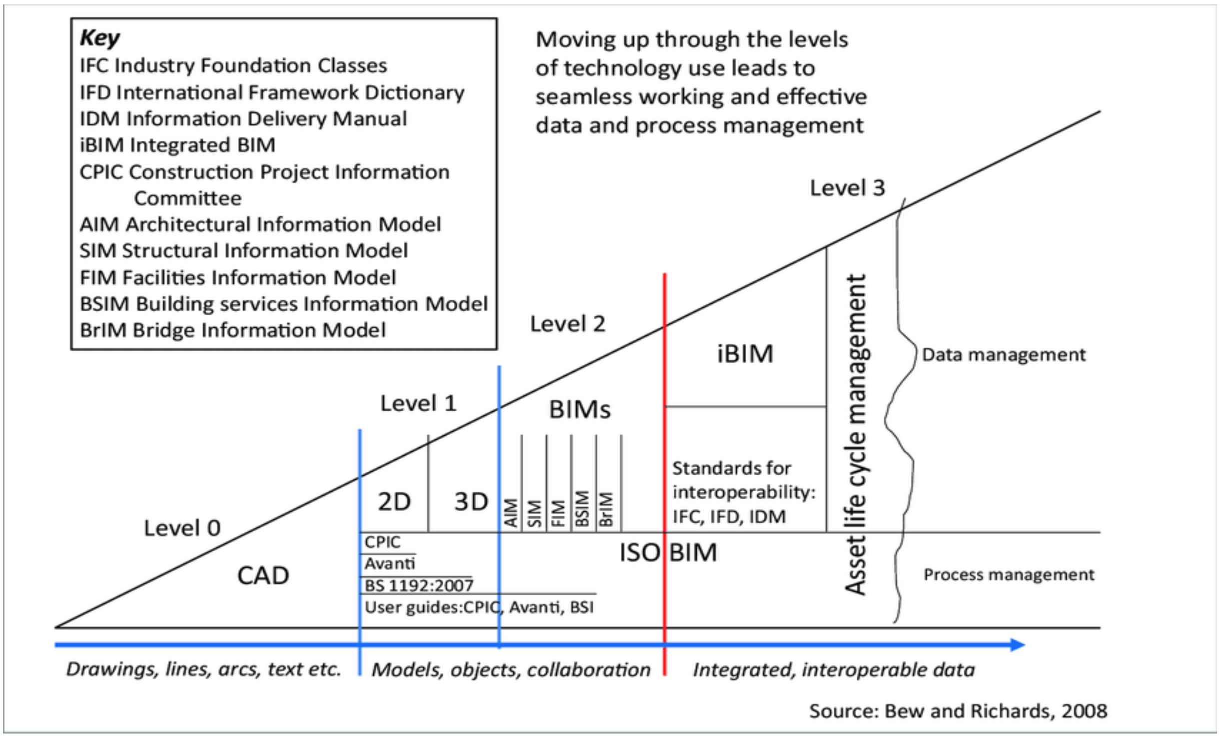
3.5 General Status Of BIM Development

Since early 2000, BIM has been widely promoted all over the world and as a result, many countries have successfully adopted BIM (Jung & Lee, 2015). McGraw Hill conducted an extensive global survey that tackled BIM evaluation and implementation around the globe since 2007 (McGraw Hill, 2014). Moreover, SmartMarket Report and NBS International Reports also revealed the status of global BIM adoption. These annual surveys indicated that, as a result of global BIM adoption, varieties of national-level BIM supported standards, strategies, guidelines and maturity levels, have been developed over the years. The USA, UK, and Scandinavian countries were the foremost countries to develop these national initiatives (RICS, 2017). Therefore, different maturity models and BIM supported documentation has evolved along with BIM globalization.

3.5.1 BIM Maturity Models

Varieties of BIM maturity measurement and various maturity models have evolved, such as COBIT, Control Objects for Information and related Technology, CMMI, Capability Maturity Model Integration, CSCMM, Construction Supply Chain Maturity Model, P-CMM, and People Capability Maturity Model, (Succer et al., 2017). These enable organisations to identify BIM improvement levels through their performances. Among them, a BIM maturity model, developed by Mark Bew and Mervyn Richards in the UK (see Figure 3.5) has been a useful diagram for the supply chain to identify what they are expected to deliver and their required capabilities, while the client can comprehend what the supply chain is offering (NBS, 2017). Moreover, any apprentice to BIM can easily assess their current BIM adoption level by combining BIM dimensions (see section 3.1) with BIM levels 0, 1, 2, and 3 (Mordue, 2019).

Figure 3.5: UK BIM maturity model (Bew & Richards, 2008)



As illustrated in Figure 3.5, the construction industry has moved from the drawing board to the computer and the digital age through different maturity levels. The different levels are understood as follows:

Level 0 - defined as unmanaged CAD, which is the starting point of the model. At this stage, there is no collaboration between the project team and information is shared through traditional paper drawings (NBS, 2017). Even though 3D visualizations can be used, 2D lies at the core of all documents; therefore, quantities, cost estimates, and specifications are not linked with the model (Kjartansdóttir et al., 2017). At this stage, no digital collaboration can be seen except for paper drawings, electronic prints, or a mixture of both (McPartland, 2016).

Level 1 – a mixture of both 2D and 3D information using standards such as BS 1192:2007 with a collaboration tool that develops a common data environment (CDE) (NIBS, 2017). Therefore, this is a transition level between a paper-based environment into 2D and 3D with a focus on collaboration and information sharing (RICS, 2014). Compared to level 0, level 1 has minor process changes, such as 3D CAD use for concept work, although 2D is used for documentation and product information (RICS, 2014). However, data sharing is done electronically in CDE, and collaboration does not occur between different disciplines (Kjartansdóttir et al., 2017).

Level 2 –different disciplines actively cooperate with others through a model-based collaboration process (RICS, 2014). Besides, each discipline builds its model and shares information between different disciplines where collaboration appears (Kjartansdóttir et al., 2017). Any CAD software, and any discipline use should be capable of exporting to a common file format, such as IFC (Industry Foundation Class) or COBie (Construction Operations Building Information Exchange). This enables organisations to integrate data with their model and thereby use the information (NIBS, 2017). Moreover, NBS developed a guide ISO 19650 that includes information on working at BIM Level 2 (Mordue, 2019).

Level 3 – the preparation of a rich, network-based, integrated model where everyone can depend upon one model that is stored in the Cloud or another web service (Hengsberger, 2019). Models at this stage are interdisciplinary nD models that allow for complex analysis from the early stages of the project (UK Construction, 2018). Moreover, this will merge many strategies, such as Industrial Strategy – Construction 2025, the Business and Professional Services Strategy 22, the Smart Cities Strategy 23, and the Information Economy Strategy 24 (Mordue, 2019). However, level 3 is not yet fully defined and unlikely to happen within the next 10 years (CIOB, 2019).

Succer (2009) investigated the need for a maturity model to assess and reported on significant variations within service delivery and their underlying causes. Succer developed the BIM Maturity Index (BIMMI), which reflected on the specifics of BIM technologies, processes, and policies as illustrated in Figure 3.6.

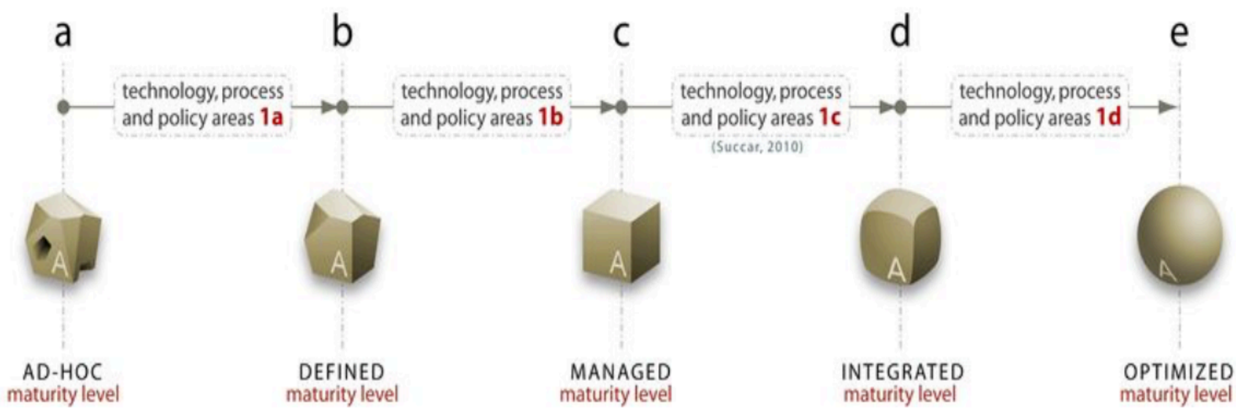


Figure 3.6: BIM Maturity Index (BIMMI) (Succer, 2009)

This model consists of five stages:

1. **Maturity Level a (Initial** or **Ad-hoc):** the absence of a BIM adoption strategy, defined policies and processes, but no collaboration among stakeholders.
2. **Maturity Level b (Defined):** BIM adoption is driven according to the vision of senior managers, where most processes, policies, innovations, and opportunities are well documented.
3. **Maturity Level c (Managed):** BIM implementation strategy is developed with detailed action plans after careful understanding of the BIM vision and its implementation by the majority of staff.
4. **Maturity Level d (Integrated):** BIM implementation integrates into the organisational, strategic, managerial, and communicative channels, at a stage where business opportunities arise, modelling deliverables are well synchronized, BIM roles are defined, and BIM standards and performance benchmarks are incorporated into quality management and performance improvement systems.
5. **Maturity Level e (Optimized):** organisations are actively achieving their BIM vision. Moreover, the BIM implementation strategy, software tools, and collaborative responsivities are repetitively revisited to align with other strategies to ensure the best possible quality in processes, products, and services (Succer, 2009).

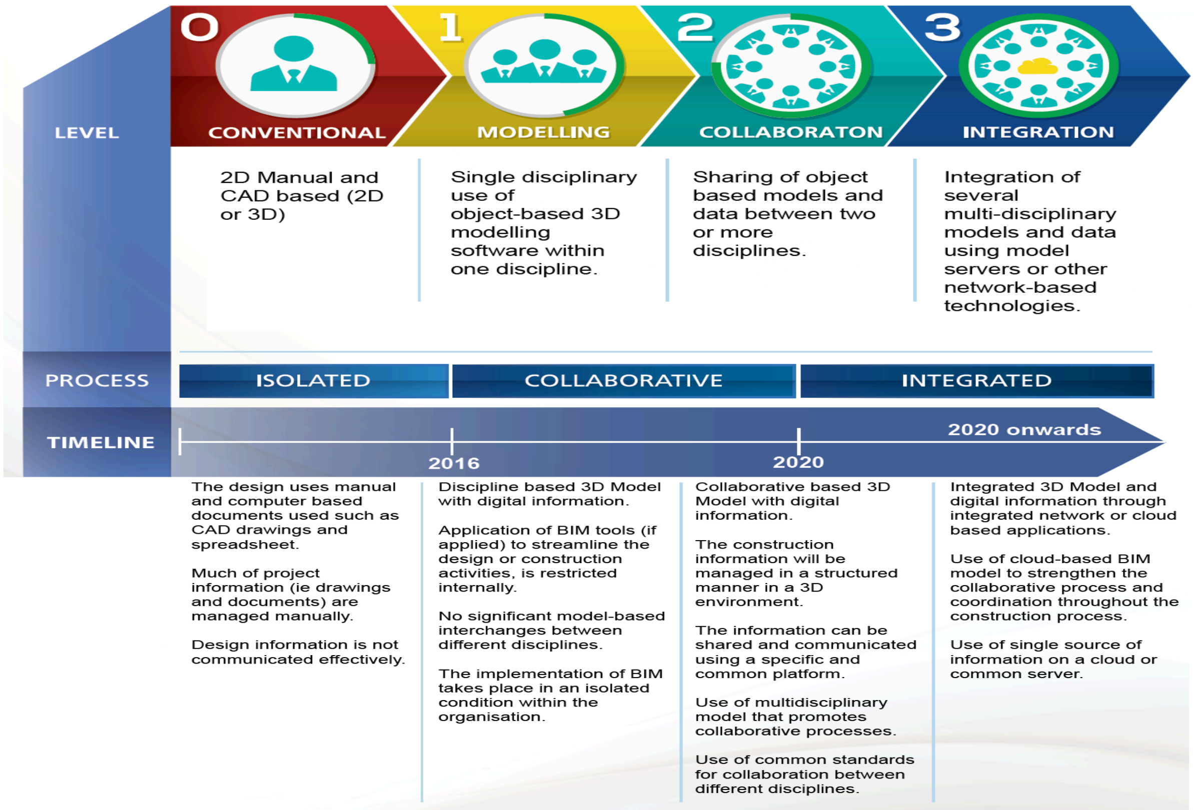


Figure 3.7: Malaysian BIM maturity model (CIDB, 2016)

Figure 3.7 illustrates the Malaysian BIM maturity model and offers detailed explanation for each level. Accordingly, the model is designed with four main stages including a defined process and timeline. Accordingly, different maturity models are developed nationally to measure the BIM adoption status of particular organisations and countries.

3.5.2 BIM Supported Documents

As BIM becomes widely accepted around the world, numerous BIM supported documents, such as standards, handbooks, and guides are developed to support BIM adoption and to overcome the challenges faced by the BIM adopters (Davies et al., 2017). These documents are developed organisationally, nationally, and globally. Moreover, alongside continuous BIM development, modifications and revisions have been added to some previously developed documents to cater to BIM needs. Table 3.2 illustrates a summary of some global and nationally recognized BIM supported documents.

Table 3.2: BIM Supported Documents

Standards/Protocols/Hand books	Originated country	Purpose	Year
BS 1192	UK BIM Level 2	Collaborative production of construction, engineering, and architectural information.	2012
PAS 1192-2		Specification for data management for the capital and delivery phase of construction projects using BIM	2013
PAS 1192-3		Specification for information management for the operational phase of assets using building information modelling.	2014
BS 1192-4		Briefing for design and construction. Code of practice for facilities management (Buildings infrastructure). Collaborative production of information. Fulfilling employer's information exchange requirements using COBie. Code of practice.	2014
PAS 1192-5		Specification for security- minded building information modelling, digital built environments and smart asset management.	2015
BIM protocol		Provides considerable detail in defining key BIM roles and their responsibilities, and outlines supporting roles with the requirement that the project proposal should include "BIM qualifications, experience, and contact information for the following: BIM Manager; Technical Discipline Lead BIM Coordinators for all major disciplines	2012
BS 8536-1		Buildings infrastructure – Code of practice	
ISO 12006-2:2015		Classification – Compliant implementation	2015
Digital Plan of Work (dPoW)			
BS 8541-1	UK BIM Level 3	Library objects for architecture, engineering and construction. Identification and classification. Code of practice.	2012
BS 8541-3		Library objects for architecture, engineering and construction. Shape and measurement. Code of practice.	
BS 8541-4		Library objects for architecture, engineering and construction. Attributes for specification and assessment. Code of practice.	
BS 8541-5; BS 8541-6		Level 3 isn't yet fully defined when it comes to in-depth details on standards.	
ISO 12006-3 – Building construction – IFD			
ISO 16739 – IFC for facility management and construction industries			
ISO 29481-1 – Methodology and format of IDM			
ISO 29481-2 – Interaction framework of IDM			
BS EN ISO 55001:2014	UK	Asset management. Management systems. Requirements.	2014
BS EN ISO 9001:2015		Quality management systems. Requirements.	2015
BS 8536-1:2015		Briefing for design and construction. Code of practice for facilities management (Buildings infrastructure).	2015

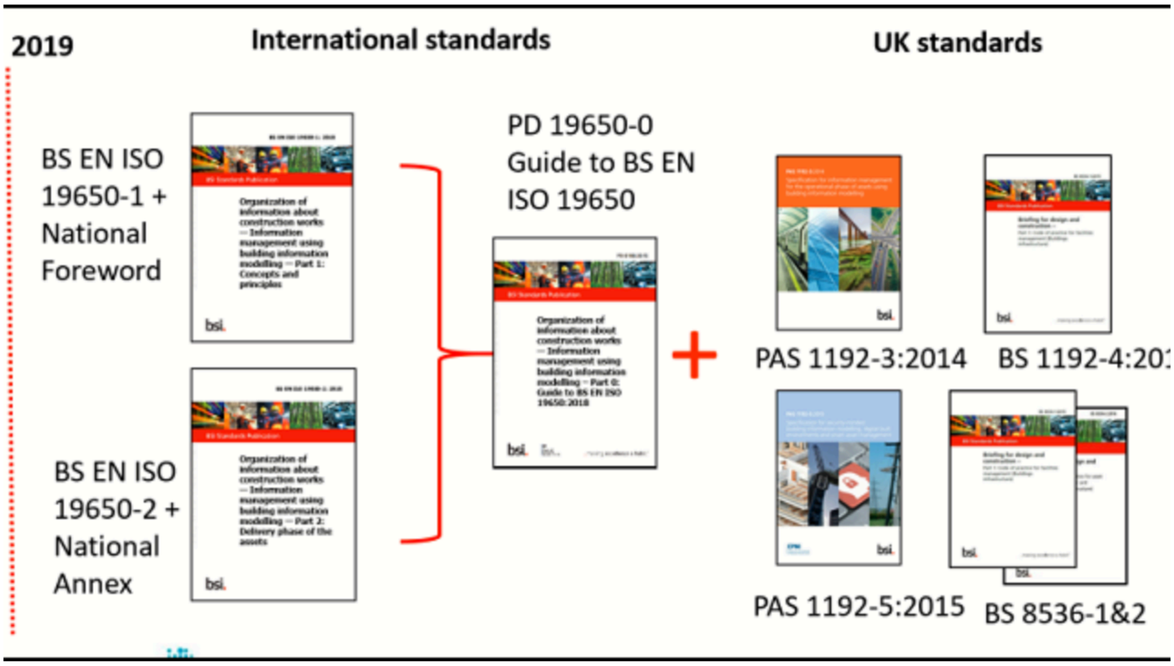
BS 8536-2:2016		Briefing for design and construction. Code of practice for asset management (Linear and geographical infrastructure).	2016
BS EN ISO/IEC/27001:2017		Information technology. Security techniques. Information security management systems. Requirements.	2017
BS ISO 44001:2017		Collaborative business relationship management systems. Requirements and framework.	
PAS 1192-6:2018		Specification for collaborative sharing and use of structured Health and Safety information using BIM.	2018
BS EN ISO 19650-1:2018		Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) Information management using building information modelling. Concepts and principles. This will supersede BS 1192:2007+A2:2016.	
BS EN ISO 19650-2:2018		Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) Information management using building information modelling. Delivery phase of the assets. This will supersede PAS 1192-2:2013.	
BS ISO 10004:2018		Quality management. Customer satisfaction. Guidelines for monitoring and measuring.	
PD 19650-0:2019		Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM). Guide to BS EN ISO 19650:2018	2019
BIM Object Standard 2.0	NBS	NBS BIM Object Standard defines requirements for the information, geometry, behaviour and presentation of BIM objects, to give reassurance of quality that will enable greater collaboration and efficient information exchange across the construction industry.	2018
International BIM implementation guide	RICS UK	The guide focuses on the cost manager's requirements from the BIM model to be able to effectively incorporate 5D BIM processes in project design and development.	2015
New Rules of Measurement	UK	Provides a reliable and consistent approach to cost estimating and the RICS are in the process of developing international standards that conform to a recognised method of measurement as guidance is required to improve BIM implementation.	2015
RICS guidance note, BIM for cost managers: requirements from the BIM model		This guidance note should be used as a source of reference for quantity surveyors (QS) or cost managers when BIM has been implemented in the life cycle of a project. It offers an awareness of BIM and provides readers with recommendations for good practice when producing measurement outputs.	
AEC(UK) (2015)	UK		2015
BIM for PM	RICS, UK		2017
BIM Execution Framework for early stage estimating in PPP projects	RICS, UK	How to integrate BIM-enabled estimating at early stages of PPP projects. This model helps in developing a BIM Execution Plan (BEP) for the project. Project managers, cost managers and BIM managers involved in the project should use this proposed process protocol as the basis of a considered and systematic adoption of BIM for estimating purposes.	2019
RIBA Plan of work 2020 and specification		The specification is the backbone of any project. Products must be researched, selected and agreed with the client, with finishes and facades requiring careful consideration and discussions with clients, planners and other stakeholders.	2020
EU BIM handbook	EU	This handbook responds to the growing challenges faced by governments and public clients to stimulate economic growth and competitiveness while delivering value for public money through the wider introduction of BIM	2018
VISI	Netherland	Forms the basis of communication and information exchange between building parties.	
COINS		Refers to a Dutch integrated, complementary standard for exchanging digital information and with support for Systems Engineering.	
CB-NL		A Dutch standard that connects object libraries for objects and spaces in the built environment.	
Austrian standards	Austria	Series of standards for the implementation of BIM.	2015
ÖNORM A 6241-1		Includes requirements for BIM level 2	2015
A 6241-2		Includes requirements for BIM level 3	2018

InfraBIM		General technical references and modelling guidelines during procurement and construction.	2015
Belgium – ADEB-VBA BIM Work Group			2015
Canadian AEC BIM Protocol	Canada		2012, 2014
NUS BIM Requirements	Singapore	Define the minimum requirements for the use of BIM in the Project.	2015
BIM Particular Conditions Version 2			
BIM guide		The Singapore BIM Guide is a reference guide that outlines the roles and responsibilities.	2018
Guide to Performance Metrics and BIM to support Green Building Objectives	USA	The guide expands and extends the objectives of an initial document with special emphasis on the value of BIM in improving the results, support, standardization and measurement of the challenges achieved by the sustainable economy.	2015
Code of Practice for BIM			2016
National BIM Standard (NBS)		BIM guidelines to move industry, product data and libraries, process and data exchange, regulatory framework.	
Level of Development Specification		A guide of reference that allows AEC industry professionals to specify with a high level of clearness the information and trustworthiness of BIM through the different stages in the construction and design process.	2016 2017
OSU			2017
PANYNJ			2017
BIM protocol document		Binding relationship between the parties for agreement on the key issues such as protocols, LOD, model elements	
Project based liability insurance		Intellectual property (IP) rights	
International Construction Measurement Standards (ICMS)	Global	Collaboration between the project cost management profession and their representative professional associations on a global scale.	2017
New Zealand BIM handbook	NZ		2014, 2016
Australia and New Zealand BIM best practice guidelines	NZIQS	These guidelines highlight key knowledge areas relating to BIM, including information on what quantity surveyors need to know about BIM with specific to 5D BIM.	2018
"12th Five-Year" Science and Technology Development Planning	China		2011
Guidance on Building Information Model Application			2015
Bureau of Public works of Shenzhen Municipality BIM implementation management standards			
Unified standard for BIM application			2017
Deliver Standard of Building Design-Information Modelling			In formulation
Standard for Classification and Coding of Building Constructions Design Information Modelling			
Storage Standard of Building Information Modelling			
Standard for Building Information Modelling in Construction			

A buildingSMART International project	Australia	Producing a standardized international framework or template for future development of BIM guides, based on an analysis of standards already used in industry.	2015
Open BIM object Standard (OBOS)		Intended for use by all construction professionals – from designers and specifiers to manufacturers and BIM content developers, to assist in the creation of standardised generic, manufacturer and project-specific BIM objects.	2018
NATSPEC National BIM Guide		Document that defines roles and responsibilities, collaboration procedures, approved software, modelling requirements, digital deliverables and documentation standards for projects in general. It also provides guidance on a number of uses for BIM.	2016
Policy and principle document		Guide for using BIM in road infrastructure	2017
10-point commitment		The commitment paid close attention to procuring and managing jobs in a more collaborative way and embracing innovative approaches such as BIM, adopting it as a standard feature of major project procurement.	2018
Digital Enablement for Queensland Infrastructure		Principles for BIM Implementation (the principles) have been produced for use by officers within the Queensland Government including departments, agencies and statutory authorities.	2018
CIC BIM standard	Hong Kong	To establish a set of industrial specifications & common practice to facilitate the wider use of BIM in construction projects.	2015
BIM for Asset Management (BIM-AM) Standards and Guidelines Version 2.0			2019
Housing Authority BIM Standards and Guidelines Version 2.0			2018
BIM Guide 1-Awareness	Malaysia	This booklet will explain the definition of BIM and the development of BIM maturity levels, illustrate the components of BIM, describe the structure of information layer in BIM models, and clarify the rationale of BIM adoption in Malaysia.	2016
BIM Guide 2 - Readiness		This booklet will explain the fundamentals of BIM, types of BIM tools and Level of detail (Lod) that involves in the BIM process.	
BIM Guide 3 - Adoption		This booklet will explain BIM project requirement, roles and responsibilities, infrastructure needs, deliverables and execution plan.	
BIM Guide 4 – BIM execution plan		This BIM Execution Plan serves as a guideline and reference for the construction players to implement and execute BIM in their project.	
BIM Guide 5 - BIM Project Guide		BIM Project Guide is developed substantially with BS EN ISO 19650 with the aim of outlining the processes of BIM implementation in a construction project.	2019
ASA BIM guideline	Thailand		2015
Maru 360 Standard BEP			2016
COET-EIT BIM Guide 1		The BIM use in infrastructure projects	2017
COET-EIT BIM Guide 2			2019
COET-EIT BIM standard			2020

According to Table 3.2 different standards, guidelines, and handbooks have been published to support BIM adoption both on a staged and a professional basis. For example, in the UK ISO 12006-2:2015 and BS 8541-1 were developed to support BIM levels 2 and 3, respectively. While ISO 12006-2:2015 addressed the classification of complaints, its implementation related to CESM4, NBS Create coding and RICS New Rules of Measurement – NRM 1; BS 8541-1, which addressed the code of practice for identification and classification. Similarly, RICS, in 2017, issued guidance notes for project managers under 'BIM For Project Managers'. Moreover, particular guidance notes and standards have been developed for quantity surveyors, such as the International BIM Implementation Guide (2015), New Rules of Measurement (2015), RICS Guidance Notes, BIM For Cost Managers: Requirements From The BIM Model (2015), International Construction Measurement Standards (ICMS) (2017) and Australia and New Zealand BIM Best Practice Guidelines (2018), to accelerate BIM adoption among quantity surveyors through comprehensive guidance. These standards consist of a set of requirements that need to help to achieve the core of a particular standard. For example, PAS 1192-2 consists of eight core standards covering different areas. Most of the developed BIM documents evolved country-wise, and the use of BIM surpassed national and geographic borders (CIOB, 2018). For example, standards like PAS 1192 do not exist in the US where there are national CAD and BIM standards, thus they are quite complex (Cicco, 2018). Therefore, BIM-globalization has inevitably driven the development of norms and standards for international use.

Figure 3.8: The transition to international standards (CIOB, 2018)



As a result, in 2018, the International Organisation for Standardisation (ISO) published BS EN ISO 19650-1 and BS EN ISO 19650-2 (UK codes) (see Table 3.2 for more info) (Kosandiak & Philp, 2018). Fundamentally, BS EN ISO 19650 parts 1 and 2 are based on the UK's standards, such as BS1192 and PAS1192-2 (see Table 3.2 and Figure 3.8) and consist of BIM level 2 principles and high-level requirements for BIM adoption (SFT, 2019).

This collaborative approach would benefit all nations in strengthening their BIM adoption through a security-minded approach (Kosandiak & Philp, 2018). However, there are some changes between ISO19650 and the previously developed standards in terms of terminology and language. For example, ISO19650 uses the term 'exchange information requirements' whereas the UK equivalent is 'employer's information requirements. Moreover, changes can also be seen in Lifecycle Information Principles, Information Management Process – Delivery Phase, and BIM Maturity (ISO, 2019). Therefore, in 2019 PD 19650-0: 2019 was developed to help users of the ISO19650 by explaining the changes and differences of ISO19650 (Pollok, 2019). Nevertheless, this standard will benefit countries that are already working at BIM level 2; thus, those who are brand new to BIM are not targeted in the preparation of SO19650 (BSI, 2018). This indicates that different countries are at different stages of BIM adoption. Therefore, the next section will describe the current status of BIM adoption around the globe.

3.6 BIM Adoption Trends Around The Globe

Literature indicates that BIM initially emerged in the USA, thus the United States has been a global leader in BIM adoption. In 2003, the General Service Administration (GSA) developed a 3D-4D-BIM Program to promote policies to mandate BIM adoption for all Public Buildings Service (PBS) (Kehmlani, 2012). Moreover, mandates were developed in association with BIM vendors, other federal agencies, professional associations, open standard organisations, and academic and research institutions (AEC, 2018). Unlike the UK, in the USA there was no visible government push, and, to date, no mandates have been issued by the US government to support BIM adoption (Paul, 2018). However, according to Pollok (2018), the US is unlikely to see a government mandate soon. Nonetheless, many government departments have developed guidelines and internationally recognized guidelines and standards include a national BIM standard (Smith, 2014) (see Table 3.2). However, as these standards are developed individually, none are interconnected (McAuley et al., 2017). However, Wisconsin was the first US state to mandate BIM on publicly funded projects with budgets of over $5 million (Cicco, 2018). Besides, in 2018, Los Angeles Community College District (LACCD) setup a BIM mandate for its $9.5 billion construction and renovation project across nine of its campuses (Pollok, 2018). A recent figure indicated that almost 75% of construction-related organisations have utilized BIM and are experiencing significant benefits from its deployment (Singh, 2018). According to Pathak (2019), the US reported a 21.6% annual BIM growth rate between 2016 and 2019, and this is expected to increase.

UK adopted BIM through a clear national strategy and government support (Singh, 2017). From the starting point of the US National 3D-4D-BIM Program, the UK took further steps to make BIM ‘business as usual’ by developing a framework for maturity (See Figure 3.4) with UK BIM Level 2 (Cicco, 2018). The strategy focused on four sections, such as leadership, vision, collaborative framework, and client and industry capability and capacity, and aimed to increase the productivity of the UK construction industry by 2025 through successful BIM implementation and collaboration through technology (Gov.uk, 2016; National BIM report, 2017). According to Mordue (2019), the UK government adopted a ‘push-pull’ strategy in promoting BIM adoption. However, the progress of BIM adoption was relatively slow in the UK until the UK government’s BIM Task Group released its BIM Policy in May 2011 (RICS, 2015). The BIM task group is a national digital BIM program that evolved in the UK (NBC, 2018). Besides, the UK government also introduced the Government Soft Landings (GSL) concept by mandating BIM level 2 (See Figure 3.5) BIM for all the public projects from 2016 (Paul, 2018). With this, all central government-funded projects need to execute ‘fully collaborative 3D BIM’ (Kocakaya et al., 2019). Thus, since 2016, contractors have had to fulfill BIM Level 2 compliance in order to secure any government project. Therefore, according to Pollok (2018), the UK has the most striving and radical BIM strategy in the world and aims to accelerate BIM adoption among UK designers, contractors, quantity surveyors, and so forth. Moreover, the UK developed various BIM standards (See Table 3.2) to support BIM adoption over time. Therefore, the UK is capable of taking a global leadership role in BIM exploitation, BIM service provision, and BIM standards development (Pathak, 2019).

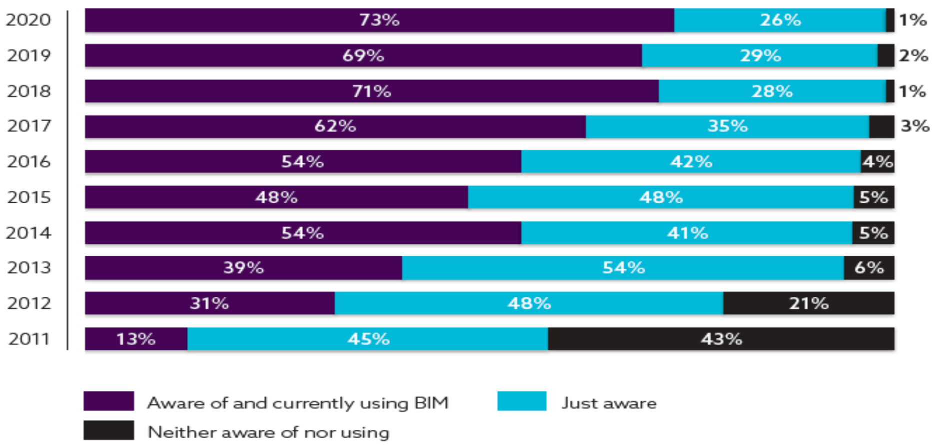


Figure 3.9: UK BIM adoption 2011-2020

A recent survey conducted by NBS (2020) revealed that 73% of the industry is now aware and has adopted BIM (Figure 3.9), which is 60% higher than 2011 when the initiative started. NBS's (2016) report revealed that a considerable number of QS organisations are working at BIM level 2; thus, compared to other professions BIM adoption among QS's still lag (Marsh, 2017). Nevertheless, at the moment, BIM has become an important factor in small, medium, and large construction-related organisations, and at every stage of projects in the UK (Boutle, 2020). Thereby, BIM is no longer limited to large practices or more complex projects, but is now widespread (Paul, 2018). Therefore, the UK's next step is to move towards BIM level 3 (See Figure 3.5), which will cover the entire building life cycle (Bew, 2019) through full collaboration (as discussed in section 3.5.1). In level 3 BIM, the UK construction industry expects to achieve boosts in productivity, increased data handling, a greater role for smaller markets, higher quality, and improved clash detection (UK Construction, 2018). Besides, transformation to level 3 requires advanced work standardization, the creation of commercial models, and the identification of technologies that will result in a completely digital economy for the built environment (Hazem, 2019). Nevertheless, Mordue (2019) suggests that this will not be possible for at least ten years. Thus, the UK is working towards BIM level 3.

Ireland achieved BIM transformation through a BIM adoption strategy that was introduced by the Irish government in 2017 with Vision 2020, which aimed to support BIM implementation throughout the project life cycle via established government policies (NBS, 2020). Accordingly, Irish government policies were: cost certainty at the tender award stage, better value for money (vfm), and more efficient delivery of public works projects (Ismail, 2018). The strategy mainly consists of action 68 and 69 to implement level 2 BIM and work with industry organisations to promote BIM (GCCC, 2017). Moreover, the NBC Roadmap 2018-2021 (see Figure 3.10) offers guidance on how the industry can integrate BIM between 2018 and 2021 (NBC, 2018). The policies of the roadmap are: 20% reduction in project delivery program, 20% increase in construction exports, and 20% reduction in capital costs. Similar to the UK, the Irish government is expected to mandate the public use of BIM in the near future for the following reasons:

1. To ensure that public bodies invest the necessary resources to adopt BIM in line with the strategy;
2. To impose standards for delivery across the public sector.

As a member of the European Union, Ireland is using international standards, such as EN ISO 19650 series (Lynam, 2018). However, recent figures indicated that 76% of Ireland construction practitioners are aware of and using BIM, whereas 24% are not (NBS, 2019). The survey results are similar to the UK figures, and Ireland is expecting nine out of ten construction practitioners to adopt BIM within the next five years (Archer, 2019). Besides, more than 60% of QS firms have already adopted BIM and 50% are carrying out model-based quantity take-offs (RICS, 2017). Among them 55% of QSs are working to achieve BIM level 2 within the next few years (CITA, 2019).

Figure 3.10: NBC Roadmap to 2021 (NBC, 2018)

In Europe most of the countries have adopted BIM through open BIM standards and mandates, BIM mandates for public construction, or through active programs goal-setting by future mandates (Figure 3.11). With the establishment of the EU BIM task group, EU level BIM took a promising step forward. The aim is "to deliver a common European network aimed at aligning the use of Building Information Modelling in public works", by bringing together national efforts into a common aligned European approach (EU BIM Task Group, 2018). As a result, the EU BIM Task Group published their handbook 2017 in, which aimed to support national-level BIM policy development and to address issues in BIM adaptation (Magi CAD, 2018). Moreover, as a consequence of BIM use, national digital programs evolved across the EU, as illustrated in Table 3.3, to support BIM adoption through developed strategies, standards, and guidelines.

Table 3.3: Rapidly evolved national BIM digital programs in the EU (NBC, 2018)

Germany	Planen Bauen 4.0 (Germany's BIM Task Group) Digital plan, efficient building, sustainable operation initiative.	**Norway**	STATSBYGG (Norwegian Directorate of Public Construction and Property)
France	Plan Transition Numérique dans le Bâtiment (Plan for Digital Transition in Construction)	**Spain**	Comisión para la implantación de la metodología BIM (Commission for the implementation of BIM methodology)
Finland	Senaatti (Senate Properties)	**Denmark**	Bygningsstyrelsen (Danish Building and Property Agency)
Netherlands	Rijkswaterstraat (Ministry for Infrastructure and the Environment)	**UK**	Centre for Digital Built Britain, UK BIM task group.

However, in terms of BIM adoption, EU different countries are at different stages. Among them Austria and Norway are the first countries to launch open BIM standards and an open BIM mandate, requiring level 3 BIM on public projects (Berger, 2017). Other Nordic countries, France and Russia have also developed targeted level 2 BIM mandates and are preparing to move to level 3 BIM through different schedules (Ali, 2019). Considering the current growth of BIM, many other countries have recently introduced BIM programs with a view to eventually establishing a BIM mandate (McAuley et al., 2017). Accordingly, Italy has introduced an action plan to mandate BIM for public sector projects exceeding 100 million EUR from 2019, and to fully implement BIM for all public procurement projects from 2022 (Paul, 2018). However, this mandate does not apply to smaller projects such as residential work.

Germany, Spain, and the Czech Republic have different BIM programs and are expected to establish BIM mandates in a few years (EU BIM, 2018). In Germany, BIM adoption grew with the number of BIM events organized on a weekly basis throughout Germany; among them, were events organized by buildingSMART Germany and BIM World, which attracted by many industry practitioners (May, 2020). With increased BIM awareness, 90% of project owners have been requesting BIM, and as a result, in 2015, the German government announced a digital building platform that was developed by the German BIM task group in association with industry-related organisations to develop a national BIM strategy (Steinmann, 2018). Accordingly, the government emphasized the "standardizing of process and device descriptions, develop[ing] guidelines for digital planning methods, and provid[ing] sample contracts" (Paul, 2018). However, experts believed that BIM implementation through a national BIM mandate would be difficult to achieve across 16 autonomous or semi-autonomous states and local authorities (Biblus, 2018). Nevertheless, the government's roadmap consists of three phases (see Figure 3.12). With government involvement, a number of BIM pilot projects have been executed, the Berlin BIM Competence Center has been established, and there are recent attempts to develop the first German BIM standard (Dobrindt, 2017). Moreover, the government is set to mandate BIM use for public infrastructure projects by 2020 by achieving the third phase of the strategy (May, 2020).

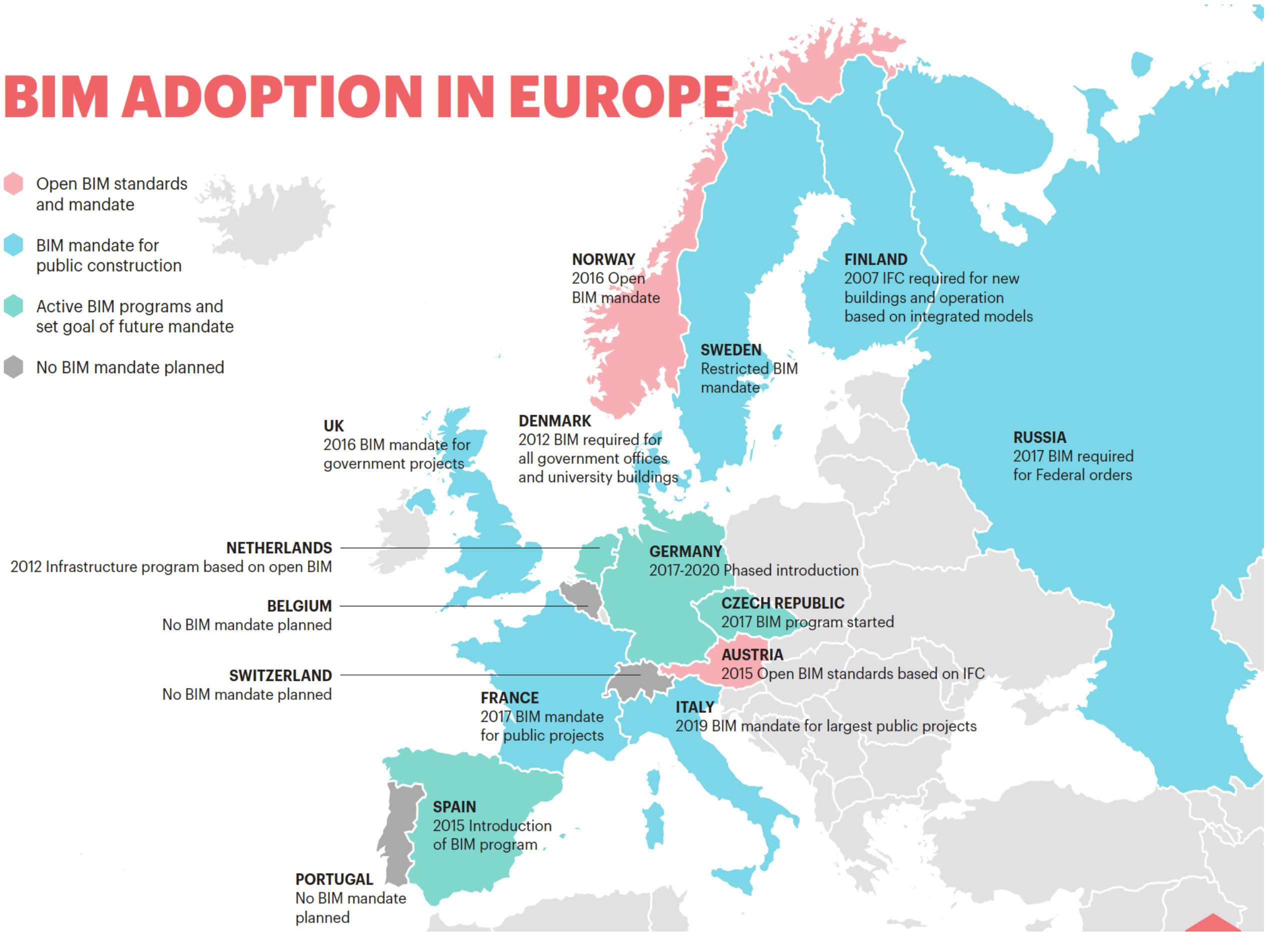


Figure 3.11: BIM adoption in Europe (CITA, 2017)

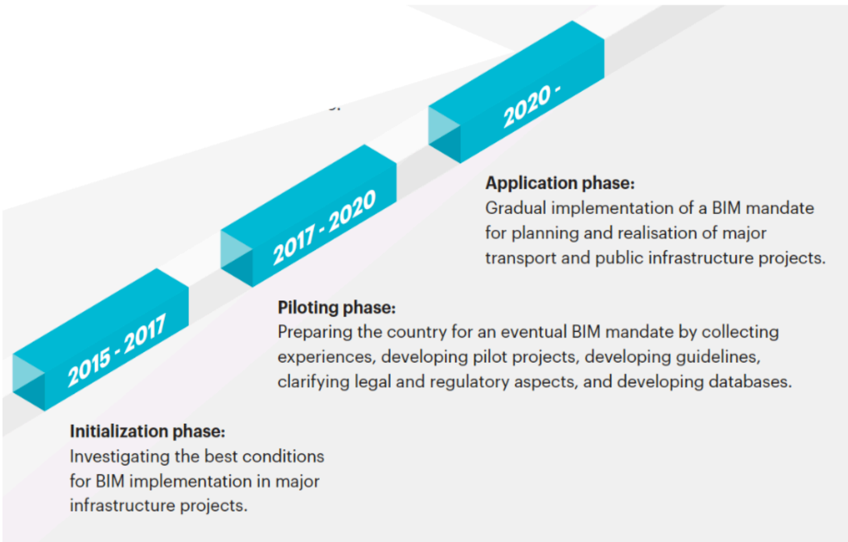


Figure 3.12 German Road Map (MagiCad, 2018)

In 2012, the Netherlands introduced BIM to their infrastructure projects (ECS, 2016). Even though they have not published any official BIM mandate, Netherland has one of the highest rates of BIM adoption countries in the world and almost 60% of projects are BIM-based construction (Dekker, 2018). The country has formulated different standards to support BIM (see Table 3.2). However, according to Lekx

(2018), the only government publication relating to BIM adoption is the RVB BIM norm, which does not provide any requirements. He also emphasized that the absence of government mandate has not prevented Netherlands companies from adopting BIM; thus, they have developed their strategies to support BIM adoption. Nevertheless, government agencies are working with a future vision of shortly introducing open BIM standards to all infrastructure projects (ECSO, 2019).

According to Figure 3.11, Spain introduced BIM in 2015 and established a BIM commission to develop a strategy for BIM adoption (Azzouz, 2018). According to the developed BIM adoption strategy, the use of BIM was mandated for public construction projects in 2018 and for public infrastructure projects in 2019 (Papadonikolaki, 2018). BIM was introduced in Denmark in 2012, and since then its adoption has accelerated through standards and classification systems that set the criteria for cross-disciplinary projects to flourish by semi-government bodies (Paul, 2018). Like most EU countries, the Danish government also provides stronger support for BIM adoption with mandated BIM use for all the projects from 2022 (Singh, 2019). In Austria, there is no government strategy for BIM adoption; thus, the Austrian Standard Institute (ASI) acts as the main responsible body for its adoption. However, in 2015 they adopted BIM through open BIM standards (See Table 3.2), which were developed by the ASI. However, these are just technical standards and there are no specific legal guidelines to date (Weselik, 2018). Nevertheless, Kompolschek (2017) stated that BIM would be mandatory for all the Austrian public projects from 2018; however, there is no official documentation that determined whether BIM has been mandated in Austria.

Finland started working on BIM in 2002, and in 2007 the Confederation of Finnish Construction Industries mandated that all software packages should pass the Industry Foundation Class (IFC) Certification (McAuley et al., 2016). In 2010, and due to on-going pressure from the industry, a set of national BIM guidelines was published entitled the Common National Requirements for Building Information Modelling (COBIM) for R&D projects (see Table 3.2) (EC, 2016). Currently, Finland has focused on developing an international standard for BIM to improve information management efficiency by 50% (BICP, 2017). As a result, the government developed BIM Roadmap 2030 (Figure 3.13) with a series of annual steps to achieve until 2030.

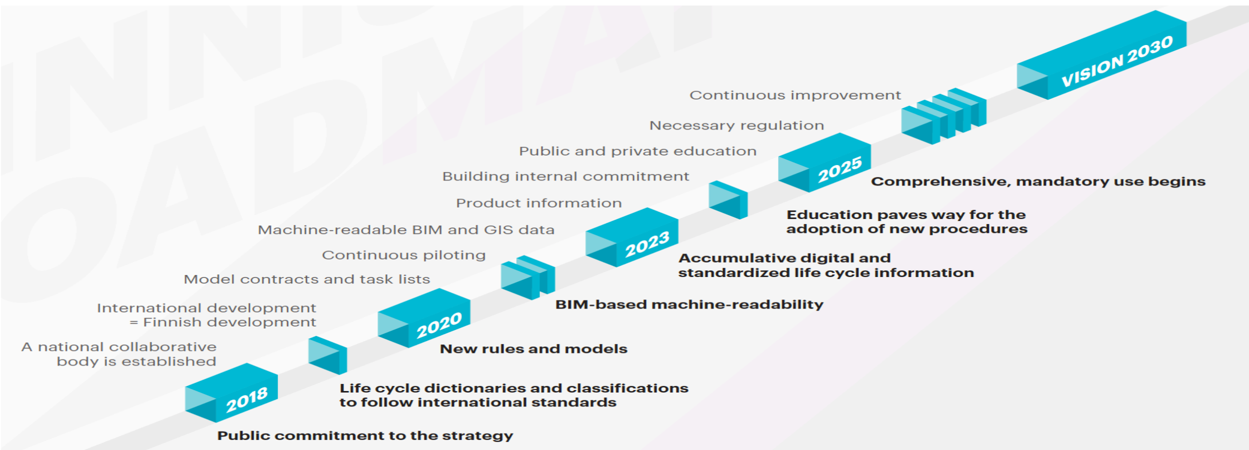


Figure 3.13: Finnish Roadmap 2030 (MagiCAD, 2019)

France is also among the leading BIM adopters in the EU. The government encouraged BIM use for a housing development project in 2017 (Dekker, 2019). However, the adoption of BIM is not mandatory in France. The government in 2017, which provided plans for educational kits, released a BIM standardisation roadmap; it meant that France took a leading position on this in the EU (BICP, 2017). Plan BIM 2022 was launched at the end of 2018, which encouraged construction stakeholders to introduce BIM within their daily work (Paul, 2018). Switzerland, Belgium, and Portugal have no planned BIM mandate to date; however, this does not indicate whether BIM is active in those countries. Thus BIM is actively promoted through organisations and initiatives (Keinonen, 2018). Accordingly, the majority of EU countries have adopted BIM through strategies, roadmaps, frameworks, standards, and guidelines developed nationally or internationally.

In Australia, BIM adoption accelerated between 2012 and 2018, and its recently estimated value indicated that BIM adoption in 2025 would increase Australian GDP growth by an additional 5 bps (Biblus, 2018). The main push for BIM has come from the Federal Government and various state government departments, professional bodies, and BIM-related organisations. The state and federal government has issued a series of long terms plans to accelerate BIM adoption. Accordingly, in 2016 BIM use became compulsory for government-funded infrastructure projects exceeding $50million in costs (Morrissey, 2019). Besides, the NSW government mandated BIM use for Sydney Metro Northwest (Consult Australia, 2016). Australian government departments also play an important role in developing processes and strategies for BIM adoption; however, due to the absence of a nationally developed strategy, supply chains face difficulties in understanding the various approaches, processes, and information requirements for each department and state (Paul, 2018). Moreover, Australian clients are seeking UK support to develop a methodology to measure the level of maturity (Jupp, 2018). In addition, buildingSmart plays a leading role in BIM adoption by establishing an open BIM alliance for Australian software vendors in the promotion of open BIM concepts (BICP, 2017). Moreover, buildingSMART launched BIMcreds in 2017 for BIM practitioners to demonstrate their capabilities (ABSF, 2017). Furthermore, different departments and organisations, such as NATSPEC, CRC-C1, ANZRS, and BIM-MEPAUS, have developed a series of standards and guidelines (see Table 3.2) to enhance BIM adoption, although PAS1192-2 is a widely used standard (Singh, 2017). Besides, ACIF is a BIM forum established in Australia to facilitate and support an active dialogue between the main actors in residential and non-residential construction, engineering construction, industry groups, and government agencies. They support the development of several resources, such as BIM protocols, standards, digitization and contracting (Biblus, 2018). Furthermore, the Australian BIM Advisory Board (ABAB) was established to develop working methods and BIM standards at a national level (Green, 2018). Their vision is for improved productivity and asset outcomes and a Strategy to take leadership and a coordinating role in the consistent adoption of BIM including its associated integration and collaborative processes. To accomplish this strategy ABAB developed the Australian BIM strategic framework, which was designed for use across Australia (ABAB, 2018). Moreover, the development of the Australian and New Zealand BIM Best Practice Guidelines for QS's in 2018 (see Table 3.2) indicates increased BIM adoption among Australian QS's (NZIQS, 2018).

In Singapore, BIM adoption is widespread as the result of a roadmap that was developed by the Building and Construction Authority (BCA) with the aim that 80% of construction professionals would adopt BIM (BCA, 2016). Furthermore, building codes, regulations, and circulars have been published by various building and construction regulatory agencies (Paul, 2018). Among them, CORNET, published by BCA in 2012 and 2013, enhanced the implementation of the world's first BIM electronic submission (Phang et al., 2020). Thus, in 2015, in Singapore, BIM e-submission was mandated for all construction projects greater than 5,000 sqm (Kaneta et al., 2016). Moreover, BCA established a BIM fund to fulfil the cost of training, consultancy, hardware, and collaboration software by accelerating BIM adoption among practitioners (Ismail, 2018). Moreover, buildingSMART Singapore, a leading BIM-based organisation, has developed BIM supported guidelines and a library of building and design objects. Going forward, BCA has implemented a phased voluntary and mandatory submission and processed construction documents in a native BIM format (Fatt, 2017).

In Hong Kong, the Housing Authority is the earliest BIM adopter amongst the public entities (Ho, 2019). Nevertheless, the Construction Industry Council (CIC, 2018) developed a roadmap and established a BIM task group to develop BIM standards. The developed roadmap reflects both the push (to advocate the adoption of BIM amongst project clients and asset owners) and pull (to facilitate industry-wide buy-in and industry-wide ready) strategies (CIC, 2019). In 2018, Hong Kong mandated BIM use in projects that exceeded $30 million (Hui, 2019). A recent survey conducted by the CIC (2019) indicated that almost 44% of construction companies have adopted BIM in Hong Kong. Along with the BIM mandate, different standards and guidelines (see Table 3.2) were published by various BIM-related organisations. Moreover, to further enhance BIM adoption, the CIC has launched BIM initiatives, such as promotion & training, the certification of BIM managers/professionals, and BIM competitions (BSBG, 2019).

China is considered a developing country in the Asian region and started its BIM application relatively late compared to most developed countries (Liu et al., 2017). Until 2015, BIM application in China was limited to design phases due to the absence of a government BIM mandate (BSBG, 2019). However, from 2016 onwards, the Chinese government has become the major force in terms of promoting BIM in the country (Zhang et al., 2016). Accordingly, the Ministry of Housing and Urban-Rural Development issued guidelines to increase BIM adoption by 90% by 2020 (Paul, 2018). However, it is not mandatory; therefore, Herr and Fischer (2019) identified the current status of government support at the level of encouragement due to the lack of introduction to BIM-oriented standards and regulations. Several standards have been issued (see Table 3.2) to support Chinese BIM adoption; however, the establishment of BSA (after recognizing China as an international authority of organisation for BIM standardization by buildingSMART) reinforced the capability to integrate Chinese BIM standards with advanced countries' BIM standards (Liu et al., 2017). Nevertheless, most standards have developed provincially but no nation-wide standards are yet available (Biblus, 2019). Nonetheless, to promote BIM adoption initiatives such as national forums, BIM themed seminars, BIM building design competitions, and BIM senior training classes have been held successfully (Singh, 2018).

In Vietnam, the Ministry of Construction, the Institute of Construction Economies (ICE) and the standing agency of a BIM Steering Committee mainly drive BIM implementation (Ismail et al., 2017). Accordingly, ICE has developed a BIM framework by aiming to deliver all public projects at level 2 by 2021 (Bui, 2018). The framework is designed in three phases (Figure 3.14), whih are defined as follows:

1. The first phase (2017-2019) aims to raise awareness and encourage companies to explore BIM implementation.
2. The second phase (2018-2020) will implement and evaluate BIM in pilot projects.
3. The third phase (from 2021 onwards) involves a nationwide BIM roll-out (Nicolson, 2017)

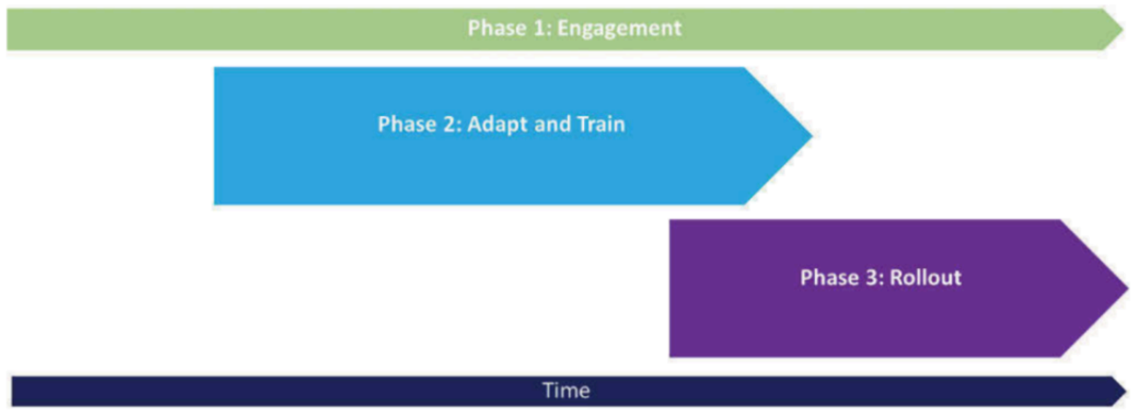


Figure 3.14: BIM Implementation Framework, Vietnam (ICE, 2015)

So far, the framework has been officially implemented through a series of forums, formulating temporary BIM guidelines, and developing standards, a strategy, and a roadmap. To increase BIM awareness, the BIM Steering Committee has launched an official website (www.bim.gov.vn) and several workshops and conferences have been held across Vietnam (BSBG, 2019). Moreover, the government has created new guidelines to incorporate BIM into university curricula; as a result, many universities, such as Hanoi Architecture, have already started BIM-based construction courses (Nguyen et al., 2018). Nevertheless, the Vietnam government is still required to play an important role in BIM implementation through the establishment of a vision, and developing standards, guidelines, and contract forms to cover different aspects of construction, such as design approval, quantity take-off, cost estimation, and so forth (Matthews & Ta, 2020). Additionally, media use in promoting BIM activities also can be seen in Vietnam; accordingly, seminars, conferences, and BIM documentaries are broadcast on television channels to increase BIM awareness (Ha-Minh et al., 2020). Besides, a BIM academic forum has been established to deliver BIM training courses, create a sustainable network, create effective and efficient communication between stakeholders and to promote social criticism and support in policies (Vy, 2017).

In Malaysia, the Construction Industry Development Board (CIDB), BIM Steering Committee, and MyBIM are the leading acting BIM implementation organisations (Ismail et al., 2017). As illustrated in Figure 3.15, CIDB has undertaken several initiatives to adopt and promote BIM within the Malaysian context (Al-Ashmori et al., 2019). According to CIDB (2019), recent BIM adoption in Malaysia has been driven by the Construction Industry Transformation Programme's (CITP) 2016-2020 Agenda to transform the Malaysian construction industry to become a more productive, sustainable, and competitive region through the use of BIM. According to Figure 3.16, the BIM adoption rate in 2017 was 33% (CIDB, 2017). However, CITP aims to achieve stage 2 BIM (according to Malaysian BIM maturity, see Figure 3.7) by 2020 with a minimum 40% BIM implementation rate (Roslan et al., 2019). As illustrated in Figure 3.15, CIDB has organized various BIM-related programs, such as National BIM day, BIM road tour, and so forth, to accelerate BIM adoption. Besides, the BIM guides (see Table 3.2) provide further guidelines for BIM adoption and reflect the different stages in Malaysian BIM maturity (CIDB, 2018). Moreover, in 2014 together with BIM steering committee CIDB further developed seven pillar roadmap with focused to seven pillars such as Standard and Accreditation (P1), Collaboration and Incentives (P2), Education and Awareness (P3), National BIM Library (P4), BIM Guidelines and Legal Issues (P5), Special Interest Group (P6) and Research and Development (P7) to motivate construction stakeholders to adopt BIM (Mohammad et al 2018).

Figure 3.15: CIDB BIM initiatives (Al-Ashmori et al., 2019)

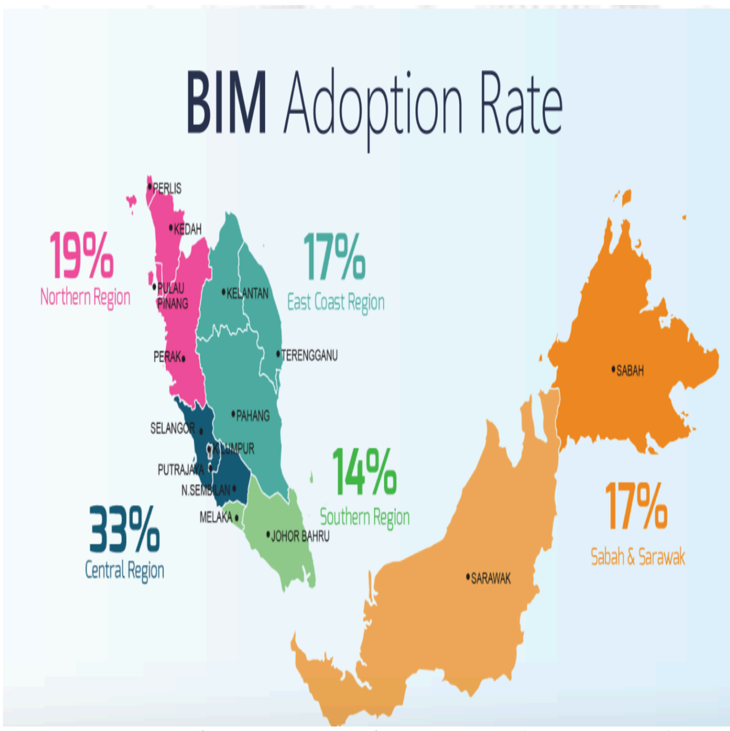


Figure 3.16: Malaysian BIM adoption rate (CIDB, 2017)

In 2020, the CIDB is expecting to introduce the Fourth Industrial Revolution 4.0 (IR 4.0) roadmap, which covers five years from 2020 (Amiruddin, 2019). This roadmap aims to provide clear direction for industry stakeholders and promote a modernized future through BIM programmes such as cloud-based integration, which is geared to level 3 BIM adoption (Ahmed, 2019). Besides, as a part of this roadmap, local authorities are expected to use BIM in the initial submission stage by 2021 (Ikhsan, 2019). The Malaysian government has also planned to run pilot projects in 2020 to promote BIM eSubmission (Bernama, 2019). According to Sharifuddin (2019), Malaysia BIM adoption stands at 17% compared to 71% in the US, 73% in the UK and 39% in Singapore. Therefore, the ministry is expecting to increase BIM adoption by 30% by the end of 2020. Sharifuddin (2019) further added that the government might shortly consider mandating BIM for all public and private projects.

Indian construction is worth around $1.8 trillion and is the third-highest construction market in the world (NIBT, 2018). According to Mishra (2019), India requires fast BIM adoption, although it seems relatively slow compared to other BIM using countries. Even though BIM can be employed in almost all stages in the construction life cycle, in India BIM adoption is still limited to the design phase (Singh, 2018). This indicates that it is more popular among Indian architects than other stakeholders in the industry. However, the Nagpur Metro Rail project provides evidence of the successful application of 5D BIM technology, which goes beyond the design phase of BIM adoption (Nehru, 2018). India's BIM Association (IBIMA) and Zigurat are the most active organisations in terms of BIM adoption in the Indian context. They have organized a range of events, such as the Indian BIM tour 2019, seminars, workshops, and a BIM summit to increase adoption through increased awareness (IBMA, 2019). A survey conducted by IBMA (2019) found that BIM-based construction is only undertaken in a few locations (see Figure 3.17), thus allocation is limited to mega-scale projects.

Figure 3.17: Details of India's high-profile BIM projects (Amaranth, 2019)

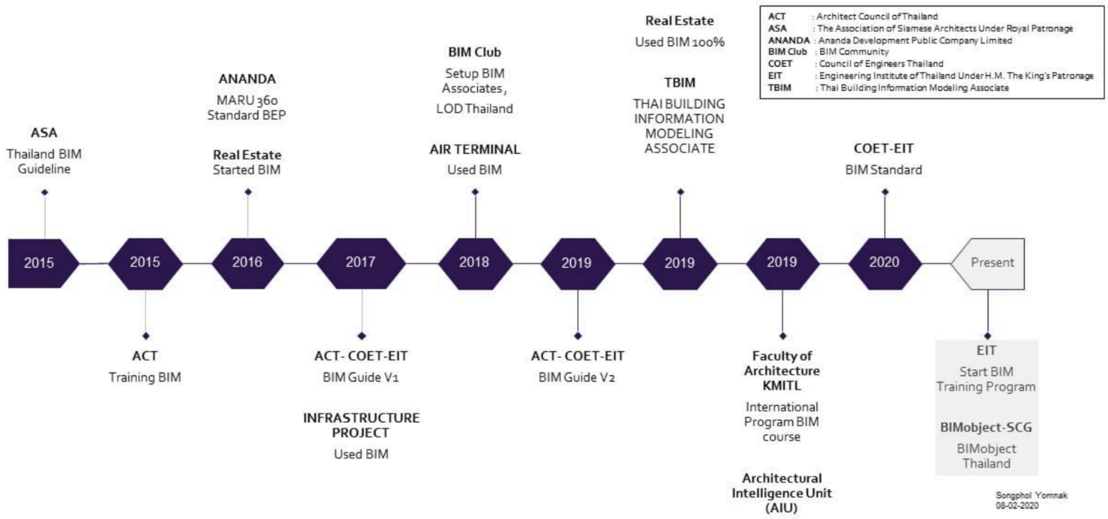
According to Amarnath CB, founder of the India BIM Association, "We have about 30-40K people who are using BIM for projects, but most of the people providing these services are for the global markets. There are very few who are providing services for Indian projects" (Amaranth, 2019). Moreover, a variety of BIM services, such as 3D BIM Services, Scan to BIM services, Drawing Production, Virtual Reality, 4D Construction sequencing, 5D Cost Integration, and Facility Management, have been outsourced to many Indian companies, such as general contractors, design consultants, architects and developers, including WIPRO, and TATA, from overseas (Zigurat, 2018). According to the BIM Community (2019), this makes India a major destination for BIM outsourcing or work-sharing for global countries. Nevertheless, the recent initiatives developed by the Indian government, such as Make in India, have enhanced BIM growth in the construction industry (Paul, 2018). Even though the public sector has mandated the use of BIM for a few selected projects, the government's BIM mandate has not yet been initiated (Datta, 2018; The Hindu, 2019). Therefore, Amaranth (2019) stated the government should publish a BIM mandate, or at least mandate BIM adoption for all mega projects. However, at the moment, Zigurat and the India BIM Association are in the process of developing national BIM standards and guidelines for future use (Demian, 2019).

In Pakistan, BIM adoption is at a lower level compared to other developing and developed countries. Like India, most architects have adopted BIM, but there appears to be relatively low BIM adoption among other professionals. A recent study conducted by Akdag and Maqsood (2019), revealed that BIM adoption in Karachi, which is the capital city of Pakistan, is higher than the rest of Pakistan. The study further revealed that firms, such as Ahmed Associates and Khatri Associates, were found to be shifting to BIM and utilizing its applications, like 3D coordination, lighting analysis, design review, and 4D Scheduling (Akdag & Maqsood, 2019). Moreover, Ali, Khan, and Maqsoom (2018) identified that BIM adoption is limited to large-scale, foreign-funded projects. Nevertheless, the Pakistan BIM Council is the leading organisation for BIM implementation, and its vision is to reduce construction costs by 40% through BIM implementation (PBC, 2019). To accomplish the vision, they have established a mission by covering six areas, namely Awareness & Implementation, Standardization of BIM, Establishment & Support, Education & Trainings, Certifications & Evaluations, and Projects & Support. As a result, some universities have started teaching and discussing BIM within their AEC courses; however, due to the absence of nationally developed standards they are focusing on internationally developed standards and protocols (Ismail et al., 2017). Nevertheless, according to Bhatti et al. (2018) many AEC industry stakeholders have raised the importance of a BIM mandate, although the Pakistani government is still unable to develop this for their construction industry.

Compared to other developing countries, in Thailand, BIM adoption is at a higher level. The Association of Siamese Architects (ASA) is one of the leaders in BIM adoption in Thailand, and in 2015, they drafted the first BIM standards and guidelines in Thai (Ongprasert & Parichatrkanont, 2019). As illustrated in Figure 3.18, BIM adoption in Thailand has increased gradually with the standards developed over time. Accordingly, BIM guide 1, BIM guide 2, and COET-EIT were developed in 2017, 2019, and 2020, respectively. Besides, the establishment of a BIM club in 2018 and the Thai BIM association in 2019 also accelerated its adoption among Thailand's industry professionals.

TBIM consists of various AEC industry professionals and the aim of the association is to promote BIM through defined standards, guidelines and manuals (TBIM, 2019). As a result, BIM's working standard committee has been established to develop various standards and guidelines to support BIM adoption. Accordingly, TBIM is expecting to implement developed standards by 2020 (Ngowtanasuwan, 2019). Besides, TBIM was expecting to organise Thai BIM-Expo 2020 for September (Bangkok post, 2020). Moreover, SCG, FTI, and TBIM have recently entered a "Memorandum of Understanding on Thailand's BIM Object Standard". The aim is to develop internationally recognized BIM standards; this step further enhances and extends BIM development in the Thai construction sector. As part of the program, they have launched a website (www.biminone.com) which serves as a BIM library platform by providing a range of BIM object data on building materials and products for users to download and create BIM models (SCG, 2020). In addition, several software distributors, BIM academies (such as MTech) and BIM-based organisations have arranged conferences and workshops to promote BIM concepts. For example, MTech provides BIM software training in Bangkok while the BIM academy provides additional support to achieve level 2 BIM (Worthington, 2018). Thereby, most AEC firms have successfully implemented BIM in their construction projects (Kamolwatcharachai, 2017). However, so far government BIM mandates have not been issued to make the use of BIM mandatory.

Figure 3.18: BIM movement in Thailand (Yomnak, 2020)



Nepal is lagging behind in BIM adoption; to date, no projects have been completed with the use of BIM tools (Karki, 2019). Although the AEC industry in Nepal has many reasons to adopt BIM, the country is not in the process of doing so. The majority of construction practitioners are unaware of BIM and the government has no intention to promote BIM adoption. Recently, Nepal's Building Information Modelling Forum (NBIMF) was established in Aalto University Finland, by a group of Nepalese BIM enthusiasts (Jaiswal, 2019) with a vision to implement BIM infrastructure projects in the Nepalese AEC industry. Therefore, RISE was developed to educate Nepalese AEC industry professionals about BIM by focusing on four main areas: BIM Research, Implementation, Standardization, and BIM Education (Suwal, 2019). Within a short period, they have organized weekly, monthly and annual events, such as conferences (Yakami, 2019). Moreover, NBIMF also worked closely with Nepalese BIM professionals to discuss digital construction solutions that could apply to the Nepalese AEC industry (Oli, 2019).

Very little information is available on BIM adoption in Myanmar. Even though the country has not adopted BIM, most Myanmar BIM practitioners work in Singapore BIM (Win, 2018). Even though, BIM adoption is not visible in the Myanmar construction industry, like in India some organisations (such as Silicon Valley) are demonstrating BIM outsourcing services covering different BIM areas such as 3D, 4D, and 5D, to various international clients (Silicon Valley, 2018). Nevertheless, BIM adoption mandates, standards or guidelines have not been developed by the Myanmar government and construction-related organisations (Ismail et al., 2017). Moreover, in Bhutan**,** a similar situation is reported. Although the Construction Development Board (CDB) was responsible for promoting BIM, it has remained inactive on this area (CDB, 2019). Even though CDB developed strong links with India, Singapore, Malaysia, and the Philippines between 2018 and 2019, BIM adoption in Bhutan is still lagging (Kuensel, 2019).

Recent BIM studies conducted in Indonesia found that BIM growth remains at a lower level and thus still stands at BIM level 1 (Hatmoko, 2019; Larasati et al., 2018; Telaga, 2017). However, the Indonesian BIM forum (BIM PUPR) and Indonesian BIM Institute (IBIMI) are leading BIM organisations in the Indonesian construction context. The vision of IBIMI is "Together, we ensure that BIM implementation in Indonesia runs well" (IBIMI, 2018). They are in the process of developing BIM friendly standards, protocols, training, and certification. Moreover, the PUPR BIM team has prepared various BIM supported resources to enhance BIM adoption. Among them, the Indonesian BIM roadmap was introduced in 2017, which consists of four main stages, namely adoption, digitalization, collaboration, and integration (as illustrated in Figure 3.19). Accordingly, they have set up plans for eight years from 2017, although both BIMPUPR and IBIMI are expecting to achieve this roadmap within five years (BIMPUPR, 2017). These organisations further organise BIM workshops and conferences to increase BIM awareness amongst construction practitioners regarding new standards and policies. However, according to Larasati et al. (2018) there are currently no BIM regulations, such as a mandate, in Indonesia.

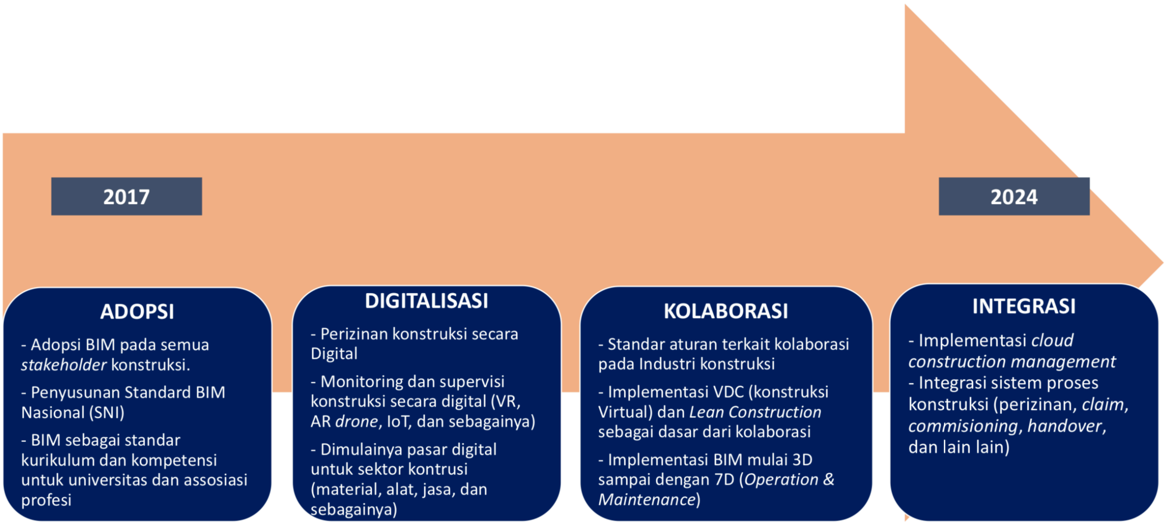


Figure 3.19: Indonesian BIM Roadmap (BIMPUPR, 2017)

The above discussion illustrates that most of the successful BIM countries (both developed and developing) have adopted BIM through nationally developed roadmaps, strategies, protocols, mandates, and supporting standards. The countries that have not developed standards, roadmaps, and so forth are lagging behind in terms of BIM adoption or at a lower level. Therefore, the next section identifies the category in which Sri Lanka could be placed in terms of BIM adoption.

3.6.1 BIM Adoption Status In Sri Lanka

Studies conducted by many researchers have revealed that BIM adoption in Sri Lanka is at a lower level, or at "Phase 0" on the Bew-Richards UK BIM Maturity Model (Epasinghe et al., 2018; Fernando, 2017; Gunasekara & Jayasena, 2013; Ismail et al., 2017; Jayasena & Weddikkara, 2012; Nagalingam et al., 2013). Unlike many other countries, in Sri Lanka BIM adoption is not that popular among architects. However, the findings of a recent survey conducted by Rathnayake et al. (2018), indicate that a considerable number of QS organisations (33%) are using BIM-related software, such as CostX, Revit, and CATO. This indicates that QS's have become the BIM leaders in Sri Lanka. Moreover, Rathnayake and Samir (2019) placed Sri Lanka at BIM level one, as most construction organisations have now transferred to 3D practices. Nevertheless, only the BIMLab Network group (operated by the University of Moratuwa) was noted as a BIM organisation in Sri Lanka. They are organizing monthly and annual BIM events, such as workshops, conferences and symposiums, to increase BIM awareness among industry practitioners. However, so far, no regulation, mandate, guidelines, or even BIM roadmap or strategy have been deployed for BIM adoption in Sri Lanka (Siriwardene et al., 2018). Thus, some educational organisations have started to introduce BIM within their AEC courses (Punnyasoma et al., 2019). However, the majority are focusing on 5D applications rather than 3D or 4D. Therefore, it can be concluded that Sri Lankan BIM adoption is at a lower level compared to other countries and its adoption is limited to only a few professionals in the industry.

Nevertheless, the level of BIM adoption varies from country to country, which is mainly due to various drivers and barriers that accelerate and hinder BIM adoption (Hosseini et al., 2015; Ismail et al., 2017; Saka 2019; Venkatachalam, 2017). These barriers or drivers could be similar or utterly different between countries or professions. Therefore, the next section will establish a systematic review of the literature for BIM adoption drivers and barriers.

3.7 The Drivers And Barriers to BIM Adoption

Section 3.5 revealed that many developed and developing countries have adopted BIM due to various motivators or driving factors. In the meantime, the majority of both developed and developing countries still find BIM adoption challenging due to various barriers. Accordingly, BIM adoption and non-adoption depends upon drivers and barriers. Moreover, drivers accelerate the adoption of BIM, while barriers hinder the acceptance of BIM. Therefore, to enable successful BIM adoption, it is vital to identify these drivers and barriers. The following section will discuss the BIM drivers and barriers that exist in the literature, from 2010 to 2020.

3.7.1 Drivers Of BIM Adoption

As defined by the Oxford Dictionary (2020), a driver is a force of someone (people) or something (knowledge, conditions) that has the power to make things happen. However, Partner White Paper by Microsoft (2009) offers a completely a different opinion: “A Driver is a brief statement that defines clearly and specifically the desired business outcomes of the organisation along with the necessary activities to reach them.” Nevertheless, for this study, drivers indicate ‘*the factors which inspire the adoption of BIM into the existing business process*’. In the literature, several authors have identified various drivers in different continuums. Table 3.4 summarises the drivers identified by different authors in different countries over time.

Table 3.4 illustrates that several driving factors are identified both in developed and developing countries. Some authors have grouped these factors into different categories, such as external, internal, and so forth. By examining the range of factors, the researcher grouped similar factors under a comprehensive heading and a more compact list of drivers were obtained.

Table 3.4: BIM drivers identified from the literature, from 2010 to 2020

Country	Key BIM Drivers	Categories		Reference
	Developed Countries	**Literature**	**Researcher**	
Singapore	Government mandate to use BIM, BIM-based e submission for approval, education and incentive programs to assist AEC industry in adoption of BIM, development of virtual design and construction leadership program		GI, BE,OI, BB	Sawhney and Singhal, 2013
	Authority encouragement and enforcement, peer effect, organizational image	External	PBI, OI	Shen et al 2016
	Benefits to organization, desire to be ahead, benefits to QS, benefits of efficiency and cost	Internal	BB	
	Producing models and drawings for construction and fabrication, integrating model management tools with enterprise systems to share data, High accuracy of model-based documentation, Data sharing and access on BIM platforms	Integration and accuracy of models (IAM)	BB	LIAO and TEO (2017)
	BIM vision and leadership from the management, Changes in organisational structure and culture, Training on new skillsets and new ways of working, Stakeholders seeing the value of adopting their own part of BIM, Owner's requirement and leadership to BIM adoption	Commitment and training from the management	OI	
	3D visualisation enabling design communication, Regulatory agencies' early participation to BIM use, Design coordination between disciplines through clash detection and resolution, Gaining competitive advantages from full BIM use	Advantages and support of implementation	BB	
	Professional bodies involvement in preparing roadmaps, building codes, regulations and circulars, establishing BIM fund,		PBI	BCA, 2016; Paul, 2018; Ismail, 2018
	BIM initiatives, BCA BIM mandates, BCA BIM fund and government intervention		PBI, GI	Zhao et al 2019
USA	GSA and other public entities like US army corps of engineers, air force, have mandated use BIM, Competitive advantage in adopting BIM		PBI, BB	Wong et al 2011
Canada	Expectation of an increase in process efficiency and project delivery, client demand,		BB, CD	Ali, 2019
UK	Increased client demand, Interoperability of BIM outputs and 3rd party applications, Provision of guidance and training, Developing BIM orientated standards.		CD, BB, BE, PBI	BCIS, 2011
	Clash Detection, Government Pressure, Competitive Pressure, Accurate Construction Sequencing, Cost Savings through Reduced Re-work, Client Pressure, Improve Built Output Quality, Time Savings, Improve Design Quality, Improve Communication to Operatives		GI, BB, CD, MD	Eadie et al 2013
	Government mandate to use BIM, owners mandate to use BIM, setting up BIM task group to aid public sector and private sector clients, competitive advantages in adopting BIM		GI, CD, BB	NBS, 2015
	Government mandate, government standards and issuing BIM adoption guidelines		GI	Hardi and Pittard, 2015
	BIM benefits and government mandate		BB, GI	Zeiss, 2016
	Interest, consistency, quality, business	Internal	OI	

	Client demand, market demand, quality, government demand	External	CD, MD, BB, GI	Papadonikolaki (2017)
	Client demand, Development of BIM standards, perceived BIM benefits, BIM government mandate		CD, GI, BB	NBS, 2019
Ireland	BIM benefits such as Visualisation, to create 2D drawings for Take-off, Onscreen 3D BIM QTO, Automated 3D BIM QTO 5D BIM with Live Cost, Plan, increased speed and accuracy of measurement, BIM related trainings.		BB, BE	RICS, 2017
Europe	Eu public procurement directives, strategic and public positioning of BIM, open standards and active private industry.		GI, MD	Petrie, 2015
	EU BIM task group, BIM mandates, BIM standards, professional bodies commitment		GI, PBI	McAuley et al 2016; EU BIM task group (2018); Paul, 2018; Keinonen, 2018; Singh, 2019; May 2020
Spain	BIM commission to develop a strategy for BIM adoption		PBI	Azzouz, 2018.
Sweden	Technical development and achievement of competitive advantage to the company, internal competence to use BIM, perceive a strong internal demand, BIM has become a standard in our environment, client demand, partners use BIM		BB, OI, CD, MD	Bosch-Sijtsema et al 2017
Australia	Development of national BIM guide by NATSPEC		PBI	NATSPEC, 2011;
	Involvement of professional bodies like Building Smart, BIM alliance, development of series of standards and guidelines,		PBI	BICP, 2017; Biblus, 2018
Hong Kong	Support from government regarding policy mandates and incentives, largely owner driven and premium general contractors.		GI	CIC, 2013
	Professional bodies involvement in preparing roadmaps, established BIM task group for developing BIM standards, Mandated BIM use, launched BIM initiatives such as promotion & training, Certification of BIM Manager/Professionals, BIM competitions.		GI, PBI	CIC, 2018; Hui, 2019; BSBG, 2019
Developing Countries				
Brazil	Host of international events – Olympic games 2016, international firms working in Brazil improving BIM adoption		GI, MD	Petrie, 2015
Malaysia	Support and enforcing the implementation of BIM by the Government, Promote BIM training program, Support from top management.		GI, BE, OI	Zuhairi et al, 2014
	Policy, process, people, organisational strategy, management, training, education, external pressure and external supports		GI, OI, BE, CD,	Enegbuma et al 2015
	Compatibility, interoperability, complexity, relative advantages	Technology	BB	Osman et al 2015
	Management, training, financial resources,	Organisational	OI, RA	

	External pressure and external supports	Environmental	CD, GI	
	Government promotion, Government financial support and subsidy, Professional bodies encouragement, Mandatory BIM use on public projects.		GI, PBI	Rogers et al 2015
	Financial, better information, better coordination, improved sustainability, improved visualization,		BB	Musa et al 2016
	Technology, organisation, process and legal.		OI, PBI, BB	Yaakob et al 2016
	Benefits of BIM adoption, organisational structure, BIM expert's education background, BIM education and training, BIM implementation plan,		BB, OI, BE, GI	Ahn et al. 2016
	Improved, visualization, clash detection, improved collaboration, improved project understanding		BB	CIDB, 2016
India	Huge investment in construction sector with participation of international firms, increase in off-site pre-fabrication requiring coordination and information flow		MD, BB	Sawhney, 2014;
	Consistency with existing beliefs and values, Availability of BIM software on trial basis, Favourable attitude towards BIM	Technological	BB, OI, RA	Ahuja et al 2018
	Compatibility with existing beliefs, values, Top Management support	Organizational	OI	
	BIM readiness by project consultants, Existing green rating system supporting BIM	Environmental	BB, MD	
	Professional bodies involvement		PBI	IBMA, 2019
	Increased and improvised coordination, Faster construction cycle, Improved visualization, Clash detection and less construction surprises, Reduced wastage, Cost reduction and control, Increased accuracy of the end product, Improved project monitoring and Change management		BB	Jagadeesh and Jagadisan, 2019
Indonesia	Possible reduction of construction cost		BB	Chandra et al. (2017)
	Time efficiency, better communication and coordination, and improved project documentation		BB	Wilis et al. (2017)
	BIM forum, BIM roadmap		PBI	IBIMI, 2018
China	Owners seeking to improve QS profession through BIM adoption, development of a draft for unified standards for BIM application		OI	Sawhney, 2014
	Design validation of BIM tools, Support from top management, Integration and coordination between the professions.		OI, BB	Tsai et al., 2014
	External influences such as government policies, and internal motivations such as people interest and attitudes		GI, OI	Ismail et al 2017
Nigeria	Collaboration, efficiency improvement and communication potential.		BB	Onungwa et al. (2017)
	Cost and time savings, and improved communication; and BIM awareness and government supports, desire for innovation to remain competitive accurate construction		BB, CD	Babatunde et al 2020

	sequencing and clash detection; streamlining design activities and improving design quality; and client/competitive pressure.			
Libiya	Availability of trained professionals, client demand, proof of cost savings, cultural change, government support		RA, CD, BB, OI, GI	Saleh 2015
	Availability of trained professionals, proof of cost savings, BIM software affordability, BIM awareness among professionals, client demand, cooperation and commitment of professional bodies, collaborative product methods, government support through legislation, cultural change among industry stakeholders		RA, BB, OI, BE, CD, PBI, GI,	Hamma-adama and Kouider, 2019
Iran	Government support; Teaching BIM in universities; Staff training; Decreasing the price of BIM software; Provision of legislation on BIM usage; Mobilizing clients on the importance of BIM; Organisation cultural change.		GI, BE, OI,	Kiani, 2015
	Increase in profit Increase in competitiveness Client's demand, BIM mandating		BB, CD, GI	Hosseini et al 2016
Vietnam	Professional bodies involvement, BIM guidelines, standards, strategy and roadmap.		PBI	Ismail et al, 2017; Bui, 2018
	New guidelines to incorporate BIM into university curriculums, BIM academic forum		GI, BE	Vy, 2017; Nguyen et al, 2018
Thailand	Professional bodies involvement, BIM standards and guidelines, BIM guides,		PBI	Ongprasert and Parichatrkanont, 2019; Ngowtanasuwan, 2019
other	Availability of trained professionals, cultural change among industry stakeholders, government support		RA, OI, GI	Badrinath et al 2016
Legend: GI – Government Intervention; BE – BIM education; OI – Organizational Intervention, BB – BIM Benefits; CD – Client Demand; PBI- Professional Bodies intervention; RA – Resource Availability; MD – Market Demand				

3.7.1.1 Government Intervention (GI)

Successful BIM adoption can be determined through nationally driven leadership and coordination (Smith, 2014; Won et al., 2013). As such, robust government intervention is vital for the development and utilization of advanced technologies and processes (David & Steinmueller, 1994). Accordingly, government intervention or government enforcement is identified as a key BIM driver for many different countries in the BIM adoption process (Hardi & Pittard, 2015; NBS, 2019; Sawhney & Singhal, 2013; Zhao et al., 2019). Gao et al. (2014) stated that government involvement could either be direct or indirect and via various roles, such as project founder, financial sponsor, risk undertaker, interest moderator, collaboration facilitator and process monitor. Consequently, governments in different countries have taken various approaches to support BIM adoption. In many countries (USA, UK, Singapore, etc) BIM adoption has been successful and accelerated through nationally developed BIM mandates (Hosseini et al., 2016; NBS, 2019; Sawhney & Singhal, 2013). For example, with the UK BIM Mandate in 2016, BIM adoption was accelerated from 51% to 75% (Rogers, 2017). Moreover, GI can also be seen through the development of roadmaps (German, Finland, Singapore, Malaysia, see section 3.5 for further detail), BIM strategies, and protocols (CIDB, 2018; MagiCAD, 2019; Steinmann, 2018). Besides, according to NBS (2015) and NBC (2018) some governments have established BIM task groups (e.g. UK BIM task group, EU BIM task group) to aid BIM adoption in both the public and private sector.

Literature also revealed that government legislation, such as BIM standards (see Table 3.2), BIM guidelines, and government policies have also motivated BIM adoption among industry professionals (CIC, 2013; Hamma-adama & Kouider, 2019; Ismail et al., 2017; Petrie, 2015). Most of these standards or guidelines have been developed nationally, thus few have been developed for international use (e.g. BS EN ISO 19650, see Table 3.2 for further detail) (CIC, 2013; Ismail et al., 2017; NBS 2019; Petrie, 2015). The development of policies for the public sector has ensured good practice amongst construction stakeholders and afforded more confidence in adopting BIM (Eadie et al., 2013). It was also found that governments, such as Brazil, have hosted international events like the Olympic games 2016 by enforcing local construction professionals to use BIM in the construction of Olympic stadiums (Petrie, 2015). However, Kiani (2015) noted that some governments, such as Oman, have decreased the cost of BIM software through GI. Notwithstanding, some governments, such as Singapore, have introduced and mandated BIM-based e-submission for construction tenders (Sawhney & Singhal, 2013). Moreover, Rogers et al. (2015) and Ahn et al. (2016) found that government promotion, financial support, and subsidy have been key drivers for the adoption of BIM amongst construction stakeholders. Therefore, GI is identified as a key BIM driver in both developed and developing countries.

3.7.1.2 Professional Bodies Intervention (PBI)

According to Table 3.4, professional body involvement was found to be another key BIM driver for many countries. Some governments were found to be the key BIM leader (UK, Hong Kong, Singapore); however, for other countries, professional bodies, such as buildingSMART (Germany, Australia), BIM Alliance (Australia), Australian BIM Advisory Board (ABAB), the Construction Industry Council (CIC), and the Institute of Construction Economics (ICE), were found to be the key BIM leaders. Nevertheless, countries where governments led BIM adoption (like the UK, Singapore) also experienced involvement by professional bodies. The literature revealed that PBI differs between countries. In some countries (such as Singapore, Hong Kong) preparing roadmaps, building codes, regulations, and circulars, alongside establishing a BIM task group to develop BIM standards were noted as key motivators in the adoption of BIM (BCA, 2016; BSBG, 2019; CIC, 2018; Hui, 2019; Ismail, 2018; Paul, 2018; Zhao et al., 2019). In Singapore, the professional body, BCA, established a

BIM fund to fulfill the cost of training, consultancy, hardware, and collaboration software and thereby accelerate BIM adoption among practitioners (Ismail, 2018; Zhao et al., 2019). Moreover, PBI also can be seen through the development of BIM initiatives, BIM mandates, and the development of BIM orientated standards and national BIM guides (such as NATSPEC) (BCIS 2011; NATSPEC, 2011). Besides, to increase BIM awareness among construction professionals, professional bodies have organised promotion and training programs, the certification of BIM managers/professionals, BIM competitions (BSBG, 2019; Worthington, 2018), the launch of official websites, workshops, conferences, seminars, BIM summits, National BIM days, and BIM road tours, (CIDB, 2018; IBMA, 2019). Furthermore, the establishment of a BIM club and BIM associations or committees (e.g. BIM working standing committee Thailand) with involvement by professional bodies has also been an influential factor in the adoption of BIM (Ngowtanasuwan, 2019; TBIM, 2019). PBI can also be seen through the support for software vendors to promote an open BIM concept (BICP, 2017). According to the above factors, professional bodies play an important role in promoting BIM in various ways. Therefore, in developed and developing countries PBI is identified as a key BIM driver to motivate industry stakeholders to adopt BIM.

3.7.1.3 Client Demand (CD)

The role of the client has been recognized as critical for BIM adoption (Azhar, 2011; Lee & Yu, 2015; Smith, 2014; Takim et al,. 2013). Therefore, clients have been recommended to act as "innovation supporters" (Nam & Tatum, 1997), "change agents" (Haugbølle et al., 2015), and "innovation champions" (Kulatunga et al., 2011) to enable systematic innovation. Clients can be from the private or public sector. In their report, NBS (2018) referred to organisations as clients. As illustrated in Table 3.4, client demand was found to be a key BIM driver for developed and developing countries (Ali, 2019; Babatunde et al., 2020; Bosch-Sijtsema et al., 2017; Eadie et al., 2013; Enegbuma et al., 2015; Hosseini et al., 2016; NBS, 2019; Osman et al., 2015; Papadonikolaki, 2017; Saleh 2015). Papadonikolaki (2017) identified client demand as one of the external pressures aside from the push from government and professional bodies. In some countries, clients have mandated the use of BIM within their construction projects (NBS, 2015). Moreover, some clients have decided to fully embed BIM in their workflows and deliver it as standard for all types of project (NBS, 2019). In addition, some clients intend to demonstrate BIM benefits, whereas others intended to include them in their project briefs (Baln, 2019).

As illustrated in Figure 3.20, many clients have repeatedly used BIM, especially in the public sector. Similarly, in the private sector clients have also applied BIM, although the majority are for one-off clients (NBS, 2020). Therefore, clients and the client role represent a key driver in the adoption of BIM for many countries.

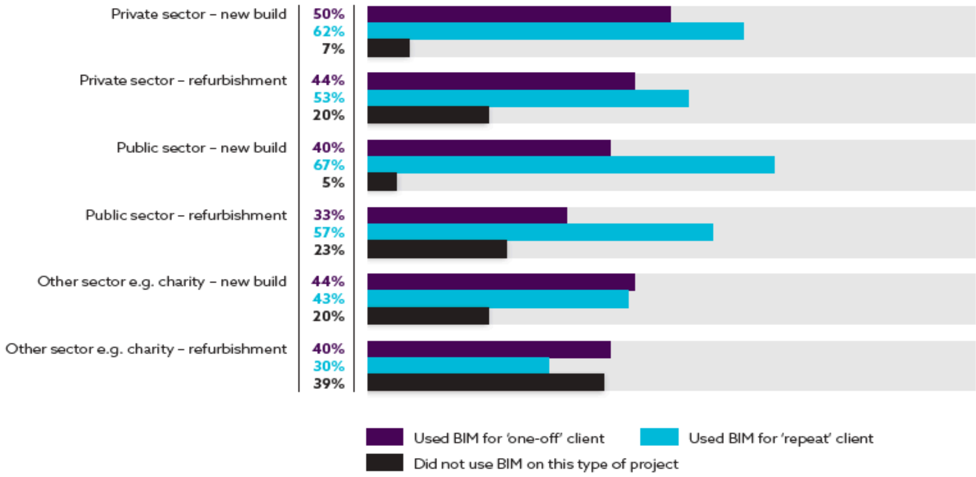


Figure 3.20: BIM adoption by different types of clients (NBS, 2020)

3.7.1.4 BIM Benefits (BB)

Literature also indicated BB as another key driver for BIM adoption (Table 3.4) (Ahn et al., 2016; NBS, 2015; NBS, 2019; Wong et al., 2011). These benefits vary between professions as well as organisationally. It was revealed that many organisations have adopted BIM due to the general benefits it offers, such as cost and time savings, increases in profit, increases in competitiveness, technical development, competitive advantage to the company, and expected increases in process efficiency and project delivery (Ali, 2019; Bosch-Sijtsema et al., 2017; Chandra et al., 2017; Hamma-adama & Kouider, 2019; Hosseini et al., 2016; Musa et al., 2016; Saleh, 2015). Besides, from a QS perspective, the key drivers in the adoption of BIM also included: clash detection, improved visualisation, the creation of 2D drawings for take-off, onscreen 3D BIM QTO, automated 3D BIM QTO 5D BIM with live costing, plans, increased speed and measurement accuracy, better information, better coordination, improved sustainability, and the ability to create accurate cost estimates (CIDB, 2016; Musa et al., 2016; RICS, 2017; Shen et al., 2016) (see section 3.3 for further details). In addition, the following are also highlighted as key BB in the literature: the production of models and drawings for construction and fabrication, integrating model management tools with enterprise systems to share data, the high accuracy of model-based documentation, data sharing and access to BIM platforms, development of virtual design; increased off-site pre-fabrication requiring coordination and information flow, faster construction cycles, clash detection, fewer construction surprises, reduced wastage, increased accuracy of the end product, improved project monitoring and change management, improved project documentation, BIM awareness and government support, streamlining design activities and improving design quality (Babatunde et al., 2020; Jagadeesh & Jagadisan, 2019; LIAO & TEO, 2017; Sawhney, 2014; Sawhney & Singhal, 2013; Wilis et al., 2017). Therefore, it can be concluded that many organisations and professionals have adopted BIM by considering its benefits, which include improvements to their workflow. Therefore, BB are identified as key BIM drivers in both developed and developing countries.

3.7.1.5 Organisational Intervention (OI)

As discussed in section 3.6.1.1 and 3.6.1.2, GI and PBI have been key drivers within some countries. Similarly, amongst countries where GI and PBI were noted as low, organisational interventions were found to be the key BIM leaders. For example, Switzerland, Belgium, and Portugal have successfully adopted BIM through OI (Keinonen, 2018). Moreover, the Netherlands has successfully adopted BIM through organisationally developed strategies (Lekx, 2018), which indicates that organisational motivation is a key influencer for BIM adoption. Some organisations have mandated the use of BIM within their organisation strategy (Bosch-Sijtsema et al., 2017). Accordingly, many organisations have changed their structure and culture to support BIM adoption and in consideration of their established vision and mission (Ahn et al., 2016; Badrinath et al., 2016; LIAO & TEO, 2017; Saleh, 2015). This stimulates people's interest and attitude to adopt BIM (Ahuja et al., 2018; Bosch-Sijtsema et al., 2017; Ismail et al., 2017) while developing internal demand for BIM use amongst employees (Bosch-Sijtsema et al., 2017; Papadonikolaki, 2017). Besides, top management support has also been identified as a key organisational BIM influence in the literature (Zuhairi et al., 2014). Many organisations have deployed leadership programs, (Sawhney & Singhal, 2013) to prepare management to support BIM adoption. Moreover, BIM training provided by organisations for existing staff has also increased employees' interest and their adoption of BIM (Eastman et al., 2011; LIAO & TEO, 2017; Osman et al., 2015). It was also stated in the literature that an organisation's financial capacity to afford BIM related software has also determined its adoption of BIM (Hamma-adama & Kouider, 2019; Osman et al., 2015). Therefore, OI is identified as a key BIM driver in both developed and developing countries according to the literature (summarised in Table 3.4).

3.7.1.6 BIM-Based Education (BE)

According to Table 3.4 BE is identified as another driving factor for BIM adoption. As discussed in section 3.6.1.2, professional bodies also conduct different educational programs, such as conferences, workshops, and seminars, to support BIM adoption through increased BIM awareness. Besides, some governments have issued new guidelines to incorporate BIM into university curriculums (Nguyen et al., 2018; Vy, 2017) and as a result, many education institutions play a vital role in promoting BIM education in different countries. Universities, such as Penn State, Georgia Tech, the University of Southern California, Montana State University, and Stanford University, are a few examples of institutions that offer BIM-based curricula and are identified as leaders in BIM education (Barison & Santos, 2010). Worldwide, 103 schools have introduced BIM into their curricula, of which 75 are in the United States and only 28 are in other countries (Barison & Santos, 2010) such as Australia, Denmark, Hong Kong, Finland, Germany, Sweden, the United Kingdom (Din et al., 2011) and Israel (Sacks & Barak, 2010). Stanford University is an award-winning institution that offers a multidisciplinary BIM education environment (Bailey, 2011). Some countries, such as Iraq, have offered free BIM courses to increase its use (Hamada et al., 2016). Besides, some institutions have established BIM-related training to increase professionals' theoretical and practical knowledge of its use (BCIS, 2011; Enegbuma et al., 2015; RICS, 2017; Zuhairi et al., 2014). Nevertheless, literature illustrates BE as a key BIM driver as it increases BIM awareness and produces BIM experts within the construction industry (Ahn et al., 2016; Hamma-adama & Kouider, 2019; Kiani, 2015).

3.7.1.7 Market Demand (MD)

MD is another key BIM driver noted in the literature (Papadonikolaki 2017; Thurnell, 2015). Accordingly, in some countries, such as Brazil and India, BIM-based international firms are working in the construction industry by providing services for international clients (Amaranth, 2019; Petrie, 2015). Ultimately, due to this practice, MD has increased for BIM in particular countries and local construction professionals intend to use BIM (Bosch-Sijtsema et al., 2017). Moreover, huge investment in the construction sector through the participation of international firms has also resulted in greater BIM adoption due to increased MD (Sawhney, 2014). On the other hand, MD has created competition among construction practitioners for BIM adoption (Bosch-Sijtsema et al., 2017; Eadie et al., 2013). Therefore, many construction organisations intend to adopt BIM to secure their position within the industry (Ruikar et al., 2015). Therefore, MD has also resulted in BIM adoption among industry professionals.

3.7.1.8 Resource Availability (RA)

RA is another highlighted BIM driver in the literature. The availability of financial resources were noted as a key resource for BIM adoption (Osman et al., 2015). Moreover, some countries, such as Singapore, have established a BIM fund to support the cost of training employees, consultancy, hardware, and collaboration software by accelerating BIM adoption among practitioners (Ismail, 2018). Moreover, according to Ahuja et al. (2018), the availability of BIM software on a trial basis has also encouraged BIM adoption among practitioners. Besides, the availability of trained BIM professionals was noted as a key resource that drives BIM adoption (Badrinath et al., 2016; Hamma-adama & Kouider, 2019; Saleh 2015). Moreover, as discussed in section 3.6.1.5, organisations have provided BIM supported tools and software to promote its adoption. Besides, literature also categorised BIM guidelines, manuals, and standards, as supportive resources for BIM adoption. Therefore, according to Table 3.4, RA is another key BIM driver highlighted in the literature.

3.7.2 Barriers To BIM Adoption

As defined by the Oxford Dictionary (2020), a barrier is an obstacle to someone (people) or something (knowledge, conditions) that has the power to prevent things happening. Nevertheless, this study barrier notes that barriers are '*the factors which uninspire the adoption of BIM within the existing business process*'. In the literature, it was noted that several authors have identified various barriers and causes in different continuums. Table 3.5 summarises the barriers identified by authors in different countries over time.

As illustrated in Table 3.5, several barriers have been identified in both developed and developing countries. Nevertheless, some authors have categorised these factors into different categories, such as external, internal, and so forth. Similar factors were grouped by the researcher under a comprehensive heading and a more compact list of barriers was obtained as follows.

Table 3.5: BIM barriers identified from the literature publications from 2010 to 2020

Country	**Key Barriers**	**Categories**		**Reference**
	Developed Countries	**Literature**	**Researcher**	
USA	Lack of knowledgeable and experienced partners; legal and contractual constraints; lack of industry standards; it takes too much time to learn; high cost of implementation; incompatibilities of BIM data with estimating formats, BIM data incompatible with current Standard Methods, Lack of integration in the model, Lack of trust in the quality of the model, Lack of team experience of BIM		LI, LBR, FB, LIP	TCUF 2010; Sabol,2010
	Lack of standardized regulations, Lack of collaboration during the construction project and work process, Lack of investment to support the initial costs of BIM implementation, Unwillingness and reluctance of the stakeholders (architects, engineers, and contractors) in adopting BIM, Lack of skilled personnel with proficient knowledge about the BIM technology		LIP, LBR FB,	Ku and Taiebat (2011)
	Training investment, lack of skilled users, buy-in among industry/ adoption on a wider scale, not as useful for small projects, lack standards for BIM across the industry.		FB, LBR, LEP	McGraw-hill (2014)
	Absence of BIM mandate, no common set of government practices, many industrial parties don't want to implement it as it is expensive technology and lack of experts are available.		LEP, FB, LBR	Pathak, 2019
Canada	Lack of client demand, high training costs, high cost for software and hardware, High cost of hardware upgrade, Low return-on-investment, Legal issues, do not see a value for BIM use.		LEP, FB, LI, **LBA**	Abdulaal et al 2017
	lack of organizational training strategy; lack of software interoperability, lack of practical standards and guidelines; low demand of BIM-based projects by clients, low return on investment; difficulty in navigating the required mentality change among professionals, lack of regulations and legal definitions that can be incorporated into contractual documents in relation to BIM and sharing data;, lack of maturation of BIM technology to merit its being sought in the market.		LBR, LEP, FB, LIP, LI	Ali 2019
UK	Initial investment, Training investment, lack of skilled users, lack of understanding lack of adoption standards for BIM across the industry.		FB, LBR, **LBA**	McGraw-hill (2014)
	lack of knowledge and interest in BIM	Reluctant to change	**LBA**	Hardi and Pittard (2015)
	Cost of hardware and software	perceived cost of obtaining the technology	FB	
	limited knowledge and experience among professionals	lack of maturity	**LBA**	
	Lack of suitably skilled and experienced staff, The ageing workforce and the undersupply of new entrants	People	LBR, LIP	Marsh, 2017
	Cost of training, cost of hardware, cost of network, cost of software, reduction in fees charge, increased competition.	Cost	FB	
	Lack of private clients, Lack of certainty of added value to the client, Lack of certainty of added value to the QS role, Fear of extinction of the QS role	Demand	LEP, LIP	
	Lack of shared knowledge banks available to the QS, Lack of confidence in the selection of appropriate software, Inadequate professional body training provided by professional bodies, The isolation of the QS from key decision makers and clients, Contractual liability concerns	Knowledge	**LBA**, LIP, LI	

	Lack of trainings, lack of expertise, lack of funds	Internal	LBR	NBS, 2018
	Lack of client demand, lack of large-scale projects to implement BIM	External	LEP	
	No client demand, Lack of in-house expertise, Lack of training Cost , The projects we work on are too small, Differences in expertise among collaborating parties in a project , BIM is not relevant to the projects we work on , Not time to get up to speed , No established contractual framework for working with BIM , Lack of collaboration , Lack of standardized tools and protocols , Operating system-specific software , Don't see the benefit , Government's commitment to BIM Liability concern		LBR, FB, PS, LIP, **LBA**, LEP	NBS, 2020
Ireland	Design information within models not being structured correctly, Lack of BIM understanding/skills, lack of client demand, Cost of BIM training, Cost of BIM software, Lack of BIM standards, Traditional procurement does not lend itself easily to using BIM, Uncertainty of Legal implications/liability when using BIM.		**LBA**, LBD, FB, LBR, LI	RICS, 2017
	Lack of in house expertise, No client demand, Lack of training, No time to get up to speed, No established contractual framework for working with BIM, Cost, Differences in expertise among collaborating parties in a project, Lack of standardized tools and protocols, Don't see the benefit , Lack of collaboration		LBR, LEP, FB, LIP, **LBA**	NBS, 2019
Hong Kong	Lack of qualified in-house staff, lack of training/education, lack of standards, lack of client demand, Lack of government's lead/direction		LBR, **LBA**, LEP	Chan 2014
	Lack of standards and protocols, lack of contracts and submission requirements, system compatibility and exchange, change of culture and mind set, investment cost		LBR, LIP, FB, LI	McGraw-hill (2014)
	locally accepted practices, dismissive mindset	Compliance-driven mindset	LIP,	CIC, 2019
	Rigid workflows and stakeholder interfacing, double handling between 2D drawings and BIM.	Double handling	LIP	
	Insufficient BIM expertise and project experience	Insufficient expertise	LBR	
EU	Lack of better processes and collaboration		LIP	McGraw-hill (2014)
Poland	Interoperability, Changing work processes, Legal issues, Training and creation of new roles and responsibilities		LIP, LI,	Walasek and Barszcz, 2017
Sweden	lack of demand from clients, lack of pressure from clients, partners, and regulatory bodies, lack of knowledge, cost versus benefits issue, lack of Internal demand, Our partners do not use BIM, High investments in hard- and software, Problem with the user-friendliness, High demands for technical competence, Partners do not always give access to the 3-D model, Does not give any clear competitive advantages, Difficult to integrate with other systems Takes a long time to learn, Expensive operating and maintenance costs, BIM-models are too complex, The information in the model is often wrong, Major internal resistance in the company,		LEP, **LBA**, FB, LIP, LBR, LI	Bosch-Sijtsema et al 2017
Saudi Arabia	Lack of knowledge, cost of implementation, fear of change from traditional methods, legal and contractual issues, team culture, client awareness and requirements, lack of strict government rules and regulations.		**LBA**, FB, LIP, LI, LEP	Alhumayn, 2018
	Undefined responsibilities of data content in the models and the legal status of these models compared to other documents	Legal problems	LI	Eadie et al 2014
	Allocations of roles, responsibilities, and rewards, cost of implementation (software and training) lack of senior management support),	Business problems	FB, LIP,	

	Fear of changes to working culture and resistance to alterations in roles, ICT literacy	Human problems	LIP,	
	Lack of training and project planning, the immaturity of software, particularly in terms of data exchange and interoperability.	Technical problems	LBR, LI	
	Lack of knowledge of the BIM adoption process, lack of support from managers to accept changing current practices, lack of practical standards and guidelines, lack of attention by policy makers and the government.		**LBA**, LIP, LBR, LEP	ALHUMAYN et al 2017
UAE	Non-existence of standards, protocols, high implementation costs and uncertain profitability, not having comprehensive BIM stated advantages, absence of proper legal system, BIM not mandated in all UAE projects		LBR, FB, LI, LEP	Koseogle (2013), Mehran, 2016; Gerges et al 2017
Australia	lack of experience and skilled staff who are knowledgeable and equipped in using BIM, cost of BIM implementation, lack of education and lack of proper training in using BIM, very low level of knowledge and understanding about BIM usage		LBR, FB, **LBA**,	BuildingSMART (2011)
	Lack of client demand, high investment cost, ROI		LBD, FB	Hosseini et al 2016
	Lack of client demand, interoperability, lack of BIM experience, cost of implementation, incomplete model, lack of knowledge, learning time, cultural resistance, legal issues and lack of standards		LEP, LBR, FB, **LBA**, LIP, LI	Aibinu, 2016; Olatunji, 2011; Smith et al 2014
	Interoperability, funding and resource cost, cultural barriers and perceived risks, lack of Client demand		FB, LEP, LIP, LI	McGraw-hill (2014)
Singapore	Myth that BIM is costly and expensive, lack of trained people		FB, LBR, LI	McGraw-hill (2014)
	Cost, time, ROI, Technical competency, Training and contractor buy-in, Organizational structure change, Investment priority,		LIP, FB, LBR, LI	Shen et al 2016
	Lack of subcontractors who can use BIM technology, cost of investment, lack of demand for BIM use.		RA, FB, LEP	Zhao et al 2019
	Developing Countries			
Malaysia	Financial barrier, process barrier, Adequately trained personnel, Legal matters, Adequate advice.		FB, LIP, LBR, LI	Rogers et al 2015
	Organizational culture curve of BIM trainees, inadequate commitment from top management, leadership issue and need for executive support, difficulty in process change management, lack of collaboration, need for information sharing and communication, trust	Learning	LIP	Musa et al 2016
	Cost of hardware and software, selection of suitable software, lack of interoperability, need for well-developed strategies for the purposeful exchange and integration of meaningful information, security, inadequate skills and competency, need for technical support.	Technology	FB, **LBA**, LIP, LBR, LI	
	No clear guidelines for implement, not clear standardization	Process	GI	
	Legal and data ownership, resistance to change, need for government strategy	Policy	LI, LIP, LEP	
	High cost of technology, high training cost, high cost of software, drawbacks in existing hardware unable run basic BIM software, complication in using BIM SW	Technology	FB	CIDB, 2016
	Lack of knowledge on BIM, insufficient availabily of trainings, lack of awareness, lack of competency among team members, reluctant to change,	People	**LBA**, LIP	

	Lack of time to experiment past BIM projects, lack of reference to assist BIM implementation, lack of time to implement, lack of direction BIM in the industry, lack of BIM mandate, unfamiliarity with the BIM use	Process	LIP, LEP, **LBA**	
	Lack of expertise, lack of standardisation, legal issues, lack of client demand, lack of additional finance for trainings, resistant to change,		LBR, LI, LEP, FB, LIP	Jamal et al 2019
India	Mindset, culture, resources, costs, and current work practices		LIP, LBR	Sawhney et al. (2014)
	Lack of human resources, high software costs, resistance to change, high implementation cost due to isolated ad-hoc use of BIM		LBR, FB, OI	McGraw-hill (2014)
	people mindset, lack of skilled workforce, other consultants are not on BIM platform, technical issues, cost, lack of awareness and demand, BIM learning difficulties, current work practices, and resources		LIP, LBR, LEP, FB, **LBA**	Ismail et al, 2017
	Full potential of BIM is unclear, BIM software is complex to use, BIM implementation is a complex process, Lack of process standardisation	Technological	**LBA**, LIP	Ahuja et al 2018
	High set up cost, High training and running costs, Lack of awareness, Long lead time required for full-scale implementation, unavailability of BIM expertise	Organizational	FB, **LBA**, LBR	
	Lack of government incentives, Lack of BIM knowledge within project, Clients do not require BIM	Environmental	**LBA**, LEP	
	Mind-set issues, Difficulties in adapting to frequent changes in design, Unavailability of specialist consultants,		LIP, LBR	Jagadeesh and Jagadisan, 2019
Indonesia	Shortage of BIM experts, low demand from clients, high investment cost, reluctance of transforming into BIM environment		LBR, LEP, FB, LIP	Wilis et al. (2017)
	Incompatibility of different kinds of software used by the practitioners		LI	Chandra et al. (2017)
	High cost of investment, lack of client demand, training cost, Software is too sophisticated, reluctant to change from existing technology		FB, LEP, LIP	Hatmoko et al 2019
China	Resistance of typical management process, conflict with benefits of traditional stakeholder roles and values, legal requirements in the construction market work against collaboration, lack of human resources, interoperability		LIP, LI, LBR	McGraw-hill (2014)
	Cultural resistance, learning difficulties, long processes, government policies, lack of people interest and attitudes.		LIP, LEP	Ismail et al, (2017) and Bo et al. (2015)
	Cultural resistance, learning difficulties, and longer processes		LIP	Ismail et al, (2017)
	Lack of BIM experts, lack of standards and protocols,		LBR	Tan et al 2019
Libiya	Lack of expertise, lack of client demand		LBR, LEP	Saleh 2015
Nigeria	Lack of expertise, lack of awareness, high investment cost on staff training, process change, software and hardware upgrade costs		LBR, **LBA**, FB, LIP	Wang et al 2015
	Lack of expertise, lack of internet connection, reluctant to change, lack of BIM object libraries, lack of awareness		LBR, LIP, **LBA**	Onugwa et al 2017
	Lack of BIM experts in organizations and project teams, lack of standards and protocols, lack of client demand, lack of government policy, lack of additional finance, lack of collaboration among project stakeholders, resistance		LBR, LEP, FB, LIP, LI	Hamma-adama and Kouider, 2019

	in sharing information among stakeholders, cultural resistance, high investment cost, ROI issue, resistance at operational level, legal issues.			
Brazil	Lack of leadership and coordinated approach from government		LEP	McGraw-hill (2014)
Iran	Lack of legal backing from authority; Lack of skilled BIM software operators; High price of software; Unclear benefits of using BIM; Lack of client demand.		LI, LBR, FB, **LBA**, LEP	Kiani, 2015
	Unavailability of skilled staff , Lack of support and incentives from construction policy makers , Cost associated with purchasing necessary packages and software , Necessary training is not available, Cost of hardware upgrade, BIM industry standards and codes are not available, Lack of buy-in from other trades in the market, BIM requires radical changes in our workflow, practices and procedures, Benefits of BIM have not been conclusively proven, Current methods are adequate for our projects and BIM is an unnecessary investment, ICT facilities and internet structure in the country are not available on projects , BIM is regarded as a low return-on-investment, We don't know where to start.		LBR, LEP, FB, LIP,	Hosseini et al 2016
Iraq	legal issue, high cost of BIM software and hardware, high cost of training on the BIM tools, lack of skilled personnel, lack of skills and knowledge for company staff, resistance to change, lack of demand from owner, lack of awareness about BIM benefits, benefits of BIM not tangible, lack of expertise, shortage of BIM applications currently and lack of support from governments		LI, FB, LBR, LIP, **LBA**, LEP	Hamada et al, (2016)
	weakness of the government's efforts, Lack of experts in the field of BIM, Poor knowledge about the benefits of BIM, resistance to change, poor training and education		LEP, LBR, **LBA**, LIP	Hatem et al 2018
Jordan	Lack of BIM specialists, lack of trainings, unawareness, cost and lack of government support		LBR, **LBA**, FB, LEP	Building Smart. (2011)
	Lack of support and incentives from construction policymakers, BIM industry standards and codes are not available, Lack of awareness about BIM, Lack of client demand, Resistance of change, Lack of a BIM specialist, Necessary training is not available, Cost (software, hardware upgrade, training, and time), BIM requires radical changes in our workflow, practices, and procedures		LEP, LBR, **LBA**, LIP, FB	Matarneh and Hamed (2017)
Other	Personal, legal, management, cost and technical		LIP, LI, FB	Ademci and Gundes 2018; Sun et al 2017
	Organizational cultural change, Lack of a legal framework, Additional resources and expenses, Lack of interoperability, Increased level of risk and liability, Complexity, Current policies for procurement methods and procedures, Lack of comprehensive framework or implementation plan, Lack of BIM skills and training across the AEC industry, Organizational and cultural challenges, Attitude and behaviour		LIP, LBR, FB, LI	Ahns (2016)
	Inadequate training, Senior management buy-in, Cost of software, Cost of required hardware upgrades, Risk of losing intellectual property; liability issues; sharing of information between, contractors and facility owners		LBR, LIP, FB, LI	Mehran (2016)
	Lack of well-trained and knowledgeable professionals, lack of guidance and support from the government, and lack of standardized regulations and policies from the policymakers.		LBR, LEP	Masood et al., (2014)
Legend: FB – Financial Barriers; LBR – Lack of BIM Resources; LBA – Lack of BIM Awareness; LEP- Lack of external Pressure; LIP – Lack of Internal Pressure; LI – Legal Issues				

3.7.2.1 Financial Barriers (FB)

Literature revealed that the majority of construction stakeholders lag behind in BIM adoption due to cost-related issues (Pathak, 2019). The general impression among industry stakeholders is that BIM implementation costs too much compared with traditional construction (Ahuja et al., 2018; Aibinu, 2016; Alhumayn, 2018; BuildingSMART, 2011; Gerges et al., 2017; Hatmoko et al., 2019; Hosseini et al., 2016; Koseogle, 2013; McGraw-Hill, 2014; Mehran, 2016; Olatunji, 2011; Sabol, 2010; Smith et al., 2014; TCUF 2010; Wilis et al., 2017; Zhao et al., 2019). According to the CIDB (2016), most hardware in current practice is unable to run basic BIM software. As a result, in most cases the installation of new hardware, with extra memory, a better graphics card, widescreen and software is a fundamental step towards BIM adoption. Thus, the cost of hardware and software was found to be too expensive for the majority of practitioners (Bosch-Sijtsema et al., 2017; CIDB, 2016; Hardi & Pittard, 2015; Kiani, 2015; Marsh, 2017; Musa et al., 2016; RICS, 2017). Yusuf (2015) revealed that the installation of hardware and software costs up to £9,000-£11,000 per workstation. Furthermore, after purchasing the necessary hardware and software, providing appropriate training for existing staff is identified as another fundamental step in the adoption of BIM. Nevertheless, according to many researchers, providing training also costs too much for organisations as well as individuals (Abdulaal et al., 2017; Ahuja et al., 2018; CIDB, 2016; Hamada et al., 2016; Hamma-adama & Kouider, 2019; Hatmoko et al., 2019; Jamal et al., 2019; McGraw-Hill, 2014; Marsh, 2017; NBS, 2020; RICS, 2017; Wang et al., 2015). For example, Matthews and Withers (2011) stated that "approximately 1 in 20 employees requiring extra training to become software 'experts' at an estimated cost of £5,000 per person". Notwithstanding, the annual upgrading costs of hardware and software licenses also require an additional cost, which is similarly expensive (Abdulaal et al., 2017; Bosch-Sijtsema et al., 2017; Hamma-adama & Kouider, 2019; Hosseini et al., 2016; Matarneh & Hamed, 2017; Mehran, 2016; Wang et al 2015).

In the meantime, Marsh (2017) revealed that the cost of the network is another financial issue, as BIM requires high-end network facilities. As illustrated in Table 3.5, a low return on investment was found to be another financial issue for the adoption of BIM (Abdulaal et al., 2017; Ali, 2019; Gerges et al., 2017; Hamma-Adama & Kouider, 2019; Hosseini et al., 2016; Koseogle, 2013; Mehran, 2016). Due to a lack of evidence on the financial benefits of BIM, many construction practitioners believe that the adoption of BIM is a waste of money as it does not provide value for money (Ademci & Gundes, 2018; Bosch-Sijtsema et al., 2017; Sun et al., 2017). However, a study that examined 10 BIM-based projects in the USA recorded an average 634% return on investment (ROI) as a result of increased productivity and efficiency on current work practices (Azhar, 2015). Therefore, due to the above reasons, in many studies financial issues were identified as a major barrier for BIM adoption both in developed and developing countries.

3.7.2.2 Lack of BIM Resources (LBR)

LBR is identified as another barrier for BIM adoption (see Table 3.5) (Ismail et al., 2017; Sawhney et al., 2014). Accordingly, the literature identified a lack of BIM expertise as a major resource issue for BIM adoption (Ahuja et al., 2018; Aibinu, 2016; BuildingSMART, 2011; Chan, 2014; CIC, 2019; Hamada et al., 2016; Hamma-Adama & Kouider, 2019; Hatem et al., 2018; Hosseini et al., 2016; Ismail et al., 2017; Jagadeesh & Jagadisan, 2019; Jamal et al., 2019; Kiani, 2015; McGraw-Hill, 2014; Marsh, 2017; NBS, 2018, 2019, 2020; Olatunji, 2011; Onugwa et al., 2017; Pathak, 2019; Rogers et al., 2015; Sabol, 2010; Saleh, 2015; Smith et al., 2014; Tan et al., 2019; TCUF, 2010; Wilis et al., 2017). Therefore, in many organisations, BIM qualified people who are capable of dealing with BIM related software and tools are in limited numbers (NBS, 2020). Moreover, a lack of industry standards, lack of practice standards and guidelines, lack of BIM mandates, and a lack of standardised tools and protocols are also identified as resource issues for BIM adoption (Aibinu, 2016; Alhumayn et al., 2017; Ali, 2019; Chan, 2014; Gerges et al., 2017; Hamma-Adama & Kouider, 2019; Hosseini et al., 2016; Jamal et al., 2019; Koseogle, 2013; McGraw-Hill, 2014; Matarneh & Hamed, 2017; Mehran, 2016; NBS, 2019, 2020; Olatunji, 2011; RICS, 2017; Sabol, 2010; Smith et al., 2014; Tan et al., 2019; TCUF 2010). In large-size countries, such as the USA, states are using different BIM mandates, due to the absence of a nationally developed mandate. According to Cicco (2018), the US government has not developed a national BIM mandate due to the size of the country. This suggests that the development of mandates also depends upon the scale of the industry or country. In most countries, existing traditional contract documents do not comply with BIM-based practice, as some conditions, such as risk allocation, compensation, insurance, and dispute resolution, cannot be directly applied to BIM-based practice (Kurul et al., 2013). Nevertheless, as illustrated in Table 3.2, many countries have developed national and international standards, guidelines and protocols to support adoption. However, from a QS perspective, most available formats are incompatible with BIM models (Thurnell, 2015). Due to these discrepancies, it would be hard to perform a model based QTO, based on the regulations provided by standard formats, for example risk allocation and allowances for waste, jointing, and lapping are not automatically applied to the model. Moreover, BIM performs QTO without these measures, which increases the inaccuracy of cost estimates (Marsh, 2016). According to Olatunji et al. (2010), it is hard to develop a country-specific standard with such filters to account for BIM as it requires considerable investment. Thus, BuildingSMART (2012) indicates that the adoption of BIM by QS's relies on the development of common standards for automated quantity measurements. In the meantime, as discussed in section 3.6.1.1, the development of BIM supported standards through GI was found to be a key BIM driver for many countries. However, the lack of BIM supported standards, protocols and guidelines also indicate a lack of GI amongst some countries.

Besides, the lack of training was also identified as another resource constraint for BIM adoption (Ahns, 2016; Building Smart, 2011; Hosseini et al., 2016; Matarneh & Hamed, 2017; Mehran, 2016; NBS, 2018). FB (section 3.6.2.2) and a lack of BIM awareness were noted as key reasons for the lack of BIM training. As discussed in section 3.5, many countries have adopted BIM through nationally or organisationally developed frameworks or strategies. However, the lack of established contractual frameworks for working with BIM amongst some countries was another resource issue noted (Ahns 2016; NBS, 2019, 2020). Moreover, it also illustrates the lack of GI (section 3.6.1.1) and OI (section 3.6.1.5). For some countries (especially developing) the lack of Internet facilities is identified as another resource constraint for BIM adoption (Hosseini et al., 2016; Onugwa et al., 2017). This is also due to the cost associated with high-speed Internet, as discussed in section 3.6.2.1. Nevertheless, some countries lack BIM applications (such as BIM-based software) which was identified as another lacking resource and hinders the adoption of BIM (Hamada et al., 2016). Moreover, Onugwa et al. (2017) stated that a lack of BIM object libraries also hinders BIM adoption, as many practitioners encounter difficulties in finding accurate BIM object information before preparing BIM models. Therefore, it can be concluded that LBR is another key barrier to the adoption of BIM.

3.7.2.3 Lack of BIM Awareness (LBA)

LBA was found to be another key barrier for BIM adoption in the literature (Table 3.5). Accordingly, many professionals lack an understanding of BIM and its benefits (Alhumayn,, 2018; Alhumayn et al., 2017; Bosch-Sijtsema et al., 2017; BuildingSMART, 2011; CIDB, 2016; McGraw-Hill, 2014; RICS, 2017; NBS, 2019, 2020). As a result, many professionals believe that it takes too much time to learn, and BIM software is too complicated to use (Aibinu, 2016; Ahuja et al., 2018; Olatunji, 2011; Smith et al., 2014). Moreover, many professionals have less experience in BIM use (Hardi & Pittard, 2015), therefore, they are less confident in selecting appropriate BIM related software that is suitable to their role (Marsh, 2017; Musa et al., 2016). Besides, due to LBA, many professionals do not intend to use BIM, which decreases demand (Building Smart 2011; Hardi & Pittard, 2015; Ismail et al., 2017; Matarneh & Hamed, 2017; Onugwa et al., 2017; Wang et al., 2015;). This indicates a strong link between BIM awareness and demand.

Nevertheless, a lack of BIM related training is one of the key reasons highlighted in the literature for LBA (BuildingSMART, 2011; CIDB, 2016; Hatem et al., 2018). According to the literature, this lack is attributed to the finding that many educational institutions pay attention to theoretical aspects rather than providing practical experience of BIM (NATSPEC, 2013). This creates a gap between knowledge and skills, where graduates fail to work in a BIM-based collaborative working environment. Moreover, according to Marsh (2017) and Chan (2014), the lack of interventions by professional bodies has caused a lack of BIM related training. In section 3.6.1.2, PBI was identified as a key BIM driver for many countries. However, for some countries (see Table 3.5), the lack of PBI acts as a key barrier for BIM adoption. Furthermore, the lack of BIM education is identified as another reason for LBA (BuildingSMART, 2011; Hatem et al., 2018; Marsh, 2017). Many studies indicate that appropriate BIM education would generate skilled graduates/BIM experts for the construction industry (Wu & Issa, 2014). Various BIM-related educational activities, such as conferences, seminars, and workshops, are undertaken by the AEC industry to educate existing professionals (Liu et al., 2015). However, most educational institutions fail to provide fully BIM-integrated courses to fulfill industry expectations (Liu et al., 2015). Moreover, many universities and BIM-based education providers have introduced BIM as a 'software' and thus only focus on its use as a form of software (Smith, 2014). Hence, the current need of the industry is to have BIM-ready graduates who can cope with BIM concepts, management, and working in a collaborative platform (buildingSmart, 2012). Thus, most educational institutions have failed to develop appropriate BIM courses, which fulfill the need for theoretical and practical aspects, and this hinders the adoption of BIM. Therefore, LBA was found to be a key barrier to the adoption of BIM.

3.7.2.4 Lack of External Pressure (LEP)

External pressure is one of the main parameters of BIM adoption. In the literature, clients, government professional bodies, and market demand were identified as main external parties who can offer supportive external pressure to encourage BIM adoption (Liu et al., 2010). In sections 3.6.1.1, 3.6.1.2, 3.6.1.3, and 3.6.1.7 it was identified that GI, PBI, CD, and MD were key drivers for BIM adoption. Accordingly, for some countries, GI was found to be a BIM leader, whereas, in some countries, PBI leads the way. Nevertheless, in some countries, external pressure for BIM adoption which should come from industry clients, is affected due to the lack of client demand (Abdulaal et al., 2017; Ahuja et al., 2018; Aibinu, 2016; Ali, 2019; Bosch-Sijtsema et al., 2017; Chan, 2014; Hamma-adama & Kouider, 2019; Hosseini et al., 2016; Jamal et al., 2019; Kiani, 2015; NBS, 2019, 2020; McGraw-Hill, 2014; Matarneh & Hamed 2017; Olatunji, 2011; RICS, 2017; Saleh, 2015; Smith et al., 2014; Wilis et al. 2017). Many clients still demand traditional

2D drawings instead of BIM models due to LBA, as discussed in section 3.6.2.3. Moreover, as a result of LBA, many clients believe that BIM adds a lack of certainty in terms of the added value to clients (Marsh, 2017). Moreover, the lack of case studies showing the financial benefits of BIM has also deterred clients from investing in BIM (Yan & Damian, 2008). Simultaneously, clients who have already experienced the use and benefits of BIM refuse to share their knowledge with other clients, which has also resulted in fewer requests for BIM (Howard & Björk, 2008).

Besides, the lack of government intervention also results in LEP (Gerges et al., 2017; Koseogle, 2013; Mehran, 2016). As a result, many countries face difficulties in BIM adoption due to absence of BIM mandates, the lack of strict government rules and regulations, no clear standardization, and the need for a government strategy (Ahuja et al., 2018; Alhumayn, 2018; Chan, 2014; CIDB, 2016; Hamma-Adama & Kouider, 2019; Musa et al., 2016; Pathak, 2019). In many countries, BIM is not mandated yet within the construction industry. Moreover, the lack of leadership and a coordinated approach from the government (McGraw-Hill, 2014), weak government efforts (Building Smart, 2011; Hatem et al., 2018), and a lack of guidance and support from the government (Hamada et al., 2016; Masood et al., 2014; NBS, 2020) have also resulted in LEP. Furthermore, the lack of interventions from professional bodies was found to be another reason for LEP in the literature (Alhumayn et al., 2017; Bosch-Sijtsema et al., 2017; Hosseini et al., 2016; Masood et al., 2014; Matarneh & Hamed, 2017). As a result, professional bodies have failed to develop relevant policies, standards, and guidelines to support BIM adoption. In the meantime, the lack of market demand is also identified as another key reason behind LEP, which is due to the lack of maturation of BIM technology to merit its being sought (Ali 2019), the lack of large-scale projects to implement BIM (McGraw-Hill, 2014; NBS, 2018), the fact that other practitioners are not on a BIM platform (Bosch-Sijtsema et al., 2017; Ismail et al., 2017; Ku & Taiebat, 2011; Zhao et al., 2019) and a lack of direction towards BIM in the industry (CIDB, 2016). Therefore, LEP also can be identified as another key barrier for BIM adoption.

3.7.2.5 Lack of Internal Pressure (LIP)

Internal pressure is another parameter in BIM adoption noted in the literature. Accordingly, findings illustrate that many organisational issues have resulted in LIP. Among them, less support from senior management (due to LBA) (Alhumayn et al., 2017; Eadie et al., 2014; Mehran, 2016; Musa et al., 2016) is a highlighted issue for many organisations. This has resulted in the lack of an organisational training strategy (Ali, 2019; Musa et al., 2016), the lack of internal demand from employees, (Bosch-Sijtsema et al., 2017), adequate advice for BIM adoption (Rogers et al., 2015), and the lack of process standardisation for BIM adoption (Ahuja et al., 2018) within the organisation. Moreover, organisational management is responsible for introducing and allocating new roles and responsibilities (such as BIM manager, BIM modeler, etc) and rewards (Eadie et al., 2014). However, the lack of management support hinders the involvement of senior management from executing these activities within the organisation.

Cultural resistance is found to be another key issue behind LIP (Aibinu, 2016; Bosch-Sijtsema et al., 2017; CIDB, 2016; Eadie et al., 2014; Hamada et al., 2016; Hatem et al., 2018; Hatmoko et al., 2019; Musa et al., 2016; Olatunji, 2011; Smith et al., 2014; Wilis et al., 2017). Many employees intend to use the traditional way of working (mostly isolated) rather than move to a team working culture (CIDB, 2016; Ismail et al., 2017). However, BIM requires a collaborative working culture that represents a completely new way of working compared to traditional practice (Fung et al., 2014). Organisations encounter difficulties when introducing teamwork culture due to the lack of collaboration among employees during a construction project and the work process (Hamma-adama and Kouider, 2019; Ku & Taiebat, 2011, McGraw-Hill, 2014; Musa et al 2016; NBS, 2019, 2020); attitude and behaviour (Ahns, 2016; Bo et al., 2015); fixed mindsets amongst employees (Ismail et al., 2017; Sawhney et al., 2014, Jagadeesh & Jagadisan, 2019, Ali, 2019; McGraw-Hill, 2014; CIC, 2019); learning difficulties (Bo et al., 2015; Ismail et al., 2017); long processes (Hosseini et al., 2016; McGraw-Hill, 2014; Matarneh & Hamed, 2017; Musa et al., 2016; Rogers et al., 2015; Walasek & Barszcz, 2017). Moreover, QS organisations find it hard to change employees' mindsets, as they believe BIM adds uncertainty to the QS role (Marsh, 2017), and provokes a fear of extinction for the QS role (Alhumayn, 2018; Eadie et al., 2014; McGraw-Hill, 2014; Marsh, 2017). Besides, a lack of trust among employees (Musa et al., 2016) also resulted in cultural resistance as many employees refuse to share information (Hamma-adama & Kouider, 2019; Mehran, 2016). Moreover, the absence of well-developed strategies for the purposeful exchange and integration of meaningful information (Musa et al., 2016) has also prevented employee BIM adoption. Therefore, it can be concluded that LIP is another key barrier for BIM adoption.

3.7.2.6 Legal Issues (LI)

Literature also revealed that LI are another barrier to BIM adoption (Abdulaal et al., 2017; Ademci and Gundes, 2018; Aibinu, 2016; Alhumayn, 2018; Hamada et al., 2016; Hamma-adama & Kouider, 2019; Jamal et al., 2019; Marsh, 2017; Olatunji, 2011; Rogers et al., 2015; Sabol, 2010; Smith et al., 2014; Sun et al., 2017; TCUF, 2010; Walasek & Barszcz, 2017). Accordingly, literature identified the lack of interoperability as a key legal issue (Ahns, 2016; Aibinu, 2016; Ali, 2019; Barszcz, 2017; Eadie et al., 2014; McGraw-Hill, 2014; Musa et al., 2016; Smith et al., 2014; Walasek & Olatunji, 2011). Interoperability can be defined as "a characteristic of a product or system, whose interfaces are completely understood, to work with other products or systems, present or future, in either implementation or access, without any restrictions" (AFUL, n.d). Hence, most existing programs were developed to work standalone and are not capable of sharing data with other programs (Paul, 2018). Redmond et al. (2012) noticed that many professionals still use different tools in terms of information exchange. The differences in these BIM tools can result in inefficient information exchange (Chandra et al., 2017; Cheung et al., 2012; Kurul et al., 2012; Steel et al., 2012). Moreover, these tools have their own data structures and do not provide a means of linking their database through a standard, which creates the biggest challenge to interoperability (Bosch-Sijtsema et al., 2017; Paul, 2018). Besides, the use of copyrighted software and tools has also limited the data exchange between multiple organisations (Steel et al., 2012). From a QS's perspective, to get the maximum benefits of BIM adoption, the information should be effectively shared across all BIM tools and participants. Hence, the lack of interoperability results in a lack of data exchange, resulting in incompatibility issues between BIM models and estimating platforms (Olatunji, 2011). In the USA, it was reported that $15.8 billion are lost annually due to interoperability issues (NIST, 2014). Therefore, challenges due to interoperability must be addressed to enable effective BIM adoption within QS practice (Steel et al., 2012; McGraw-Hill, 2014).

Moreover, QS mainly depends upon the information given in the model; therefore, accurate information is vital for a QS to prepare accurate cost estimates. However, due to liability and copyright issues (Eadie et al., 2014; Mehran, 2016; Musa et al., 2016; Zainon et al., 2017), it is hard to determine the proprietor of the model. Therefore, a QS has to face difficulties, such as incompatibilities within the BIM data's estimating formats, a lack of integration in the model, a lack of trust in the quality of the model; over-complexity amongst BIM-models and incorrect information in the model (Ahns, 2016; Aibinu, 2016; Bosch-Sijtsema et al., 2017; Olatunji, 2011; RICS, 2017; Smith et al., 2014). Moreover, further issues are encountered due to the undefined responsibility of model architects or designers, and restricted access to the 3-D model for other project stakeholders (Bosch-Sijtsema et al., 2017; Eadie et al., 2014). In addition, the absence of a proper legal system for the model and its data has increased the risk level (Ahns, 2016; Ali, 2019; Gerges et al., 2017; Kiani, 2015; Koseogle, 2013, Mehran, 2016; RICS, 2017). Therefore, it can be concluded that LI is another barrier to BIM adoption.

To summarise, the above discussion identified the BIM drivers and barriers in both developed and developing countries. It was also observed that the factors identified as drivers in some countries were found to be key barriers in other countries, for example, GI. Therefore, it can be argued that drivers - if not met – can become barriers in many countries. Moreover, it was also noted that, even though most of the major barriers are common in the majority of countries, the causes of these barriers vary. For example, in some countries the causes of financial barriers were found to be the cost of hardware and software, training costs and annual upgrading costs, whilst for some countries it was the cost of hardware and software, training costs, annual upgrading costs and return on investment (ROI). In the meantime, some countries found that network costs posed financial barriers. Hence, even if the key barriers were similar for most countries, the causes were not, in most cases. Therefore, it is important to identify the key barriers along with their root causes for the successful adoption of BIM.

3.8 Conceptual Framework

A conceptual framework is an extraction of concepts that helps to comprehend the relationship between the concepts and their influence on the phenomenon being examined (Ngulube et al., 2015). The purpose of having a conceptual framework is to link the concepts with the research problem while giving direction to the research. Nevertheless, the above conceptual framework (Figure 3.21) was developed by linking the objectives of this research with the explored concepts. According to Figure 3.21, the first objective aimed to identify the factors affecting the accuracy of pre-tender cost estimates. The first and the second objectives had a significant link through the use of BIM to improve the accuracy of pre-tender cost estimates. The third objective aimed to identify the drivers, barriers and mitigating actions to BIM adoption. Finally, the framework connected the research gap to the outcomes of the study.

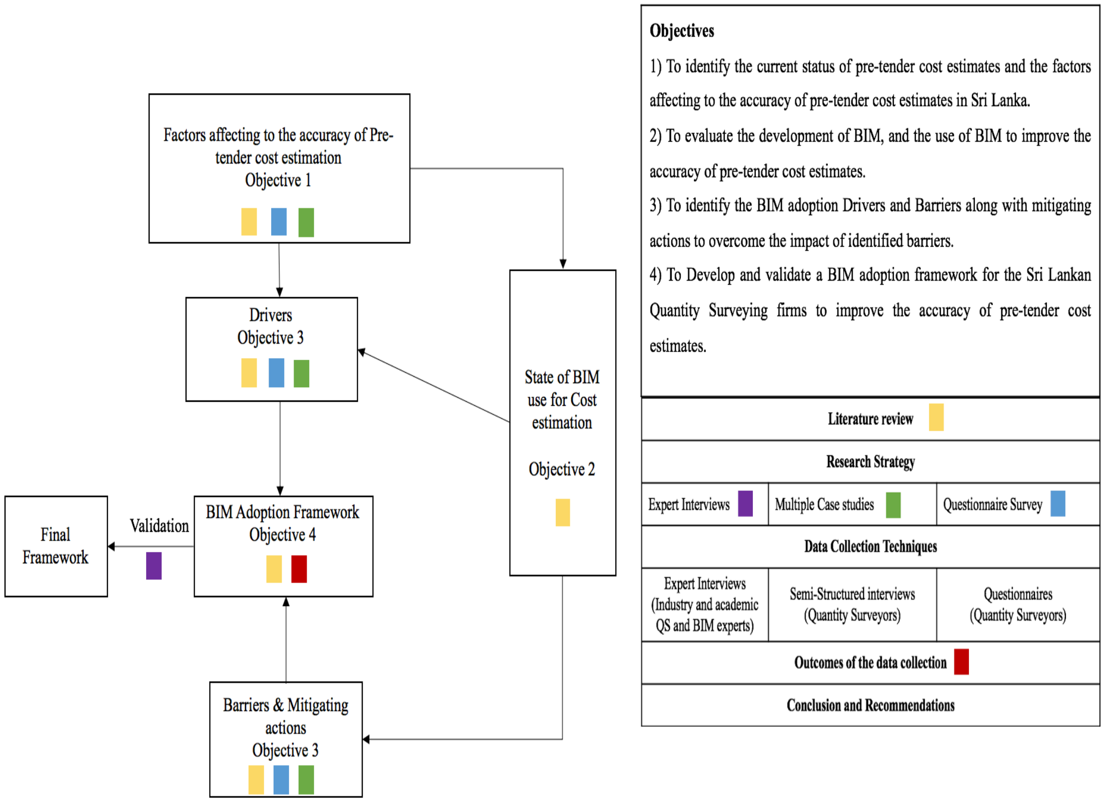


Figure 3.21: Conceptual Framework

3.9 Summary and Link

This chapter addresses objectives 2 and 3 of this research. Firstly, the chapter describes the development of BIM, BIM definitions, and BIM dimensions. Then chapter examines the use of BIM to improve the accuracy of pre-tender cost estimates. The use of BIM models, improved visualization, clash detection, better information management, Automate Quantity Take-off, time savings, and improved communication and collaboration were identified as the most prominent factors to improve the accuracy of cost estimates. Subsequently, global BIM adoption practices and the status of BIM adoption in Sri Lanka were also explored. Moreover, GI, PBI, CD, BB, OI, BE, MD, and RA were identified as the key drivers for BIM adoption, whilst, FB, LBR, LBA, LEP, LIP, and LI were identified as the most frequent barriers to BIM adoption. Finally, the chapter explained gaps in the state of the art BIM adoption and the conceptual framework's direction of the empirical research. The next chapter describes the methods adopted to conduct the empirical study.

4 RESEARCH METHODOLOGY

4.1 Introduction

A comprehensive literature review was presented in chapters 2 and 3, in order to summarise the key concepts relevant to this study. The purpose of this chapter is to discuss the most appropriate methodology that will address the research questions and achieve the established objectives. Based on Saunders et al. (2012), the mixed-method approach of the 'Research Onion' model was adopted, which included semi-structured interviews and a questionnaire survey.

The methodology consisted of three phases and started with an initial literature review and a questionnaire survey (A) as the first phase to identify weaknesses in the existing pre-tender cost estimate process. The survey data was analysed statistically using the Statistical Package for the Social Sciences (SPSS). Questionnaire survey (B) were conducted for expertise in the field to identify BIM adoption drivers and barriers. The survey data was analysed statistically. In the second phase, three case studies were selected, and semi-structured interviews were conducted for expertise in the field to identify factors affecting the accuracy of pre-tender cost estimates, BIM adoption drivers, barriers and mitigating actions. The collected data were analysed qualitatively and quantitatively both manually and by using SPSS. Finally, the third phase of this research involved semi-structured interviews with industry experts to validate the developed framework that was based on the survey results. Accordingly, the chapter is structured as follows:

- Research Methodological Design
- Research Philosophy
- Research Approaches
- Research Strategy
- Unit of Analysis
- Research Choices
- Time Horizon
- Research Techniques

4.2 Research Methodological Design

According to Creswell (2009), a research methodology is a systematic approach that can be used to achieve the research aim. Moreover, he further emphasized that the research methodology consists of a set of tools that is required to complete the research successfully. Billing (2004) identified the research methodology as a process for the conduct of research. Nevertheless, the consistency of research is fundamental to the reliability of any findings (King & Brooks, 2016). However, the identification of the most applicable research method is a critical step, as an appropriate research design can minimize the risk and uncertainties attached to the research process by identifying difficulties and problems that the researcher might encounter. Therefore, before conducting any research a proper methodology should be defined. Various academics have proposed different research models to define such procedures and assist the systematic inquiry. Among them, the nested model of Kagioglou, Cooper, Aouad, and Sexton (2000) and the Research Onion model of Saunders et al. (2016) are the two most recognised models in built environment research.

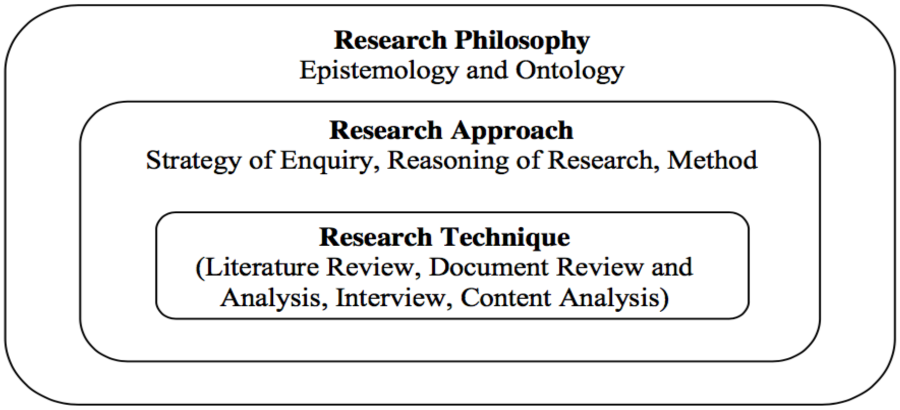


Figure 4.1: Nested Research Methodology Approach (Adapted from Kagioglou et al., 2000)

The nested model was developed by Kagioglou et al. (2000) and consists of three layers starting from the selection of the philosophical stance and narrowing down to the selection of the research approach and research technique, as illustrated in Figure 4.1. This model provides a complete evaluation of the coherent implementation of research. Accordingly, the research philosophy clarifies the core assumptions of the researcher, while the research approach clarifies the form of reasoning, and the research techniques describe the available tools to collect and analyse the data.

Saunders et al. (2016) developed the six layered Research Onion model that consisted of: the research philosophy, research approaches, research strategies, research choices, time horizon, and data collection methods, as illustrated in Figure 4.2. Compared to the Nested model, the Onion model provides a clearer understanding of the series of steps required to design a research methodology. Moreover, it further illustrates how each element and its assumptions are interconnected. Therefore, in its clear understanding of the research methodology components, Saunders et al.'s 'Research Onion' was adopted for this research, as it is capable of providing proper guidance through different layers to identify appropriate methods and tools to achieve the aim of the research. Based on the Research Onion, the selected procedures for the empirical study are presented in this chapter.

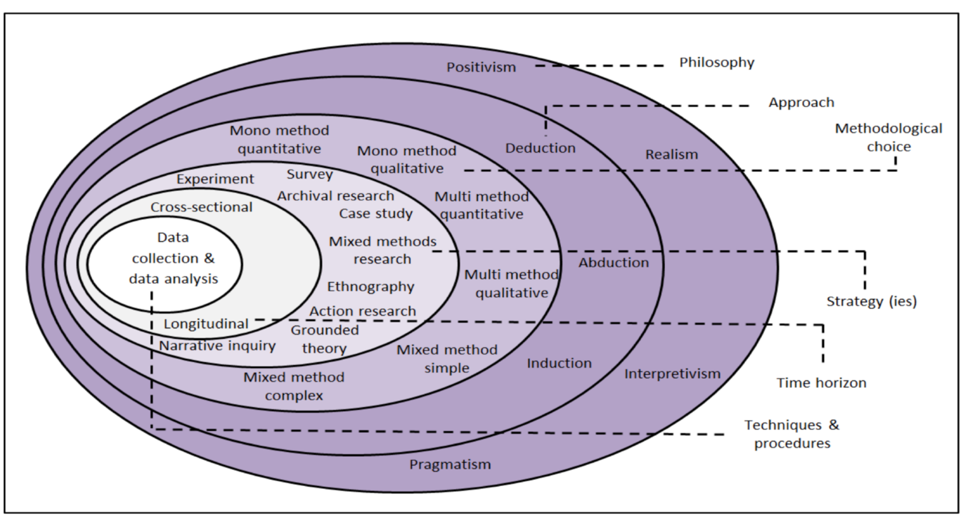


Figure 4.2: Research Onion Model (Saunders et al., 2016)

4.3 Research Philosophy

The first layer of the Research Onion presents the research philosophy (Figure 4.2). When undertaking research, the primary theoretical perception should be conducted by the researcher (Gray & Malins, 2004). This primary theoretical perception is referred to as the 'research philosophy' (Collins, 2010; Fellows & Liu, 2015; Saunders, 2011; Trochim & Donnelly, 2001). The research philosophy is a set of beliefs that are based on the way the researcher views reality. The philosophical assumptions of the researcher helps to:

- Simplify the research design.
- Identify which is appropriate and which is not.
- Recognise and generate, a design external to the researcher's experience (Easterby-Smith, Thorpe & Jackson, 2008).

Accordingly, Ontology, Epistemology, and Axiology are the three different assumptions to distinguish a research philosophy (Figure 4.3) (Burrell & Morgan, 1979; Saunders et al., 2011). Usually, these three assumptions are identified under three different views. However, Niglas (2010) believes the philosophical assumptions of a researcher coincide with a point on a multidimensional range between two contrasting points, usually referred to as objectivism and subjectivism. Therefore, the different patterns of these points with the combined set of ranges establish the researcher's philosophical position.

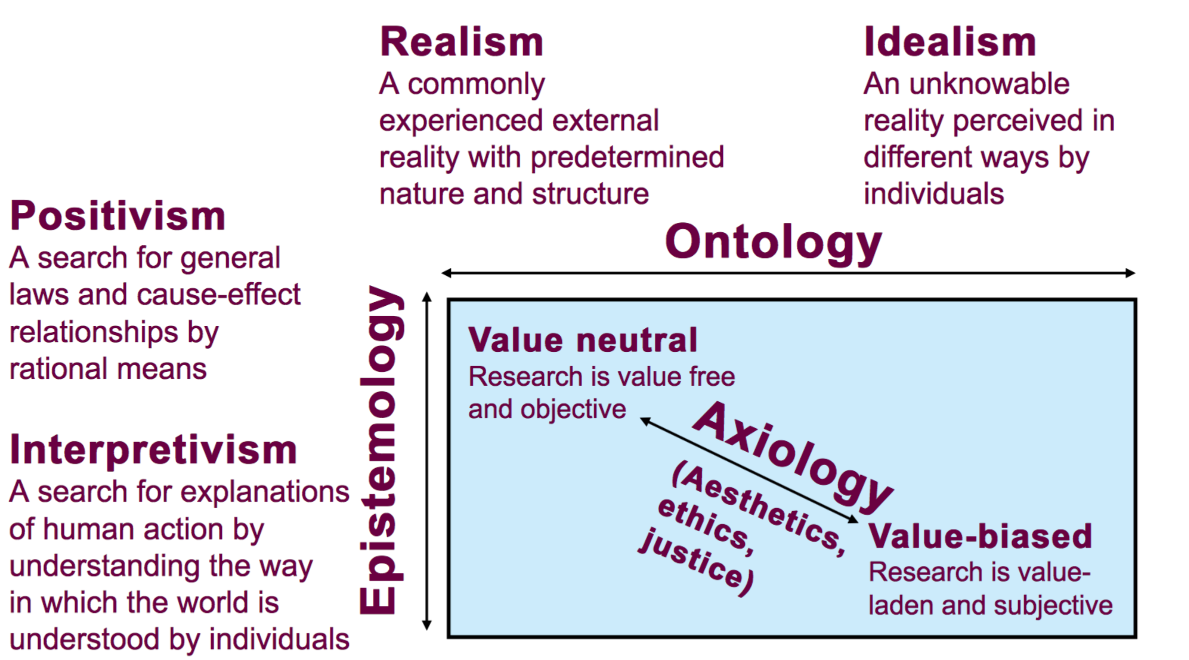


Figure 4.3: The dimension of the research philosophy (Sexton, 2003)

4.3.1 Ontology

Ontology indicates the researcher's assumptions about the nature of reality. It consists of what is known and what is considered as social reality, such as political, cultural, historical, and economic value systems

(Creswell & Clark, 2007; Dakhil, 2017). As illustrated in Figure 4.3, ontology has two extremes, namely realism (objectivism) and idealism (constructivist or subjectivist). From the realist view (Figure 4.3), it is assumed that reality exists with a predetermined nature and structure that is independent of the determination of the people. From an idealist view, reality can be perceived in different ways subject to an individual's experience (Saunders et al., 2012). Therefore, ontology describes what knowledge is and the assumptions about reality (Miles & Huberman 1994).

In this study, the researcher seeks to develop a new BIM adoption framework for quantity surveying organizations by identifying BIM drivers, barriers, and mitigating actions for barriers. This knowledge is not externally generated, and thus is a creation of the social, economic, and cultural facts that we experience in our day-to-day life, which means that knowledge is socially constructed. Moreover, a fixed variable, such as objective methods, cannot be used to measure this knowledge. Also, this includes knowledge for BIM adoption drivers and barriers and mitigating actions generated through people, how they find the BIM adoption process within their organisations, and how they are a part of the BIM adoption process. Therefore, ontologically this research tends more towards idealism. Similarly, this research assumes that reality remains subjective and represents the interpretation and interaction between stakeholders.

4.3.2 Epistemology

Miles and Huberman (1994) describe epistemology as "how we know it" and concerns assumptions about how knowledge should be acquired and accepted. In other words, epistemology concerns the way of obtaining recognized knowledge in the field of study. As illustrated in Figure 4.3, epistemology has two paradigms, such as positivism and interpretivism. At the 'positivist' end of epistemology, the researcher conducts research between observable realities, accepting that everything has a general law. At the 'interpretivist' end, researchers conduct research by using humans as social actors to search for knowledge amongst people (Saunders et al., 2012).

As described earlier, this research study aims to identify BIM adoption drivers, barriers, and mitigating actions from QS perspectives to develop a new BIM adoption framework. Accordingly, knowledge should be gathered through participation in the ostensive BIM adoption process. Such knowledge cannot be gained externally; thus, this research requires socially constructed knowledge. Moreover, knowledge depends upon people's perceptions, who are also influenced by a range of socio-economic and cultural factors, and the knowledge gained from society becomes fundamentally subjective. Therefore, this research tends more towards the end of the interpretivism extreme by understanding knowledge as a social construction.

4.3.3 Axiology

Axiology is another branch of philosophy and studies judgment about value (Saunders, 2011). According to Miles and Huberman (1994), it explains, "what research values go into it" and the assumptions about value systems. As illustrated in Figure 4.3, axiology has two extremes - value-neutral (value-free) and value biased (value-laden). At the value-neutral end of the continuum, the researcher is completely independent in terms of data and its interpretations, whilst at the value-biased extreme, the researcher is part of the data and its interpretation (Saunders et al., 2012). This research study uses people's thoughts and beliefs to obtain subjective data for the development of the framework. Moreover, the researcher's thoughts are also affected when obtaining subjective data. Therefore, this study tends towards interpretivism where decisions are value-laden. Figure 4.4 illustrates the philosophical stance related to this study, concerning the research philosophy continuum.

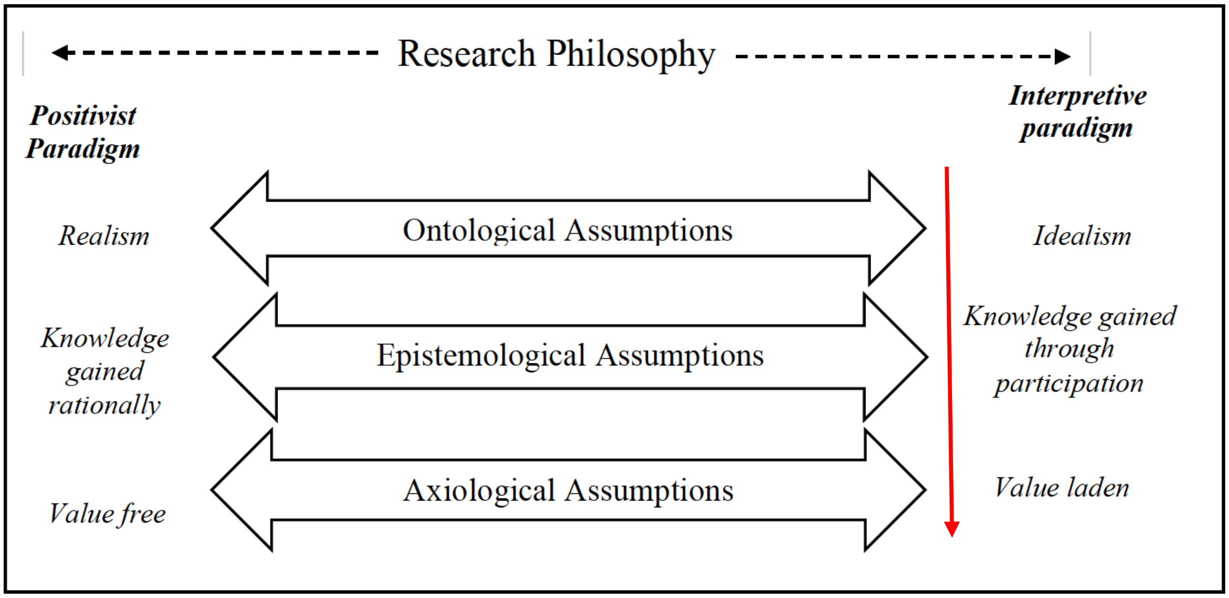


Figure 4.4: The Philosophical Stance Pertaining to the Study

Furthermore, this research involves the study of complicated interactions between organisational management, senior QS's, QS's, and Assistant QS's, involved in the BIM adoption process in a real-life scenario. The objective of the study, such as the identification of key BIM barriers and mitigating actions in the BIM adoption process, demand that this research is more exploratory in nature, than explanatory. Therefore, this further justifies the selection of an interpretive research paradigm for this research.

4.4 Research Approach

The second layer of the Research Onion by Saunders et al. indicates the type of research approach. According to Easterby-Smith et al. (2008), the approach enables the researcher to achieve research aim by finding the answers to the research questions and meeting the objectives of the study. Deductive, inductive, and abductive are the three types of research approach. The deductive approach allows the researcher to develop a theory and hypothesis**.** In many cases, a deductive approach is used in the objectivist ontology and natural sciences (Collis & Hussey, 2013). The hypothesis is tested by the research findings and, if required, the theory is modified by rejecting or confirming the established hypothesis (Gill & Johnson, 2010; Hyde, 2000; Johnson-Laird, 1999; Rice & Ezzy, 1999). According to Trochim and Donnelly (2001), deductive works from the general to the particular, which is also called a 'top-down' methodology (Hyde, 2000; Johnson-Laird, 1999; Rice & Ezzy, 1999).

The inductive approach is the opposite to the deductive approach as it starts with observations or a data collection to build up a theory. Therefore, this approach consists of views that enhance the development of a hypothesis. Moreover, observations are expected of existing phenomenon (Bryman, 2015; Kothari, 2004; Patton, 2005; Rice & Ezzy, 1999; Rosenthal & Rosnow, 1991; Teddlie & Tashakkori, 2009). In most cases, this approach is used in subjectivist ontology. This approach works from specific observations to broader theories, which are also called 'base-up' approaches (Trochim & Donnelly, 2001). Therefore, in this approach, the researcher begins with observations and measures, where the researcher identifies patterns and regularities, formulates an explorable hypothesis and finally develops general conclusions or theories (Bryman, 2015; Kothari, 2004; Patton, 2005; Rice and Ezzy, 1999; Rosenthal & Rosnow, 1991; Teddlie & Tashakkori, 2009).

However, in many studies, researchers have adopted a combination of inductive and deductive approaches, which is called the abductive approach (Bryman, 2015; Kothari, 2004; Patton, 2005; Rice & Ezzy, 1999; Rosenthal & Rosnow, 1991; Saunders et al., 2011; Teddlie & Tashakkori, 2009). This combination leads to more meaningful results, as the abductive approach does not purely adopt deduction or induction (van Hoek et al., 2005). Compared to the individual approach, the abductive process is more innovative, perceptive, and progressive as it can be developed using various disciplines that range from learning, linguistics, logic, neural networks, artificial intelligence, computer science, and so forth (Dubois & Gadde, 2002; Feilzer, 2010; Haig, 2005; van Hoek et al., 2005). Thus, the abductive approach provides a more successful way of researching certain phenomena (Bryman, 2015; Teddlie & Tashakkori, 2009).

Accordingly, this research aims to develop a new BIM adoption framework to enhance accurate pre-tender cost estimates. The expected framework offers a guiding strategy for Sri Lankan quantity surveying organizations, suggesting BIM drivers and mitigating actions to overcome identified barriers and root causes. Accordingly, this research builds theory for BIM adoption; therefore, this study also incorporates induction. On the other hand, the researcher evaluated BIM drivers and barriers identified through studies conducted in other countries to identify key drivers and barriers specific to the Sri Lankan context in order to develop the BIM adoption framework. Therefore, the researcher is testing an established theory, and thus research enters a deductive phase. As described above, the abductive approach is a combination of both inductive and deductive features. Moreover, as Saunders et al. (2012) describe, the abductive approach means travelling back and forth between theory and data throughout the entire research study by either developing a new theory or modifying an existing theory, which applies to the current study. Nevertheless, Gill & Johnson, (2010) and Jogulu & Pansiri, (2011) state the abductive approach better supports the mixed-method approach.

4.5 Research Choice

The next layer of the Research Onion outlines the research choices, such as the mono method, the mixed method, and the multi-method illustrated in Figure 4.5 (Saunders et al., 2011). In recent years, there has been an extensive argument within many of the social sciences regarding the appropriateness of quantitative and qualitative strategies for research (Hughes, 2014).

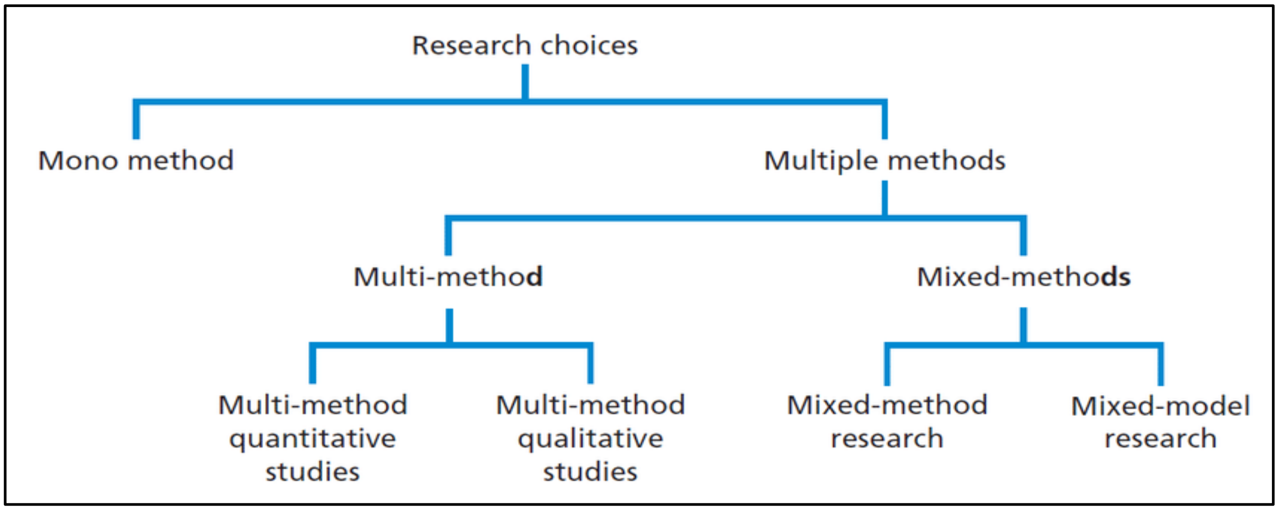


Figure 4.5: Research choice (Saunders, 2011)

Quantitative research refers to the counting of things (Berg, 2001) in order to build up a relationship between variables or theories and the findings of previous research using frequently gathered data (Kraemer, 2002). Newman and Benz (1998) stated that quantitative methods are typically employed in social research. This method draws on the positivist/objectivist continuum, which discovers theoretical evidence to confirm proposed theories. Therefore, this method mainly consists of research strategies, such as experiments, survey research strategies, archival research and case studies (Saunders, 2011).

Conversely, the qualitative method deals with non-numerical data (Kornkaew, 2012), based on people's words, perceptions, feelings, etc to confirm any developed theory (Bryman, 2015; Creswell, 2013; Saunders et al., 2011). This method is more integrated with interpretive and critical paradigms (Hughes, 2014), which are subjective. Therefore, qualitative research mainly focuses on an individual subject or unit, or even a case that is central and examined via phenomenological perceptions (Newman & Benz, 1998). This method mainly consists of research strategies, such as action research, case study research, ethnography, grounded theory, and narrative research (Saunders, 2011).

Some researchers consider these as two separate strategies, thus some use two methods together in their research. Bryman (2012) argued for a 'best of both worlds' approach in combining qualitative and quantitative approaches. Hence, Hughes (1997) warns that the combination of both methods could hinder the legitimacy associated with each method. According to Das (1983) "qualitative and quantitative methodologies are not antithetic or divergent". Hence, on many occasions, when it seems to be different, the fundamental unit might become noticeable with richer perception; in comparison, the situational incidents and objectives of the study might play a significant role in its design and implementation. This situation has led the researcher's to consider 'triangulation' in research (Yin, 2013). The aim of triangulation is to obtain strong measurements by combining methods (quantitative or qualitative) within the same phenomenon (Amaratunga et al., 2002). Mono-method and Multi-method are the main categories under triangulation (Saunders, 2011).

In a mono-method, the researcher focuses on one method, either purely qualitative or quantitative. In multiple methods, two approaches can be identified namely multi-method and mixed method research. In a multi-method approach, a broader range of methods is used (Bryman, 2015; Creswell, 2013; Saunders et al., 2011) to create individual data sets for each segment of the research and to then analyze these data sets individually using the different techniques for quantitative or qualitative methodologies (Feilzer, 2010). This approach will be purely subjective or objective even if it covers more than one philosophical paradigm (Bryman, 2015; Creswell, 2013; Saunders et al., 2011).

In the mixed-method approach, more than one method is combined to create one dataset (Flick, 2015). In this case, the researcher starts with a subjectivist philosophy and continues with an objectivist philosophy, or vice versa (Collis & Hussey, 2009; Kothari, 2004; Patton, 2005; Rice & Ezzy, 1999; Teddlie & Tashakkori, 2009). Simultaneously, qualitative data can be analyzed using quantitative techniques or vice versa, as it mixes qualitative and quantitative data, different methods, methodologies, and/or paradigms in a particular approach. Therefore, considering the following factors, a mixed-method approach has been selected to address the research question of this study.

- This research attempts to identify key BIM drivers and barriers along with mitigating actions to overcome the impact of the barriers identified. Therefore, this need cannot be accomplished by using one type of data, e.g. by using a quantitative method, as it is hard to identify mitigating actions, as it requires more qualitative data.
- As a result, the use of different types of data collection techniques, such as questionnaires and interviews, and analysis procedures are required for this study.
- Moreover, it also increase the reliability of the findings, as it offers the chance of checking the findings derived from one method (ex. quantitative) against those derived from qualitative.
- Besides, the use of mixed methods provides a better understanding of the contextual background of the research to the researcher through a broader perspective (Bryman, 2015; Creswell, 2013; Saunders et al., 2011).

Moreover, as different types of mixed method design are available, namely sequential explanatory, sequential exploratory, concurrent triangulation, and concurrent nested (Bryman, 2015; Creswell, 2013; Saunders et al., 2011). The overall purpose of the research should be considered (e.g., exploration or generalization), when deciding on a mixed methods design. Accordingly, this research adopts an explanatory sequential mixed method (ESMM) approach (Figure 4.6), which consists of separate quantitative and qualitative data collection methods and analyses, which are divided into two phases within the study (Creswell et al. 2003).

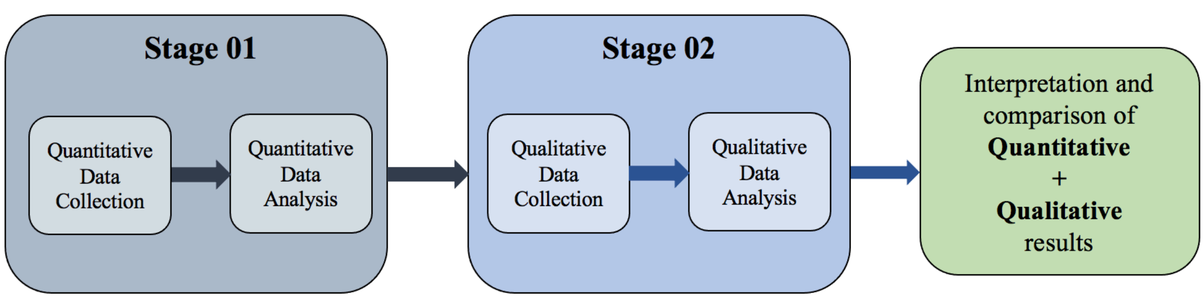


Figure 4.6: Explanatory sequential mixed method approach (Creswell et al., 2003)

As illustrated in Figure 4.6, ESMM starts with quantitative data collection and analysis, which helped to build qualitative data based on the quantitative findings (Creswell et al., 2003). The second phase consists of qualitative data collection and analysis, where the researcher can conduct an in-depth qualitative study. For the present study, the researcher aims to identify key drivers and barriers based on previously developed theories, which required quantitative data collection. Moreover, these findings required further explanation if the findings identified statistically significant differences. Therefore, through an in-depth qualitative study, the reasons behind these results can be further explained. In other words, this helps the researcher to identify root causes for key factors, and in the meantime, mitigating actions for each root cause. Therefore, ESMM design exclusively suits this study. Moreover, as the qualitative data collection is based on the quantitative data findings, it gives a clear understanding to the researcher of what exactly needs to be obtained within the qualitative data collection. Besides, as the data collection is undertaken over two phases, the data analysis can be written into two phases in order to provide a clear explanation for the readers (Ivankova & Stick, 2007).

4.6 Research Strategy

The next layer of the Research Onion represents the research strategy. Denzin and Lincolin (2011) define the research strategy as "a plan of how researchers going to achieve the research aim by answering established objectives". Several authors have proposed various approaches (Creswell, 2003; Lu & Sexton, 2004; Saunders et al., 2012; Yin, 2014); however, an appropriate strategy or strategies should be carefully selected in order to consider the nature of research questions, objectives, available time, the amount of available knowledge, the available resources, and the defined philosophical stances (Saunders et al., 2011). Saunders et al. (2016) listed eight common research strategies: experiment, survey, archival research, case study, ethnography, action research, grounded theory, and narrative inquiry. However, according to Creswell (2003), the most frequently used research approaches in social science research are experiments, surveys, ethnographies, grounded theory, and case studies.

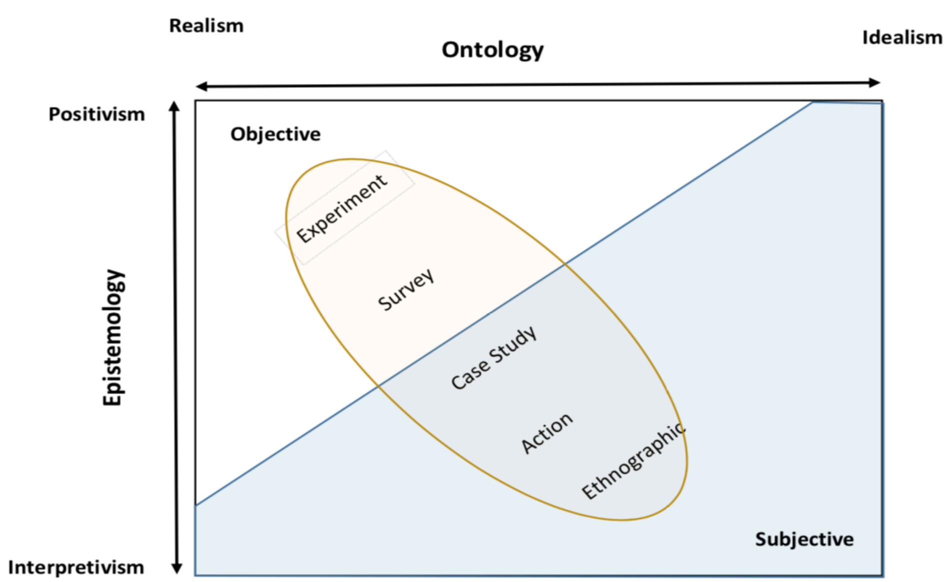


Figure 4.7: Dimensions of a research philosophy (Sexton, 2007).

However, some of these strategies are associated with particular philosophical stances, such as ethnography, which is associated with both realism and interpretivism. A case study, perhaps of an individual organization, is often associated with interpretivism; case studies are also used in positivistic research. (Saunders et al., 2011). Figure 4.7 illustrates the relationship between research philosophy and research strategy (Sexton, 2007). Moreover, Table 4.1 justifies the selection of a research strategy based on the capability of answering the established research questions.

Table 4.1: Justification for selecting the research method (Adapted from Yin, 1994)

Research strategy	Forms of the research question	Requires control of behavioural events	Focuses on contemporary events
Experiment	How, Why?	Yes	Yes
Survey	Who, What, Where, How many, How much?	No	Yes
Archival analysis	Who, What, Where, How many, How much?	No	Yes/No
History	How, Why?	No	No
Case Study	How, Why?	No	Yes

Accordingly, an appropriate research strategy can be selected based on the research questions, which controls what the investigator exercises over actual behavioural events and the extent of focus on contemporary events (Table 4.1). For this research, what, how, and why questions were formed. What questions indicate an exploratory investigation, which is conducted when existing knowledge on the issue in question is poor (Kohtamäki et al, 2018). Therefore, according to the research questions, all five strategies can be identified within the research.

The third column of Table 4.1 focuses on the requirement to control behavioural events. Accordingly, except for the experiments, the other four strategies do not require any controlled behavioural event. The experiment is a method to test the hypothesis in a controlled environment. Moreover, this method is more suitable for testing an experimental group against a control group in order to validate or falsify a hypothesis (Saunders et al., 2012). However, this study aims to conduct an in-depth study on people in an uncontrolled environment. Hence, the experimental method is inappropriate for this study. The fourth column (Table 4.1) focuses on the type of event, which can be contemporary or not. This study focused on a contemporary event, namely BIM adoption. Therefore, the historical method is inappropriate for this study as it does not focus on contemporary events. According to Saunders et al. (2016), the archival method is more appropriate for investigating past events and changes that happen over time. This study intends to develop a framework based on recent findings but does not intend to consult past records. Therefore, the archival research strategy is not appropriate for this study.

Accordingly, the remaining methods are case studies and surveys. As this research poses what, why, and how types of questions both survey and case study approach can be adopted as the research strategy. The following section will describe the adaptation of the combined research method, as the research strategy for this study.

4.6.1 The Use of Case study and Survey as a Combined Method of Research Strategy

The importance of combining research methods in research has gained substantial attention (Gable, 1994). Generally, the combined use of both quantitative and qualitative methods is very popular among researchers. Hence, the use of combined research strategies, such as fieldwork (e.g. case studies) and survey research, are not particularly popular among researchers. The reason for this is because many journals evaluate the use of specialized methods, thus boosting the use of a single method. Gable (1994) suggested that journals and reviewers of papers should emphasize the advantages of using an integrated strategy by encouraging junior researchers and doctoral students to use a combined approach within their research studies. However, according to Gable (1994), the use of a combined research strategy is not new; hence, it has not been appreciated. Therefore, researchers occasionally use a combined strategy, even if it is sometimes not emphasised within their report (Nissen et al, 1991). According to Nissen et al (1991), the following reasons hinder the use of a combined approach;

- Doubts exist over the acceptability or feasibility of combining positivist and interpretive approaches;
- Vulnerability stems from the close correspondence between many researcher's value systems and their single methodology paradigm; and
- Practical concerns arise over possible contradictory results from multiple methods.

Various research strategies can be integrated for better results. However, it was identified that case studies and surveys were the most suitable strategies for this research. Therefore, case studies and survey strategy were combined and adopted under a single research design. A survey is a more convenient strategy to generalize results and based on data gathered from a sample population (Creswell, 2013; Saunders et al., 2011). This is a non-experimental strategy that can be conducted in a natural setting without any specially created environment (Boudreau et al., 2001). On the other hand, as this research poses 'what' questions, especially to address objective 1, this requires richer and stronger evidence than case studies can provide. Moreover, collecting a generalizable data set before conducting the case studies for objectives one and three would increase the reliability of the qualitative findings. Therefore, as explained in section 4.4, the survey and case studies were conducted into two phases (firstly, survey and secondly case studies) and presented in the analysis phase as separate data sets. As Vidich and Shapiro (1955) stated "Without the survey data, the observer could only make reasonable guesses about study area of ignorance in the effort to reduce bias". Fundamentally, this strategy relies on quantitative data and quantitative analysis methods to find answers to the research questions (Oates, 2005). Similarly, the following weakness can reduce the robustness of the survey research:

- It provides only a "snapshot" of the situation at a certain point in time, yielding little information on the underlying meaning of the data.
- Some variables of interest to a researcher may not be measurable by this method (root causes of drivers, barriers and mitigating actions).

These weaknesses could be overcome with the use of case studies. Cases studies are more suitable where the researcher seeks to find answers to questions starting with 'how' and 'why', and focuses on contemporary events over which the researcher has no control (Yin, 2014). Cases studies were selected as another research strategy for this study for the following reasons;

- This study seeks to address research questions starting with "why" and "how" concerning people and their behaviour over which the researcher has no control.
- It enables an in-depth investigation to identify factors and their root causes which affect the accuracy of pre-tender cost estimates, BIM adoption drivers, barriers and their root causes, and mitigating actions through a critical review of the literature and semi-structured interviews.
- It does not require any control environment to conduct the investigation and allows participants to freely express their thoughts regarding the factors, BIM adoption barriers, drivers, and mitigating actions.
- It analyses a contemporary event (BIM adoption), which will help the researcher to identify new themes and results.

Therefore, features of this study fit well with the case study approach, and will help to answer the research questions. Nevertheless, Lee (1989) identified four major weaknesses in the case study approach, namely the lack of controllability, deductibility, repeatability, and generalizability. Moreover, the conclusions may specific to certain organizations where studies have been undertaken and cannot be generalisable (Thomas, 2003; Yin, 1994). This study consists of a set of objectives, where some objectives require a generalizable data set, and some might not need it. Accordingly, objectives 1 (identify affecting factors for the accuracy of pre-tender cost estimates) and 3 (drivers, barriers and mitigating actions) of this study need to obtain a generalizable data set from a large group of people, which cannot be accomplished just by using case studies. However, as discussed above, the survey approach helps to overcome weaknesses in the case study approach.

Table 4.2: Relative Strengths of Case Study and Survey Method

Relative strength	**Case study**	**Survey**
Controllability	Low	Medium
Deductibility	Low	Medium
Repeatability	Low	Medium
Generalisability	Low	High
Discoverability (exportability)	High	Medium
Representability (potential model complexity)	High	Medium

Table 4.2 summarises the strengths of these two methods through the dimensions identified. However, it is observed that many strengths of one method compensate for weaknesses in the other. Gable (1994) identified the advantages of a combined case study and survey approach. Accordingly, for this study

quantitative findings from the survey can be used as a rich source of detail to interpret the qualitative findings.

Moreover, it also helps to identify and develop a close relationship between organisations and the researcher by conducting a pilot test to validate survey instruments. Besides, this method also allows the researcher to collect extra data by returning to the same case to test new ideas. Meanwhile, the researcher can conduct further study after the survey and supplement this with cross-sectional survey data and richer explanatory data from the case studies. Therefore, if the researcher misses some points in the survey approach they could be addressed during the case studies. Therefore, this research adopts a combined strategy of case studies with a survey approach. Accordingly, the survey approach was mainly used to identify factors affecting the accuracy of pre-tender cost estimates, BIM adoption drivers, and barriers in the Sri Lankan context (through findings derived from the literature survey). Furthermore, case studies were mainly used to identify the root causes of factors affecting the accuracy of pre-tender cost estimates, BIM adoption drivers, barriers, and mitigating actions.

4.6.2 Case Study Design

A case study has been defined by Yin (2.14, p.18) as "an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident". As this study seeks to evaluate phenomena in a real-life situation, case studies provide a platform for the researcher to get a clear picture of the relationships and processes within the phenomena. The justification for selecting case studies has been discussed in detail under section 4.5.1.

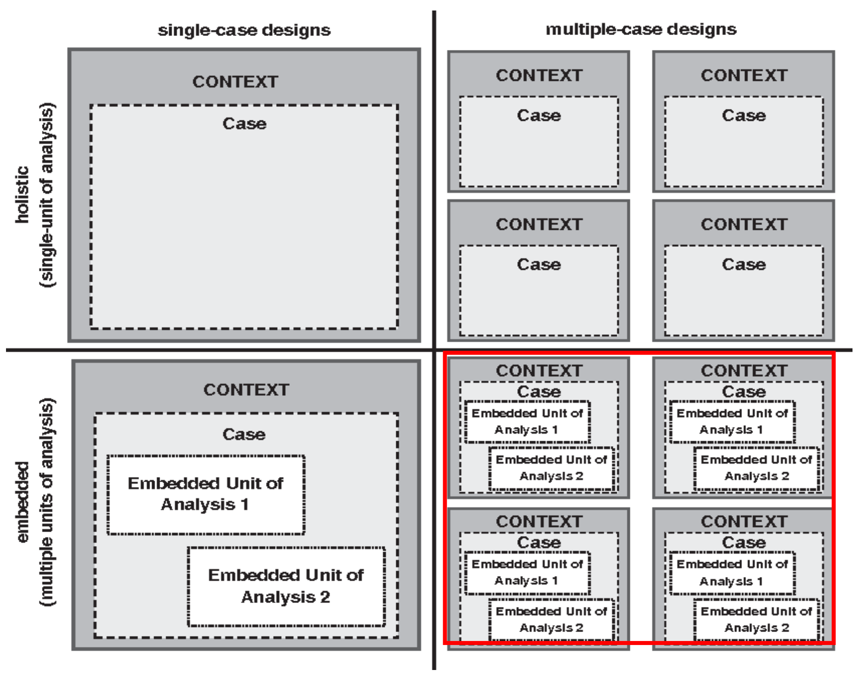


Figure 4.8: Types of case study based on number and units (Kulatunga, 2008)

Yin (2009) identified four types of case study design based on the number of cases and units for analysis, such as single holistic, single embedded, multiple holistic, and multiple embedded designs (Figure 4.8). The purpose of using cases studies for this research is to identify the key factors and root causes of the factors affecting the accuracy of pre-tender cost estimates, key BIM drivers, barriers and their root causes, and mitigating actions in Sri Lankan QS organisations. In this context, multiple-case studies allowed researcher to examine the phenomenon in more than one case along with replication across the cases. Therefore, the evidence and conclusions from multiple-designs are more reliable and convincing than those based on single-case designs; thus, the findings are more likely to be generalised (Yin, 2014). Moreover, multiple case study evidence is often considered more compelling; therefore, an entire study becomes more robust (Herriott & Firestone, 1983). The critical response from experts involved in the two-different contexts will help to develop a more robust and valid theory to contribute to knowledge. Accordingly, multiple case studies have been selected for this study.

According to Yin (2014), holistic and embedded are the two variants of the multiple case study design. Case study analysis based on one unit is called holistic, whilst analysis based on more than one unit is called embedded. According to Sekaran (2003, p.132), "the unit of analysis refers to the level of aggregation of the data collected during the subsequent data analysis stage". Moreover, according to Yin (2014) the unit of analysis could be a 'case' which can include individuals, event(s), an entity(ies), communities, programs, practices, and so forth. Accordingly, this research attempt studies the phenomena of BIM adoption from various perspectives. Therefore, evidence will be collected through different units namely factors affecting the accuracy of pre-tender cost estimates, BIM adoption drivers, BIM adoption barriers and mitigating actions to overcome the barriers. Thus, this study is considered an embedded variant. Therefore, a multiple embedded case study was adopted as the case study design for this study (Figure 4.8).

Yin (2014) identifies four categories, such as single case study, multiple- case study, an option for either a single-case or multiple-case study, and an option for a multiple-case study only to analyse and present data derived from cases studies. In this study, the researcher adopted the final option, as it allows the researcher to analyse and present the research findings as one set of data. According to Yin (2014) multi-case studies can be analysed as one set of data where the researcher focuses on studying the phenomena itself but not the case. In this study, the researcher's focus is to identify factors affecting the accuracy of pre-tender cost estimates, BIM adoption drivers, BIM adoption barriers and mitigating actions in general, but not the phenomena existing separately in each case. Yin (2014) provided different examples, such as the research carried out by Kaufman (1981) to examine the administration behaviour of Federal Bureau Chiefs in six Federal Bureaux. Although this research was conducted with different chiefs in different bureaux (cases), the data synthesized the lessons learned from the overall experience rather than focusing on each case separately (Yin. 2014).

Prior to selecting number of cases, it is fundamental to define the case study boundaries. According to Yin (2014, p.237), case boundaries can include "the time period, social groups, organizations, geographic locations, or other conditions that fall within the case". Boundaries will help the researcher to identify the limitations of the data collection (Yin, 2014). This is supported by Baxter and Jack (2008) who point out that, "the boundaries indicate what will and will not be studied in the scope of the research project". Accordingly, Sri Lanka was selected as a highly suitable country to conduct the empirical study, as justified in Section 1.2. Thus, the selection of large-scale quantity surveying organizations located in Colombo district denotes the boundary for the case studies.

4.6.2.1 Selection Criteria for each Case Study

In a multiple case study approach, there is no generally recognized number of cases for selection (Tzortzopoulos, 2004). According to Yin (2003), the process of case selection should be dictated by the replication of logic. The selected cases will be tested, and successful cases will be used to prove or disprove previous findings. Therefore, the number of cases should be decided based on the extent to which new information or perceptions could be gathered (Dyer et al., 1991). The replication logic of multiple case design, according to Yin (1994), is illustrated in Table 4.3. According to Table 4.3, this study is considered under literal replication logic, as three cases marked the point at which data collection saturation was achieved.

Table 4.3: Replication logic strategies for determining the number of cases in multiple-case designs (Yin, 1994).

Replication logic strategies	**When the ---** difference between opposing theories is degree of certainty required is differences between the cases is	Initial number of cases
Literal replication	Low	3-4
Theoretical replication	High	6-8

Eisenhardt (1989) stated that by filling gaps in theory with relevant examples through polar types of result, the selected cases should be able to replicate previous cases or the degree of developed theory. Therefore, to draw final conclusions at the end of the study a thorough but rigid selection of cases is vital to confirm that the researcher has collected sufficient information. In this research, cases were selected by considering the research aim and objectives as follows:

a) The research develops a framework to support BIM adoption for QS organisations to improve the accuracy of pre-tender cost estimates. Therefore, the selection criteria were based on major QS organisations within the Sri Lankan capital. Considering the financial capabilities to afford BIM adoption, this study only focused on large scale organizations. In order to select large-scale organisations, the researcher selected those registered by the Construction Industry Development Authority (CIDA) in Sri Lanka, as it is the professional body responsible for the registration and grading of construction organisations in Sri Lanka. Accordingly, CS1 ($3000 \geq X > 1500$ Rs. Million financial limit) and CS2 ($X > 3000$ Rs. Million financial limit) are large construction organisations; therefore, the organisations that have obtained CS1 and CS2 are considered when selecting the cases.
b) This study intends to identify factors affecting the accuracy of pre-tender cost estimates through BIM adoption. Therefore, the selected organisation should mainly deal with pre-tender cost estimation, or both pre and post, in order to obtain appropriate data covering the pre-tender stage.
c) Moreover, the case study organisations must currently use, or be in the process of adopting, BIM, as this study aims to identify BIM adoption drivers, barriers and mitigating actions. Selecting organisations that have already adopted, or are in the process of adopting, BIM would enable the researcher to obtain more reliable data.

d) The selected organisation should also be capable of granting the researcher access to collect required data within their organisation; therefore, firms in the capital city, Colombo, were chosen.

As BIM is not used much within the Sri Lankan construction industry, before starting the investigation an assumption was made that few companies have taken BIM as potential business marketing, which led to the claims to adopt BIM, although their statuses were arguable. In many publications, it was identified that the primary technology for BIM is the use of 3D parametric tools (Construction Project Information, 2009; Eastman et al., 2008; Elvin, 2007; National Institute of Building Science, 2007; Smith & Tardif 2009). Therefore, in this study, organisations were selected based on the use of BIM tools, such as Revit and CostX. The following techniques were used to identify BIM-based organisations:

a) Direct communication with QS organisations in Sri Lanka
b) Attachment and collaboration with ICTAD and IQSSL (Institute of Quantity Surveyor's Sri Lanka)
c) Direct communication with construction professionals in Sri Lanka

The researcher was able to identify nine organisations, along with contact numbers and email addresses. Requests to conduct preliminary interviews were issued through the contact details obtained. Out of nine organisations, five positively responded to the request. The aim of the preliminary interview was to identify the level of existing BIM practice within these organisations. The following questions were asked during the preliminary interviews:

a. As part of the screening process to ensure the company has fully/partially incorporated BIM within their business.
b. As part of the refinement to the interview questions, to get a brief picture of the company. This information helps to identify the questions that suit the company's level of BIM usage.
c. As part of the research strategy, to develop trust and credibility so that the researcher could gain access to carry out data collection.

With regard to the interviews, three case studies were selected for this study and more detail of the selected organisations are discussed in Chapter 6. The next section will discuss the selected time horizon for this study.

4.7 Time Horizon

The next layer of research onion refers to the time horizon, which considers the organisation and management of the research within the given time frame. Different time horizons are possible, such as 'snapshot' cross-sectional or 'diary' and longitudinal (Saunders et al., 2016). PhD studies have to be undertaken within a given time frame. In cross-sectional studies, the researcher undertakes a sequential process, such as the literature review, methodology, sketching a framework, data collection, and the researcher can work all stages at the same time. For the longitudinal horizon, each stage depends on the results of the previous stage; therefore, the researcher can only work on one stage at one time. Time pressure can mean that researchers take shortcuts (Bell, 2014); therefore, Green et al. (1993) argued that it is important to define a time horizon for research. This research conducted under a PhD program within a given period focuses on a particular phenomenon. Research must be undertaken under defined university rules and regulations. As this research is time-constrained, a cross-sectional approach has been selected.

From the semi-structured interviews and questionnaire survey, this research gathers cross-sectional data to develop the BIM adoption framework.

4.8 Research Technique

The inner layer of Saunders' et al. Research Onion represents a research technique that consists of data collection and data analysis methods. Saunders (2011) identified this as the most important part of the conduct of the research. Saunders (2011) identified some key issues in relation to the data collection, such as 'sampling', 'secondary data', and 'primary data'. Both qualitative and quantitative techniques were employed for this research, such as triangulation, which boosted the researcher's personal understanding of the phenomena. Moreover, the use of both types of method helped the researcher to meet study purposes by developing a database consisting of all relevant numerical and non-numerical evidence. Therefore, three linked research techniques have been used in this study, namely a literature review, semi-structured interviews, and questionnaire surveys. Interviews were selected, as the study demands an in-depth exploration within the social phenomenon. Moreover, as this study adopted a mixed method design a questionnaire survey was also incorporated as a research technique. These selected techniques are discussed further in the context of the current research.

4.8.1 Literature Review

A critical evaluation of the literature helps to develop a clear picture of the research area through gathering existing knowledge in the subject area (Saunders et al., 2011). Moreover, it also helps to justify the importance of conducting research and evaluating the current need for a particular study (Khoshgoftar & Osman, 2009). This research literature involves two stages. In the first stage:

- A critical literature review was conducted to identify the problem through which it was possible to develop the research aim and objectives.
- After developing the aim and objectives, a more extensive literature review was conducted around the subject area to identify factors affecting the accuracy of the pre-tender cost estimate process, the use of BIM in the estimation, BIM adoption worldwide, and drivers and barriers for its adoption. Based on the literature review findings, a questionnaire survey and semi-structured interviews were conducted, to identify the components of the developed BIM adoption framework.

In the second stage, the literature review was used to explain, justify, collect data, and validate the research findings.

4.8.2 Questionnaires

The questionnaires used to gather survey data numerically, which is easy to analyse (Dörnyei & Taguchi, 2010). Once the respondent sample is selected (see section 4.8 for information on data sampling), the questionnaire can be distributed (Babbie, 2011). According to Cohen and Manion (2000), three types of questionnaire can be identified, as follows:

- Structured: includes closed questions that are analysed statistically, due to the generation of response frequencies.

- Semi-structured: contains open-ended questions designed within a certain structure and sequence that permits respondents to concentrate their answers in a particular way while responding in their own words.
- Unstructured: includes completely open-ended questions, letting respondents write whatever they want with minimal structuring.

In this research, structured questionnaires have been used, as developed by the researcher and based on the literature review findings (Babbie, 2011; Fellows & Liu, 2008; Tharenou et al., 2007). Two sets of questionnaires have been developed, one to identify factors affecting the accuracy of pre-tender cost estimates (Questionnaire A), second to identify the barriers and drivers for BIM adoption (Questionnaire B). Moreover, questionnaires can be managed by hand, email, or online (Fellows & Liu, 2008; Tharenou et al., 2007). Therefore, questionnaire A was conducted as a survey (not within selected cases studies), and copies were distributed mainly by hand and via email. Questionnaire B was limited to the selected case studies and distributed by hand. This is because respondents need to have BIM knowledge in order to fill the questionnaire B. Figure 4.9 illustrates how the questionnaire survey was conducted. The questionnaire offers different advantages; for example, it is easier to collect data from a large population, while collected responses are easier to process (Babbie, 2011). Moreover, data can be used to develop models of any particular relationships between the variables studied (Saunders et al., 2012). Therefore, in this context, the final results of the survey have formed a possible relationship among main research paradigms, which enables the development of a framework for the research.

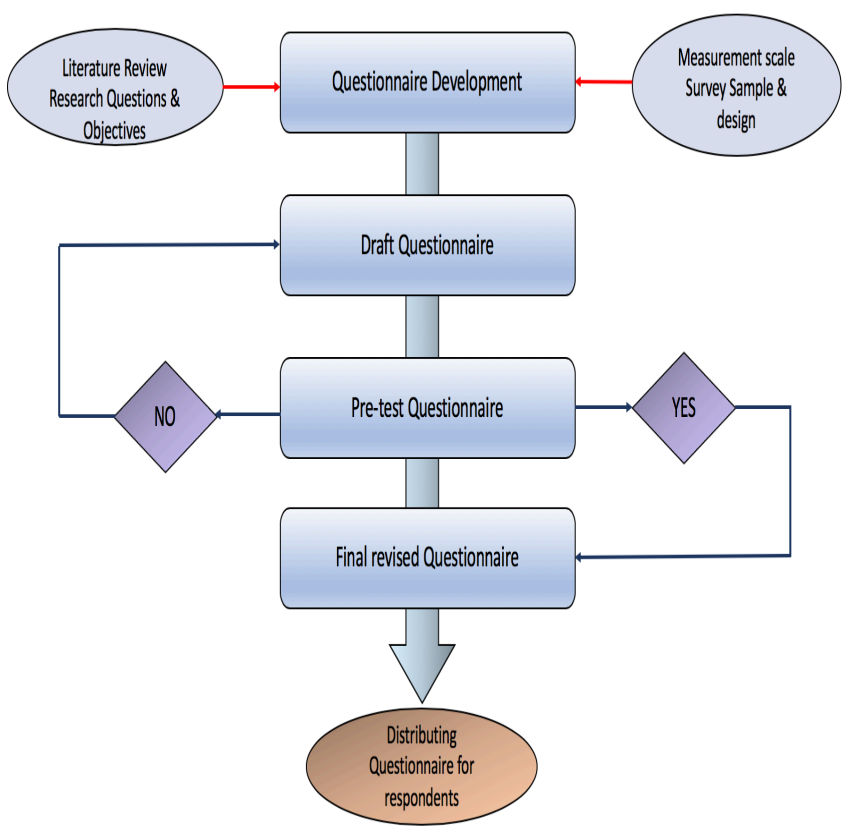


Figure 4.9: Process of the questionnaire survey

As previously mentioned, questionnaires were developed based on the literature findings (Figure 4.9). Questionnaire A consists of two sections, namely the background of the respondents and factors affecting the accuracy of the pre-tender cost estimation process (see Appendix B). Questionnaire B also consists of two sections, such as the background of the respondents and questions relating to the BIM drivers and barriers (see Appendix C). Based on the type of data collected, the researcher has to determine the measurement scale for the questionnaire (Creswell, 2012). The type of data can either be categorical or numerical. Categorical data cannot be measured in numbers, but rather categorised according to the variables' characteristics; meanwhile, numerical data refers to data that can be counted (Saunders et al., 2009). These two categories also consist of subcategories, such as nominal and ordinal data (categorical), and interval and ratio data (numerical) (Sekaran, 2003). In this research, nominal, ordinal and interval are the most used scales as response options for the respondents. According to Creswell (2012), in this research nominal scales are used to check respondents' background information, such as working experience, current role, and so forth, for both questionnaires. Ordinal scales are used to describe the level of BIM awareness, and the importance of using BIM for cost estimation. Finally, in both the questionnaires, interval scales are applied to ascertain the level of agreement on the item descriptions in the questionnaire. A 5-point Likert scale (strongly agree, agree, neutral, disagree, and strongly disagree) was used, and Table 4.4 represents the values designated for this scale.

Table 4.4 Values designated for the Likert scale

Scale	**Strongly Agree**	**Agree**	**Neutral**	**Disagree**	**Strongly Disagree**
Value	5	4	3	2	1

Besides, a separate section for further comments has been added at the end of section 2 in both questionnaires to minimize the tendency to give an inaccurate answer when the respondents lack knowledge or opinion on a specific question topic. Once the questionnaire designs were completed, a pilot study was undertaken with experts to test the success of developed questions.

4.8.3 Questionnaire Pre-Testing

Piloting, or pre-testing, is essential for a questionnaire before its distribution among respondents, as it identifies and eliminates problems that respondents might encounter when answering the questionnaire (Cooper & Schindler, 2003; Frazer & Lawley, 2000; Zikmund et al., 2007). A pilot study needs to be conducted with experts and testing conducted as a two-stage process. As recommended by Frazer & Lawley (2000), the questionnaires designed for this research were pre-tested with academics. However, all the selected academics used to work in the industry, therefore their expertise covered both academics and industry capabilities. Moreover, testing of questionaries also required BIM knowledge (questionnaire B), therefore the use of academics was more useful in terms of testing questions.

Rather than carrying out pre-testing to test the entire questionnaire and survey procedure, the researcher was able to get specific feedback on each item of the questionnaire from the experts. Moreover, it was possible to identify complicated words in questions that could lead to problems, and bias caused by the question order. After pre-testing, revisions were made to both questionnaires based on the experts' feedback. The revised questionnaires were then released to the selected sample of respondents. Properly conducted pre-testing can ensure that the data collection process collects precise, good quality answers to the questions posed in order to achieve the research objectives.

4.8.4 Interview

A qualitative interview allows the researcher to ask questions of the interviewees (Babbie, 2011) to gather their feelings and views (Tharenou et al., 2007) about the area of study. According to Yin (2009), the selection of the interview technique is based on the valuation level that the researcher could achieve from the collected data. The conduct of the interviews is important due to the confidentiality of some evidence, such as company and personal records. Therefore, in this research, interviews were conducted within the selected case studies and considered as a primary data collection technique. Kumar & Phrommathed (2005) and Naoum (2012) defined interviews as a process where the researcher obtains data from a person or source. They can be conducted face-to-face (Tharenou et al., 2007) or through a medium like the Internet or telephone. According to Easterby-Smith et al. (2012), there are three types of interviews, namely 'structured', 'semi-structured', and 'unstructured'. Moreover, they also highlighted that in qualitative research in-depth and semi-structured interviews are essential. This research is considered semi-structured, as the researcher has designed a set of questions based on the questionnaire findings and literature. Figure 4.10 illustrates the semi-structured interview process for this research.

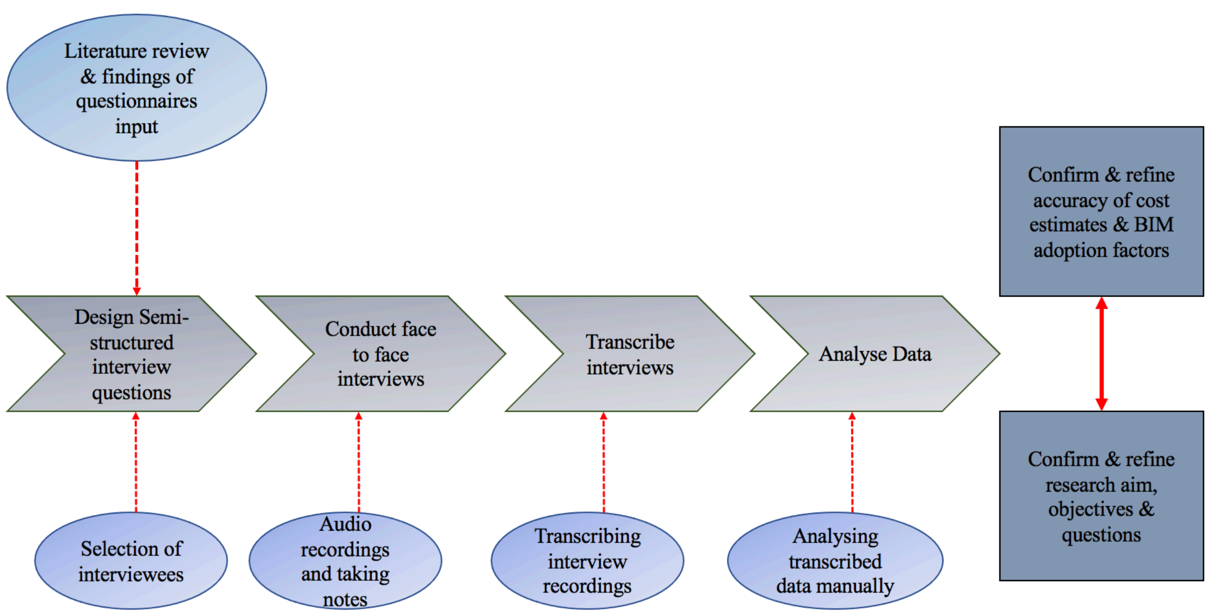


Figure 4.10: Process of semi-structured interviews

Hence, this structure could be varied based on the interviewees' experiences, knowledge, ideas, and impressions (Robson, 2002). An audio recorder was used to record the conversation alongside taking notes, which helped when transcribing the interviews and used within the data analysis (Dawson, 2009; Fellows & Liu, 2008). The transcribed interviews were analyzed using thematic analysis (see section 4.10) (Tharenou et al., 2007). From the interviews, it was possible to understand the current role of QS organisations in BIM adoption in Sri Lanka, to identify the drivers that influence the adoption of BIM, to note the barriers they experienced and why were those barriers occurred, and what actions were or could be taken to mitigate the impact of the barriers. Moreover, it also helped the researcher to understand the level of current BIM awareness within the organisation including the extent of their current BIM usage. The researcher created codes for the analysis to identify the BIM drivers and barriers; this helped to create particular themes related to the adoption of BIM, and ensured the semi-structured interviews were the most appropriate technique to gather the data.

Table 4.5 summarises the method adopted to address each objective. Accordingly, different techniques were used to achieve different objectives. Moreover, some objective solely depended on one technique such as objective 2. Meanwhile, some objectives required all techniques.

Table 4.5: Research techniques adopted to achieve the objectives of the study

Objectives		Literature Review	Questionnaire Survey	Semi-Structured interviews
1	To identify the current status of pre-tender cost estimates	•	•	•
	Factors affecting the accuracy of pre-tender cost estimates in Sri Lanka.	•	•	•
2	To evaluate the development of BIM, and the use of BIM to improve the accuracy of pre-tender cost estimates.	•	•	•
3	To identify the BIM adoption drivers and barriers	•	•	•
	The mitigating actions to overcome the impact of identified barriers.	•	•	•
4	To develop and validate a BIM adoption framework for Sri Lankan Quantity Surveying firms to improve the accuracy of pre-tender cost estimates.	•	•	•

After describing the data techniques, the section defines the data sample according to the research context.

4.9 Data Sampling

Researchers need to delineate their sample from a well-defined population (Czaja et al., 2014). The concept of sampling indicates a representation of the selected group from a large population that enables the researcher to get the information required in order to generalise the findings without the need to study the entire population (Ary et al., 2010). To avoid bias, the researcher must be confident that the selected sample represents the population. Therefore, in research, a manageable sample is required which represents the entire population (Saunders et al, 2016). Probability and non-probability sampling are the two major types of techniques available.

According to Czaja et al. (2014), probability sampling is also known as random sampling where the sample is selected by using a random process. In this method, the chance of selecting sample size mostly depends on the data collection technique (Saunders, 2011). In most cases, probability sampling techniques are more suitable where statistically analysed data are required (survey-based); therefore, the findings need to consider whether they represent the entire population (Saunders, 2011). Non-probability sampling determines the sample by considering judgment, convenience, or quota without engaging any random process. According to Figure 4.11, both sampling techniques consist of different methods.

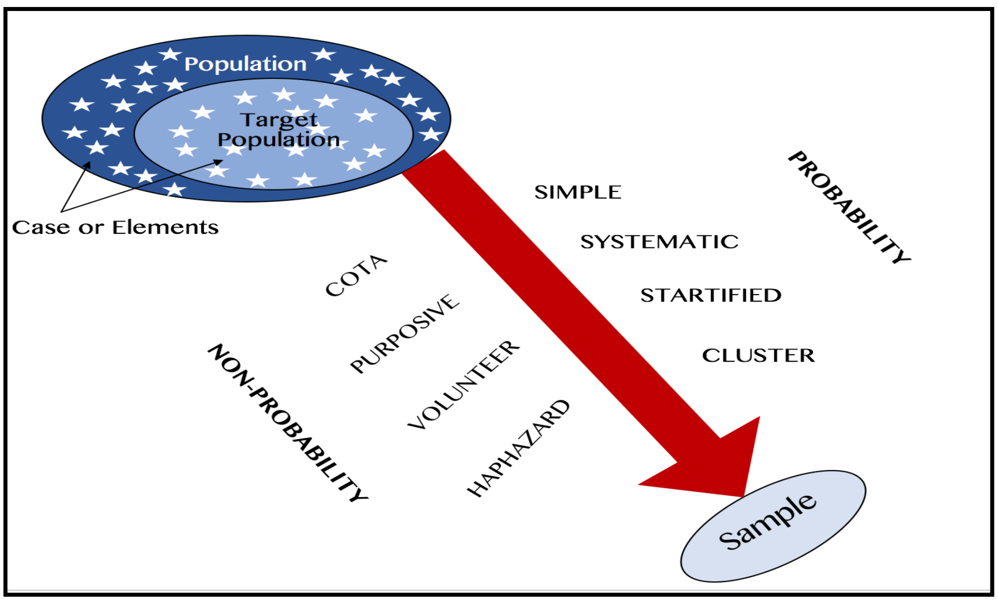


Figure 4.11: Sampling Techniques

In terms of this research, multiple methods have been adopted that consider the chosen data collection techniques. To conduct the questionnaire survey A, probability sampling technique was selected. Under the probability sampling option, a systematic sampling method was selected. Sri Lankan quantity surveyors registered with the Institute of Quantity Surveyors Sri Lanka (IQSSL) were the target population. There are about 300 members registered with IQSSL, yet only 169 could be considered within the research sample (calculated on the Krejcie & Morgan (1970) table). Hence, after contacting IQSSL, it was found that only 120 remained from the Sri Lankan construction industry, as the rest were working abroad. Therefore, for this research questionnaire, the sample size was limited to 120 quantity surveyors. After contacting IQSSL it was able to identify charted quantity surveyors, senior quantity surveyors, quantity surveyors and assistant quantity surveyors from the given list. Therefore, the selected sample consisted of surveyors mainly dealing with pre-tender cost estimation process, and BIM adoption, which included: charted quantity surveyors, senior quantity surveyors, quantity surveyors and assistant quantity surveyors. In terms of questionnaire B, probability stratified method was selected. Using stratified method, it was able to identify the desired respondents to obtain relevant data. Accordingly, 50 respondents (BIM knowledgeable QS's) were identified as the sample size for the questionnaire B.

This research aims to develop a BIM adoption framework; therefore, the views of experts within BIM-based quantity surveying organisations are important. The in-depth data collection was conducted to identify the factors affecting the accuracy of pre-tender cost estimates, BIM adoption barriers, drivers, and the mitigating actions, which were used to develop the framework. In that continuum, each person in the sample was studied in more detail and researcher focused on a quality rather than quantity sample in order to collect rich data. Considering the aforesaid argument, purposive sampling was selected to determine the sample for the semi-structured interviews. According to Figure 4.11, purposive sampling is a sub-set of non-probability sampling where a specific sample is selected in a non-random way to obtain rich and specialised data related to a study (Kumar, 2011; Saunders et al., 2011).

Deciding the sample size is more complex in qualitative research compared to quantitative research. Moreover, unlike in statistical research, in qualitative research, the sample size is an essential consideration (Kumar, 2011). Once the researcher reached the point of data saturation, they have achieved an adequate size. Such a point is achieved when no new themes are discovered, or new information is received (Kumar, 2011; Saunders et al., 2011). Saunders et al. (2016), summarises the non-random minimum sample size for different types of study, as shown in Table 4.6.

Table 4.6: Non-random minimum sample size (Saunders et al., 2016)

Nature of Study	**Minimum Sample Size**
Semi-structured/in-depth interviews	5-25
Ethnographic	35-36
Grounded Theory	20-35
Considering a homogenous population	4-12
Considering a heterogeneous population	12-30

By combining purposive and heterogeneous sampling methods, the interviewees were selected from the selected case studies. Saunders et al. (2016) stated that the minimum non-probability sample size for semi-structured interviews, which is shown in Table 4.6, 9 semi-structured interviews were conducted. Moreover, this number was based on similar research conducted by Guest et al. (2016) who found that data saturation occurred after nine interviews in qualitative studies. Saunders et al. (2009) also recommended this technique when an in-depth understanding is required about the issues. The sample consists of management level QS, charted quantity surveyors, senior quantity surveyors, quantity surveyors, assistant quantity surveyors who are dealing with the main preparation of cost estimates using BIM-related tools in a BIM adoption process and have more than five year's experience in the same position and as organisation managers.

4.10 Ethical Considerations for the Research

Throughout the entire research process, the researcher considered all ethical issues. The main ethical considerations in this research included inter alia: obtaining the informed consent of the research participants; conveying assurance to the participants that their anonymity and confidentiality of the research data would be maintained and preserved; the researcher maintaining objectivity and openness (Fellow and Liu, 2008; Saunders et al., 2012), and adhering to the University's ethical research approval process. Approval was obtained from the University's Ethics Approval Panel (see Appendix A).

4.11 Data Analysis Approach

Data analysis is based on the researcher's style of empirical thinking and interpretation. In quantitative data analysis, descriptive statistical methods were used to analyse the data collected from the questionnaires, which were processed using MS Excel software. Moreover, a Relative Important Index (RII) was used to determine the relative importance of the:

1. Factors affecting the accuracy of pre-tender cost estimates,
2. BIM adoption drivers, and
3. BIM adoption barriers identified through the literature review.

A study by Braun and Clarke (2006) indicated that thematic analysis is the basis for many highly diverse qualitative approaches. Therefore, to analyse the semi-structured interviews, thematic analysis was used as it allowed the researcher to identify, analyse, and report the themes within the data. Accordingly, Braun and Clarke (2006) defined six stages, as illustrated in Table 4.7, which is a step-by-step guide for researchers when undertaking thematic analysis.

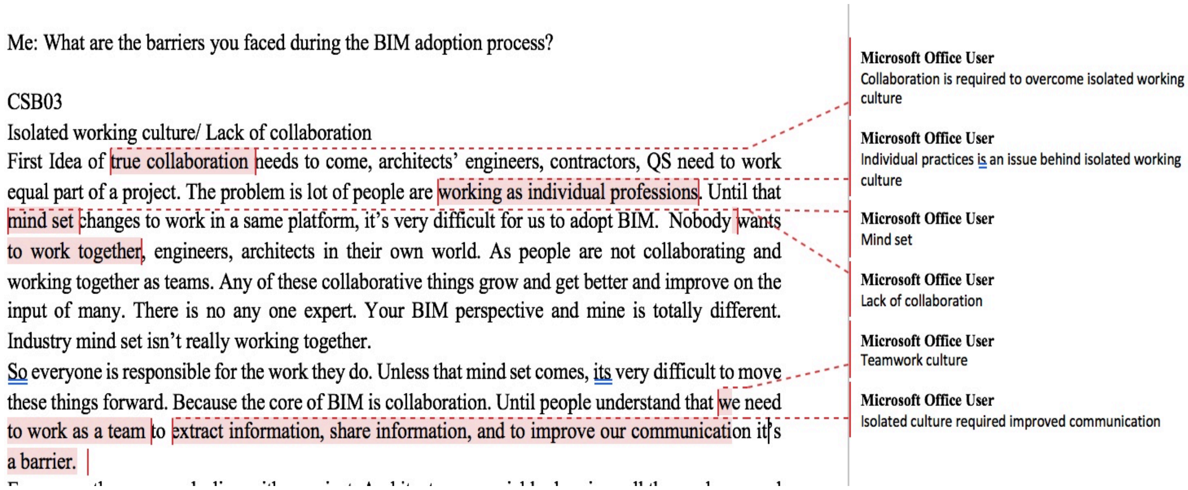
Table 4.7: Phases of Thematic Analysis (Braun & Clarke, 2006)

Phases	Description of the process
1.Make yourself familiar with your data	Read and re-read the transcribed data
2. Start initial coding	Coding interesting features of the data in a systematic fashion across the entire data sets, collating data relevant to each code
3. Searching for possible sub-themes	Collating codes into potential sub-themes, gathering all data relevant to each potential theme
4.Reviewing sub-themes	Checking if the sub-themes work in relation to the coded extracts (level 1) and the entire data sets(level 2)
5. Defining and naming themes	Ongoing analysis to refine the specifics of each theme, and the overall story the analysis tells, generating clear definitions and names for each theme
6. Completing the report	The final opportunity for analysis. Selection of vivid, compelling extract examples; final analysis of selected extracts; relating back the analysis to the research question and literature; producing a scholarly report of the analysis

For this study Braun and Clarke's (2006) steps were followed to analyse qualitative data as follows;

- Step 1: As stated all data were transcribed from audio to text using Microsoft Word. Once the data were fully transcribed, all transcriptions were saved into one folder by allocating a password. The purpose was to create a database that included all opinions, perspectives, and conceptions on the phenomenon that were gathered in the same place. A separate code was given to each interview, and the codes were used while writing the analysis, which enabled the selection of quotations and helped to form the themes. To become familiar with the data, the researcher started to read the transcript carefully.

- Step 2: After becoming familiar with the data set, the researcher started the initial coding (see Figure 4.12) to identify important keywords stated by the respondents. As this was the researcher's first experience thematic analysis, she did not allow herself to drive the code. Therefore, the codes were generated from the data, and in some cases, the researcher used the same words used by respondents to represent the codes.



Me: What are the barriers you faced during the BIM adoption process?

CSB03

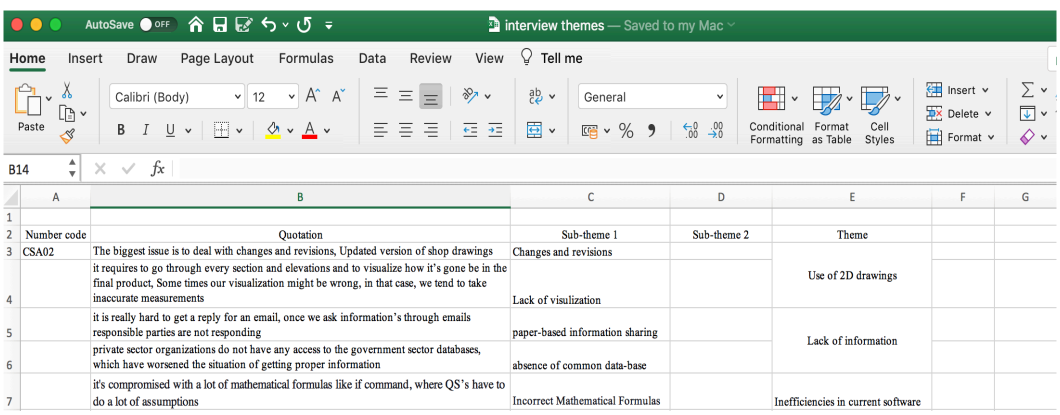
Isolated working culture/ Lack of collaboration

First Idea of true collaboration needs to come, architects' engineers, contractors, QS need to work equal part of a project. The problem is lot of people are working as individual professions. Until that mind set changes to work in a same platform, it's very difficult for us to adopt BIM. Nobody wants to work together, engineers, architects in their own world. As people are not collaborating and working together as teams. Any of these collaborative things grow and get better and improve on the input of many. There is no any one expert. Your BIM perspective and mine is totally different. Industry mind set isn't really working together.

So everyone is responsible for the work they do. Unless that mind set comes, its very difficult to move these things forward. Because the core of BIM is collaboration. Until people understand that we need to work as a team to extract information, share information, and to improve our communication it's a barrier.

Figure 4.12: Example of the Coding Process

- Step 3: Once the coding was applied to all textual data, the researcher started to identify the links among similar codes to create sub-themes. However, this was driven by the codes themselves and not the researcher. In other words, the researcher highlighted the links between codes, which were suggested by the codes themselves in the sub-themes. A Microsoft Excel sheet was used to accomplish this step (see Figure 4.13) as it is easier to collect all data under sub-themes. Besides, the same spreadsheet was used in steps 4 and 5 to create and finalize the main themes. Moreover, lines (extracted from interview transcripts) included in the Excel sheet were used during the writing of the report (step six) to support the themes.



	A	B	C	D	E
2	Number code	Quotation	Sub-theme 1	Sub-theme 2	Theme
3	CSA02	The biggest issue is to deal with changes and revisions, Updated version of shop drawings	Changes and revisions		Use of 2D drawings
4		it requires to go through every section and elevations and to visualize how it's gone be in the final product, Some times our visualization might be wrong, in that case, we tend to take inaccurate measurements	Lack of vizulization		
5		it is really hard to get a reply for an email, once we ask information's through emails responsible parties are not responding	paper-based information sharing		Lack of information
6		private sector organizations do not have any access to the government sector databases, which have worsened the situation of getting proper information	absence of common data-base		
7		it's compromised with a lot of mathematical formulas like if command, where QS's have to do a lot of assumptions	Incorrect Mathematical Formulas		Inefficiencies in current software

Figure 4.13: Create themes and sub-themes by using Excel sheet

- Step 4: Once all codes were placed under the sub-themes, the major themes were created. The major themes were created as suggested by the sub-themes. Therefore, the researcher was not responsible for creating them, but rather for representing them. In other words, the researcher did not have any intention of driving the sub-themes, but left the codes to do so.

- Step 5: After identifying the initial themes, the researcher revisited them to clarify their meaning or to modify the theme names by adding more value. However, this does not mean any changes to the themes; thus, the themes were clarified in line with the codes and sub-themes.
- Step 6: The last step of the thematic analysis was to write the report. During this step, the researcher had to bring all the quotations, sub-themes, and themes together to make sense of the data in a textual written format. The themes and sub-themes were presented as suggested by the codes, which were derived from the textual script of the data (see Figure 4.12).

4.12 Validity and Reliability

To ensure the validity and reliability of the research two factors needed consideration. The terms validity and reliability are interpreted differently depending on the context of a qualitative and quantitative study. Construct validity, internal validity, external validity, and reliability are the four tests listed by Yin (2014) as suitable for confirming validity and reliability in case study research. Construct validity employs methods appropriate to the concept under study, as subjective decisions could be involved in the collection of data. Therefore, the use of multiple data collection techniques helps to confirm construct validity. Internal validity can be achieved by comparing similar occurrences across the cases. However, as Yin (2014) argues, for descriptive or exploratory research, internal validity is not essential. The third test concerns external validity to test the extent that the research findings can be generalized beyond the scope of the case study concerned. This is provable using replication logic in multiple case studies. Finally, reliability means the process by which a study can be repeated within and beyond the study. This is most applicable to a positivist stance; thus, this cannot apply to an interpretivism stance as this type of study conducted in a non-controlled context (Easterby-Smith et al., 2008). Therefore, in this study reliability is confirmed by following a standard protocol that can be replicated. Moreover, it can be determined by ensuring that respondents understood the questions properly (Silverman, 2009).

The reliability of the questionnaire survey data was tested using quantitative techniques, specifically Cronbach's alpha using SPSS software, which is the most frequently used reliability coefficient test (Cho & Kim, 2015). Consequently, the said test was conducted to confirm the reliability of the quantitative data (see section 5.2.3 for detailed test information).

4.13 Outcome of the Research and Validation

A framework that enables BIM adoption among Sri Lankan QS organizations is the intended outcome of this research. The final framework was developed based on the analysis of the outcomes. The framework (see Chapter 7) lists drivers for BIM adoption, barriers and their root causes, and suggests mitigating actions for each barrier. The framework is validated for authenticity and credibility by another set of expert interviews. A group of experts was engaged in the validation process, and each driver, barrier, and mitigating action was validated based on their opinions (see section 8.2 for further information).

4.14 Summary

This chapter consists of a description of the methods followed to conduct the empirical study of this research. Firstly, the philosophical stance of the researcher was justified, following which the research approach and methodological choice were described, along with the survey design, case study design, and justification of the case selection. The study adopts an explanatory method by conducting a questionnaire survey followed by a case study. This chapter then presented the data collection tools, data analysis techniques, and accordingly, the qualitative data were analysed by using thematic analysis to identify the sub-themes and themes. The quantitative data were analysed descriptively and RII was used to determine the rank of each identified factor. This chapter finally illustrates the validation strategies. Figure (4.14) illustrates the selected methods and techniques for this research study.

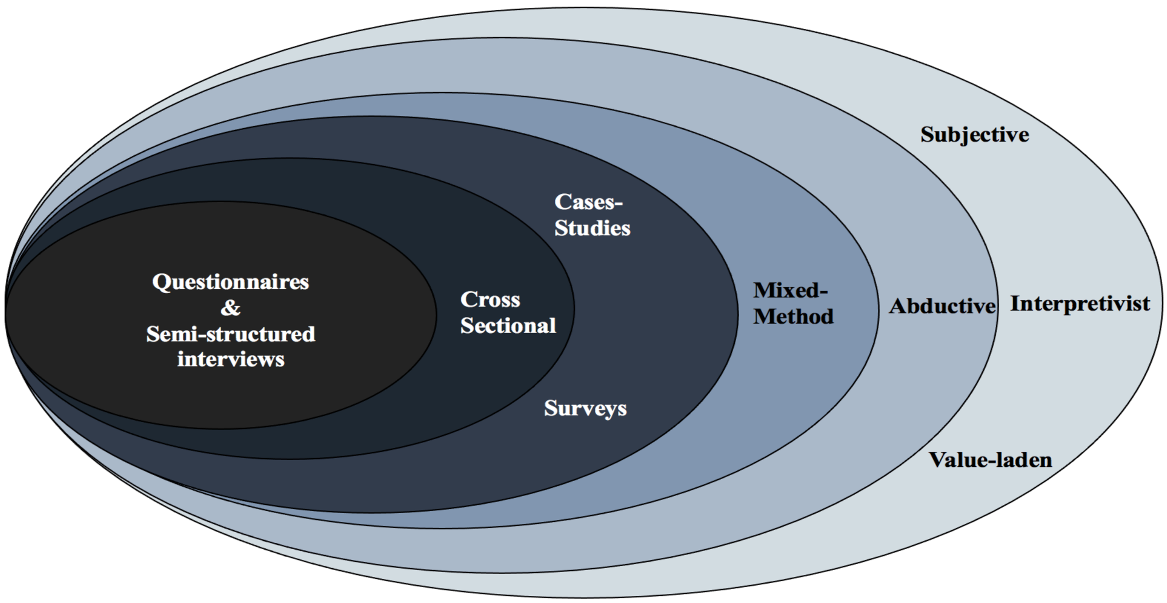


Figure 4.14: Adopted methodology for this research

5 ANALYSIS AND FINDINGS FROM THE QUANTITATIVE ENQUIRY

5.1 Introduction

This chapter describes the findings from the quantitative data analysis for both Questionnaires A and B. The aim of questionnaire A is to identify major factors affecting the accuracy of pre-tender cost estimates in Sri Lanka by achieving objective 1 of this research. Questionnaire A consists of two sections; section 1 mainly consists of the respondent's background and their level of current BIM adoption. The respondent's profile was evaluated based on their experience in construction cost estimating, professional background, current position within the organisation and the business nature of their organisation. Also, to identify BIM adopted organisations for questionnaire B, respondents were also asked the level of BIM adoption within their organisation and knowledge in BIM. Section 2 targets the factors affecting the accuracy of pre-tender cost estimates and consists of various factors, which were based on the findings of the literature review. Questionnaire B was designed to achieve objective 3, which aims to identify BIM adoption drivers and barriers. This questionnaire consists of three main sections; section 1 consists of the respondent's professional background, BIM usage within the organisation, types of BIM software use and application, BIM usage and productivity, the effect of BIM on the current role of the Quantity Surveyor, the nature of their organisation's business, and their planning for future BIM usage. The second and third sections identify the drivers and barriers for BIM adoption, respectively.

To analyse both questionnaires, descriptive analyses were applied in which the frequencies or sample distribution percentages were described using tables, charts, and figures. Descriptive analysis is important to statistically interpret the data. Ultimately, the patterns that emerge from the data analysis could be translated in a more meaningful way. For sections 2 and 3 of both questionnaires, the Relative Important Index (RII) was calculated to identify the key drivers and barriers, and the results have been presented in tables. The analysis for both questionnaires consisted of various steps, such as the examination of the preliminary data, coding, and the validity and reliability tests for the questionnaire responses.

5.2 Preliminary Data Analysis

Before analysing the data, the returned questionnaires needed to be checked and researcher needed to determine that appropriate data had been obtained for the statistical analysis. The appropriate questionnaires were then finalised for coding and data entry using Ms Excel and SPSS. Finally, the validity and reliability tests were conducted on the data for evaluation to ensure that only valid and reliable responses were used for the analysis.

5.2.1 Response Rate

In this research, questionnaires were distributed among Sri Lankan Quantity Surveyors registered with Institute of Quantity Surveyors in Sri Lanka (IQSSL). As discussed in section 4.8, the sample size for questionnaire A was limited to 120 although 102 responses were obtained. The sample size for questionnaire B was based on the responses received from questionnaire A. The results of questionnaire A revealed that, out of 102 respondents only 50 respondents were engaged in a BIM-based practice. Therefore, for questionnaire B sample size was limited to 50 respondents. Table 5.1 shows the total number and percentage of overall responses in this research for both questionnaires.

Table 5.1: Total number and percentage overall responses for questionnaires A and B

Questionnaire A	**Sample**	**Number of responses received**	**Percentage (%)**
Registered with IQSSL	120	102	85%
Unusable Questionnaires	120	0	0
Usable Questionnaires	120	102	85%
Overall Response Rate			85%
Questionnaire B			
Registered with IQSSL & BIM-based practice	50	50	100%
Unusable Questionnaires	50	10	20%
Usable Questionnaires	50	40	80%
Overall Response Rate			80%

For research validity purposes, Baruch (1999) stated that only usable responses should be identified within the suitable response rate, which directly reflects the numbers and percentage of usable questionnaires. Therefore, 100% completed questionnaires identified as usable and incomplete questionnaire identified as unusable. However, by deducting unusable responses from the sample, the overall response rate was calculated at 85% and 80% for questionnaires A and B respectively. According to Johnson and Wislar (2012), there is no universally accepted response rate for any research hence, 60% is generally used as the limit. Nevertheless, Baruch (1999), found an average response rate of 55.6% was acceptable from his studies. For this research, both questionnaires (at 85% and 80%) achieved acceptable response rates, which are considered satisfactory for the data analysis.

5.2.2 Coding and Data Entry

For both questionnaires A and B, the finalised responses (102, 40 respectively) were obtained from the survey, which were then treated as raw data. In order to analyse them statistically, numerical and character symbols were assigned to the questionnaire items, which enabled the data coding. The coding was limited to section 2 of questionnaire A and sections 2 and 3 of questionnaire B. Once coding has been conducted, all data were manually entered into Ms Excel for further analysis. Prior to entering the data into the software, variables specifying the required information were defined to align with the earlier coding set. The variables that make up the data files should have been given appropriate name and value labels. Questionnaire A and B have two sections (section 1 and 2), and three sections (1,2 and 3) respectively for evaluation. Therefore, in sections 2 and 3 of both questionnaires each item is represented by a unique code.

5.2.3 Instrument Validity and Reliability

Validity refers to the degree to which an instrument measures what it is supposed to measure (Polit & Hungler, 1985). In this research, the validity of the survey instruments (Questionnaire) was tested through a pilot study using a set of academics. Rather than carry out pre-testing on the entire questionnaire and survey procedure, it was possible to get feedback from experts that was specific to each item in the questionnaire. Moreover, it was possible to identify complicated words in the questions, problems with leading questions, and bias caused by the question order. Based on their feedback, necessary revisions were made to both questionnaires before distribution.

In comparison, reliability is concerned with the accuracy of data measurement, which is free of random error when estimated (Cooper & Schindler, 2003; Pallant, 2013; Zikmund et al., 2007). As this questionnaire was designed with a Likert scale, the researcher needed to determine the reliability of the scale. Reliability can be measured using the Coefficient alpha (referred to as Cronbach's alpha). This research adopts the following rules stipulated by George and Mallery (2003) that provide the Cronbach's alpha values for reliability tests: "_>0.9=Excellent; _>0.8=Good; _>0.7=Acceptable; _>0.6=Questionable; _>0.5=Poor; _<0.5=Unacceptable". The summary of the reliability test for both data sets is presented in Table 4.2; all items in the questionnaire sections have a high level of reliability.

Table 5.2: Summary of the reliability test of the overall responses for questionnaires A and B

Questionnaire A			
Sections	**Cronbach's Alpha**	**Number of Items**	**Reliability**
Section 2: Factors affecting the accuracy of pre-tender cost estimates	0.918	57	High
Questionnaire B			
Section 2: Drivers for BIM adoption	0.948	42	High
Section 3: Barriers for BIM adoption	0.938	46	High

5.3 Relative Important Index (RII)

RII has been widely used in construction research to determine the relative importance of the surveyed variables (Holt, 2014). Chan and Kumaraswamy (1997) used the following formula to determine the relative ranking of factors. Therefore, in this study RII was computed for the filtered factors from the descriptive analysis in both the questionnaires.

$$\text{Relative Importance Index} = \frac{\sum w}{AN} = \frac{5n_5 + 4n_4 + 3n_3 + 2n_2 + 1n_1}{5N}$$

Equation 5.1 Formula for RII (Source: Chan & Kumaraswamy, 1997)

Where W, which is the weighting given to each factor by the respondent, ranges from 1 to 5; A is the highest weight (i.e., 5 in the study) and N is the total number of respondents. In this study RII was used to identify the most important and least important factors such as affecting factors for the accuracy of pre-tender cost estimates, BIM barriers and drivers.

5.4 Data Analysis and Findings from Questionnaire A – Section 01

This section explains the background information of respondents regarding their current role, educational background, experience in construction cost estimating, nature of their business organisation and their current level of BIM knowledge. These data help to describe the general nature of survey respondents, which has a significant role in determining that reliable outcomes for this research. The results are presented using tables, pie charts, graphs, and figures.

5.4.1 Professional Background

The respondent's professional background was investigated in order to identify their current role within the organisation as it indirectly reflects the pattern of responses given for this survey. This survey was mainly aimed at Quantity Surveyors with a quantity surveying background, as most of their practice involves construction cost estimating works. The survey results indicated that all respondents were from a quantity surveying background, which is 100% of the overall percentage (refer Table 5.1). As illustrated in Table 5.3, the sample consisted of the following: Trainee QS (9%), Assistant QS (28%), Quantity Surveyors (46%), Senior QS (12%), Charted Quantity Surveyor (3%) and Charted Senior Quantity Surveyor (2%). Therefore, the results confirm reliable and valid sources who can provide adequate and useful data for the research.

Table 5.3: Distribution of respondents based on their professional backgrounds in their organisations

Profession	**Frequency**	**Percentage (%)**
Trainee Quantity Surveyor (TQS)	9	9%
Assistant Quantity Surveyor (AQS)	29	28%
Quantity Surveyor (QS)	47	46%
Senior Quantity Surveyor (SQS)	12	12%
Charted Assistant Quantity Surveyor (CAQS)	0	0%
Charted Quantity Surveyor (CQS)	3	3%
Charted Senior Quantity Surveyor (CSQS)	2	2%
Total	102	100%

5.4.2 Performing Roles in Organisations

As the role of the QS consists of many tasks, it is difficult to conclude that by having a quantity surveying background all respondents would deal with cost estimating within their organisations. In some cases, they might have been assigned to perform different roles within a quantity-surveying context. As the main focus of this research is cost estimation, it is vital to confirm whether respondents have been actively involved in cost estimation within their profession. Therefore, a survey question was designed considering this subject.

Table 5.4 demonstrates the most common roles amongst respondents within their organisations. Thus, the most frequently performed tasks are cost estimation (69%), taking off quantities (90%) and the preparation of BOQ (74%). Moreover, respondents also perform tendering (50%), cost planning (30%), document preparation (60%), cost control (38%) and interim valuations (67%). As the majority of respondents deal with cost estimation tasks, their responses met the research requirements, which required data from the appropriate respondents to generalise relevant findings.

Table 5.4: Distribution of respondents based on their roles within the organisations

Roles	Frequency	Total Number of Respondents	Percentage (%)
Estimation	**71**	102	**69%**
Taking off Quantities	**92**	102	**90%**
Tendering	52	102	50%
Cost Planning	31	102	30%
BOQ	**76**	102	**74%**
Document Preparation	62	102	60%
Cost Control	39	102	38%
Interim Valuations	68	102	67%

5.4.3 Experience in Construction Cost Estimating

Based on the questionnaire, respondents were categorised into five main groups, namely less than 1 year, 1-3 years, 4-5 years, 6-10 years and more than 11 years of experience in construction cost estimating. The following table (5.5) demonstrates the distribution; the majority of respondents had more than 5 years of experience (27%) in cost estimating and 23% of respondents had more than 11 years of experience. Nevertheless, the percentage distribution did not differ significantly between the rest of the groups. Furthermore, 21% of respondents had 4-5 years of experience, 21% ranged from 1-

3 years of experience, and 9% had less than 1 year of experience in construction cost estimation. This distribution amongst the group of respondents positively contributed to this research by helping to identify weaknesses in cost estimation and awareness, knowledge, and application within the context of BIM.

Table 5.5: Distribution of respondents based on construction cost estimating experience

Experience	Frequency	Percentage (%)
< 1 Year	9	9%
1-3 Years	21	21%
4-5 Years	21	21%
6-10 Years	28	27%
>11 Years	23	23%
Total	102	100%

5.4.4 Business Nature of the Current Organisation

It is important to know the business nature of the respondent's current organisation, as the scope of this research is pre-tender cost estimation in the Sri Lankan context. Therefore, to confirm that organisations are based in Sri Lanka, respondents were asked to indicate "In which geographical locations does your company carry out work?" The results indicate that all 102 (100%) respondents confirmed they work in organisations that carry out work within Sri Lanka. Apart from Sri Lanka, UAE (50%), India (20%), Australia (10%) and Maldives (5%) are the other locations in which companies work.

As this research focuses on pre-tender cost estimating, it is vital to know the type of businesses that these organisations are engaged with. This is because organisations can be involved at different stages of the construction project lifecycle. Survey results indicate that 60% of respondents work for contracting quantity-surveying organizations and 40% work for consulting quantity surveying organisations. Although contracting organisations represent less than 60%, they also deal with pre-construction works within their business.

Moreover, respondents also were asked what types of contracts they engage with order to certify that they conduct pre-tender cost estimation (Figure 5.1). The results indicate that 27% of respondents are completely engaged in the process of preparing pre-tender cost estimates; however, the majority of respondents (55%) are engaged in the preparation of both pre- and post-contract cost estimates. Only 18% of respondents are totally engaged in the process of post-contract work.

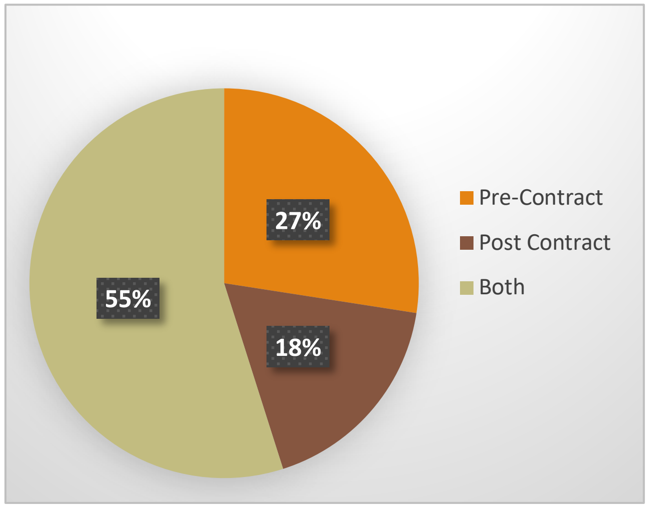


Figure 5.1: Nature of contract types of organisations

5.4.5 Respondents' BIM Awareness and Usage

The background profile for this questionnaire was developed to define the characteristics of an entire group of respondents, thus verifying the appropriate responses for analysis. However, this section also examines the level of BIM adoption amongst respondents from a Sri Lankan quantity-surveyor's perspective. The aim of this section is to identify and filter the respondents who're in a BIM-based process for questionnaire B.

To examine their current level of BIM knowledge, they were given a scale of novice, intermediate or advanced. According to Figure 5.2, of 102 respondents, the majority (63%) considered themselves intermediates in terms of BIM knowledge. Only 1% of respondents had advanced knowledge, as the rest (36%) were novices to BIM. Therefore, it can be concluded that most respondents have a moderate level of knowledge of BIM.

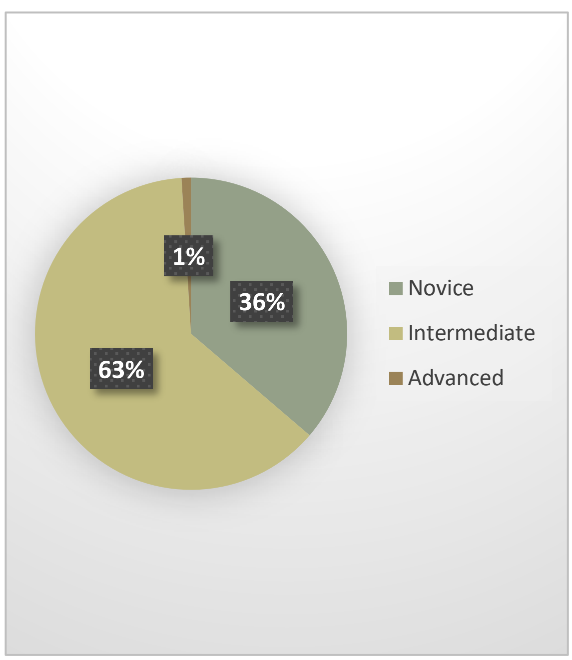
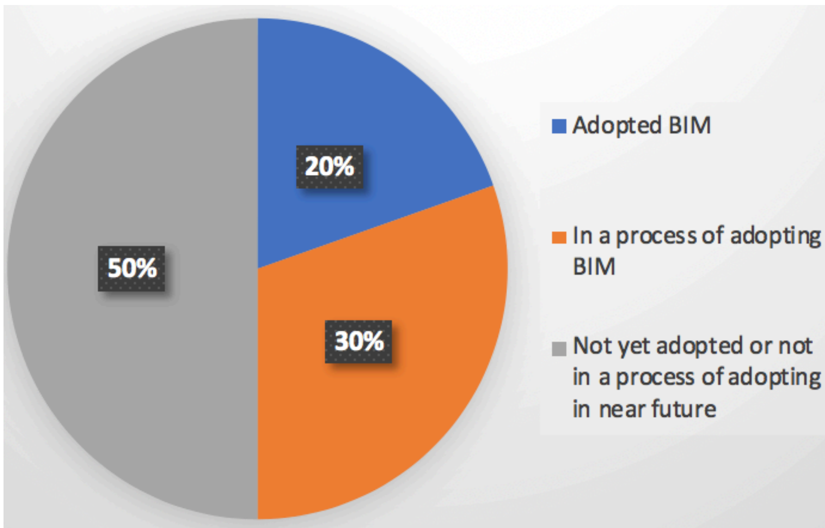


Figure 5.2: Respondents' awareness of BIM

Respondents were also asked to indicate the level of BIM usage within their organisation. According to Figure 5.3, of the 102 responses, 20% have already adopted BIM while 30% are in the process of adopting BIM in their organisation. This implies that a considerable number of respondents expected to use BIM in the near future. They might potentially believe that BIM would continuously bring improvement to their existing practice; therefore, its usage should be extended for future projects.

Figure 5.3: Respondents' level of BIM adoption



However, the majority of respondents (50%) have not yet adopted or are not in the process of adopting BIM in the near future. This might be due to a lack of awareness of BIM and its benefits. However, it was possible to identify BIM knowledgeable respondents to conduct questionnaire B. Accordingly, the respondents who have adopted and in the process of adopting BIM (nearly 50) were given questionnaire B. This is significant as respondents were required to have BIM knowledge to answer the given questions.

5.5 Data Analysis And Findings From Questionnaire A: Section 2

Section two of questionnaire A aimed to identify the factors affecting the accuracy of pre-tender cost estimates. Accordingly, the questionnaire consisted of 57 closed-ended questions (factors) under 11 main headings, which were based on the literature review in chapter 2, namely the use of 2D drawings, a lack of information, software issues, a lack of communication, a lack of coordination, time constraints, manual QTO, estimator experience and knowledge, and a lack of proper site investigations. The factors were tested in the questionnaire using a five-scale approach, and the results are discussed below.

The frequency values of the responses identifying issues with the use of 2D drawings are illustrated in Table 5.6. According to the table, D1 received the highest percentage of agreement (95%), which indicates the accuracy of design drawings are important for the accuracy of cost estimates. Besides, the lowest agreement was recorded for D2 (47%). However, the rest of the factors recorded over 65% agreement among the participants. In terms of disagreement with the factors, D2 received the highest percentage (25%). Besides, the lowest percentage of disagreement was recorded for D5 and D9 (both 1%). The results indicate that the majority of participants agreed with all statements in Table 5.6. Therefore, it can be concluded that the use of 2D drawings affects the accuracy of cost estimates.

Table 5.6: The use of 2D drawings

Coding	The use of 2D drawings	SA	AG	NU	DA	SD
D1	The accuracy of the design drawings directly affects the accuracy of cost estimates.	54%	41%	3%	2%	0%
D2	As 2D drawings do not allow any relationship between the components of the drawings (Ex: wall and window), it is difficult to map the costs to each element in the drawings.	3%	44%	28%	23%	2%
D3	2D drawings have individual views and changes in one view will not automatically reflect in other views.	16%	71%	11%	2%	1%
D4	The editing of plans, sections or elevations in 2D drawings requires that all other sections are checked and updated manually.	30%	57%	10%	3%	0%
D5	The manual revision of drawings is time-consuming and delays the entire estimation process.	32%	56%	11%	0%	1%
D6	2D drawings provide limited visualisation and make it more complex for Quantity Surveyors to interpret.	9%	56%	24%	12%	0%
D7	The lack of visualisation may lead to errors, such as the use of incorrect quantities of building elements, materials, plants, etc.	21%	57%	17%	6%	0%
D8	Wrong assumptions and incorrect decisions can be made by QS based on drawings, which would directly affect the accuracy of cost estimates.	20%	60%	18%	3%	0%
D9	Errors and omissions in drawings significantly affect the accuracy of cost estimates.	34%	55%	10%	1%	0%

Table 5.7 illustrates the frequency values for responses identifying issues related to a lack of information. Accordingly, I2 received the highest agreement percentage (93%), whereas the lowest agreement was recorded for statement I5. However, all statements recorded over 65% agreement among the participants. In terms of disagreement with the factors, I6 received the highest percentage (5%), whereas I1, I2, I3, and I4 received the lowest disagreement percentage (1% each). The results indicate that the majority of participants agreed with all statements in Table 5.7 and resulted in a lack of information. Therefore, it can be concluded that lack of information is a factor that affects the accuracy of cost estimates.

Table 5.7: Lack of information

Coding	Lack of Information	SA	AG	NU	DA	SD
I1	The accuracy of cost estimates positively correlate with the level of given or available information.	27%	61%	11%	1%	0%
I2	Insufficient information increases the inaccuracy of cost estimates	40%	53%	6%	1%	0%
I3	Insufficient information leads to inaccurate decisions/assumptions by the QS	33%	51%	15%	1%	0%
I4	The quality and appropriateness of the information impacts on the accuracy of estimates.	24%	59%	17%	1%	0%
I5	Paper based manual information exchange practices increases the inaccuracy of cost estimates.	22%	43%	31%	4%	0%
I6	Poor information flow during the estimation process, which increases the inaccuracy of cost estimates.	24%	51%	21%	5%	0%

Four issues were extracted from the literature and identified as belonging to the factor 'inefficiencies in existing cost estimating software'. These issues were tested in the questionnaire survey and results are summarised in Table 5.8.

According to Table 5.8, S4 received the highest agreement percentage (82%), whereas S1 recorded the lowest agreement (36%). On the other hand, S1 recorded the highest disagreement percentage (40%), which indicates that 'Generic systems such as Microsoft Excel used for estimation' is not a root cause behind the factor inefficiencies in cost estimating software. Moreover, the lowest disagreement was recorded for S4 (0%). Apart from S1, the remaining statements recorded over 50% agreement among the participants. Therefore, findings indicate that the majority of participants agreed with statements S2, S3 and S4. It can be concluded that inefficiencies in existing cost estimating software affects the accuracy of cost estimates, according to S2, S3 and S4.

The next section of the questionnaire asked about causes related to the lack of communication, as extracted from the literature. Accordingly, causes and their findings are illustrated in Table 5.9. The highest percentage of agreement was received for COM1 (94%). In the meantime, the lowest agreement was recorded for COM10 (55%). In terms of disagreement, COM10 recorded the highest percentage (20%), whereas COM1 and COM8 recorded the lowest percentage (1%). Thus, all statements in Table 5.9 recorded over 55% agreement among participants, which indicates that the majority of the participants agreed that COM1 to COM10 resulted in a lack of communication. Therefore, findings indicate that a lack of communication was a factor affecting the accuracy of cost estimates.

Table 5.8: Inefficiencies in existing cost estimating software

Coding	Inefficiencies in existing cost estimating software	SA	AG	NU	DA	SD
S1	Generic systems, such as Microsoft Excel, which is used for estimation, represent a major reason for the reduction in the estimate accuracy.	7%	29%	24%	32%	8%
S2	Current computer programs tend to unrealistically overestimate, e.g. the software imposes higher risk allowances compared to estimates through human interaction.	6%	45%	27%	21%	1%
S3	Generic software, such as Excel, needs to be programmed manually by the QS before can be used effectively for estimation.	14%	69%	16%	2%	0%
S4	Human errors in defining repetitive functions in excel could lead to miscalculations measurements.	20%	62%	19%	0%	0%

Table 5.9: Lack of communication

Coding	Lack of communication	SA	AG	NU	DA	SD
COM1	Communication with team members is vital to prepare accurate cost estimates.	41%	53%	5%	1%	0%
COM2	Communication and data sharing are challenging due to intense competition that ultimately results in less accurate cost estimates.	9%	68%	18%	6%	0%
COM3	Communication and data sharing are challenging due to a lack of trust that ultimately results in less accurate cost estimates.	8%	65%	25%	3%	0%
COM4	Communication and data sharing are challenging due to, short-term relationships that ultimately result in less accurate cost estimates.	8%	59%	25%	6%	2%
COM5	Communication and data sharing are challenging due to, selfishness that ultimately results in less accurate cost estimates.	10%	61%	18%	10%	2%
COM6	Paper-based manual information sharing affects the accuracy of cost estimates.	19%	48%	25%	8%	0%

COM7	Formal feedback from project participants, such as the design team and the estimating team, is essential where changes have to be made during the estimation process	36%	51%	13%	0%	0%
COM8	Isolated working culture is a major reason for poor communication.	28%	49%	22%	1%	0%
COM9	A lack of online meetings or emails for communication will lead to less accurate cost estimates.	18%	46%	28%	7%	1%
COM10	Face to face meetings will lead to less accurate cost estimates, as it takes considerable time to organise meetings.	18%	37%	26%	15%	4%

Participants were also asked about the causes related to a lack of coordination, as extracted from the literature. Accordingly, causes and their findings are illustrated in Table 5.10. The highest percentage of agreement was received for COO3 (87%). In the meantime, the lowest agreement was recorded for COO4 (57%). In terms of disagreement, COO2 recorded the highest percentage (3%), whereas COO1 and COO3 recorded the lowest percentage (0%). Thus, all statements in Table 5.10 recorded over 57% agreement among participants, which indicates that the majority of participants agreed that COO1 to COO5 resulted from a lack of coordination. Therefore, findings indicate that a lack of coordination is a factor affecting the accuracy of cost estimates.

Table 5.10: Lack of coordination

Coding	Coordination	SA	AG	NU	DA	SD
COO1	The lack of coordination between cost management, design, and construction causes difficulties in cost estimating.	42%	43%	15%	0%	0%
COO2	A lack of coordination results in delays and disruption to the accurate measurement of works, which create less accurate cost estimates.	26%	60%	11%	3%	0%
COO3	A low level of coordination amongst project participants results in a low level of communication and information sharing.	24%	63%	14%	0%	0%
COO4	A lack of interactivity among project members leads to repetitive work during the preparation of cost estimates.	28%	45%	25%	1%	1%
COO5	Poor documentation among project members lead to repetitive work during the preparation of cost estimates.	28%	54%	16%	1%	1%

The next section of the questionnaire concerned time constraints and their causes, as extracted from the literature. Accordingly, causes and their findings are illustrated in Table 5.11. As illustrated in the table, the highest percentage of agreement was received for T4 (81%). In the meantime, the lowest agreement was recorded for T1 (72%). In terms of disagreement, T2 and T4 recorded the highest percentage (5%), whereas T3 recorded the lowest percentage (0%). Thus, all statements in Table 5.11 recorded over 72% agreement among participants, which indicates that majority of participants agreed that T1 to T4 resulted in time constraints. Therefore, findings indicate that time constraints represent a factor affecting the accuracy of cost estimates.

Table 5.11: Time constraints

Coding	Time constraints	SA	AG	NU	DA	SD
T1	Limited time given for the preparation of cost estimate reduces the accuracy of cost estimates.	27%	45%	25%	2%	1%
T2	QS's are tempted to take shortcuts, such as guess estimation, when under time pressure to complete a cost estimate.	21%	57%	18%	5%	0%
T3	Identifying and reflecting on design changes and incorporating them within estimates or measurements are the most time-consuming tasks.	10%	68%	23%	0%	0%
T4	Limited time available to the estimator to verify assumptions increases the inaccuracy of cost estimates.	28%	53%	14%	5%	0%

Participants were also asked about causes related to the lack of experience and knowledge amongst quantity surveyors, as derived from the literature. Table 5.12 illustrates the findings for the lack of experience and knowledge amongst quantity surveyors. Accordingly, the highest percentage of agreement was received for KNW2 (91%). In the meantime, the lowest agreement was recorded for KNW3 (86%). In terms of disagreement, KNW2 recorded the highest percentage (4%), whereas KNW1 and KNW3 recorded the lowest percentage (0%). Thus, all statements in Table 5.11 recorded over 86% agreement among participants, which indicates that the majority agreed to KNW1, KNW2 and KNW3 resulted in a lack of experience and knowledge amongst quantity surveyors. Therefore, findings indicate that a lack of experience and knowledge amongst quantity surveyors represent a factor affecting the accuracy of cost estimates.

Table 5.12: Lack of experience and knowledge amongst quantity surveyors

Coding	**Lack of experience and knowledge of quantity surveyor**	**SA**	**AG**	**NU**	**DA**	**SD**
KNW1	The accuracy of an estimate heavily depends on the level of estimator experience.	50%	36%	14%	0%	0%
KNW2	Even though different tools are available for estimation, professional experience and knowledge are essential to operate them appropriately and achieve accurate estimates.	49%	42%	5%	4%	0%
KNW3	Lack of construction technology knowledge will lead to inaccurate cost estimates, due to wrong assumptions made by QS.	48%	38%	14%	0%	0%

The next section of the questionnaire asked about the causes related to MQTO, as extracted from the literature. Accordingly, causes and their findings are illustrated in Table 5.13. The highest percentage of agreement was received for MQTO1 (92%). In the meantime, the lowest agreement was recorded for MQTO5 (70%). In terms of disagreement, MQTO5 recorded the highest percentage (6%), whereas MQTO1, MQTO2 and MQTO3 recorded the lowest percentage (1% each). Thus, all statements in Table 5.9 recorded over 70% agreement among participants, which indicates that the majority of participants agreed that MQTO1 to MQTO5 resulted in MQTO. Therefore, findings indicate that Manual Quantity Take-Off (MQTO) represent a factor affecting the accuracy of cost estimates.

Table 5.13: Manual Quantity Take-Off (MQTO)

Coding	**Manual Quantity Take-Off (MQTO)**	**SA**	**AG**	**NU**	**DA**	**SD**
MQTO1	Manual quantity take-off and calculations are more time-consuming tasks in the estimation process.	40%	52%	7%	1%	0%

MQTO2	The QS needs to track and account for design changes in drawings and update quantities and costing during the QTO.	32%	57%	10%	1%	0%
MQTO3	Design changes will demand re-measurement, which is a tedious task and can mean the production of inaccurate estimates.	21%	60%	19%	1%	0%
MQTO4	The risk of double counting is greater during a manual take-off.	27%	48%	20%	5%	0%
MQTO5	Conventional QTO does not allow preparing various cost estimates for different design alternatives, without the need to go through a substantial rework.	14%	56%	25%	6%	0%

The last question concerns the lack of proper site investigations and the causal factors extracted from the literature review. Accordingly, causes and their findings are illustrated in Table 5.14. The highest percentage of agreement was received for SV2 (91%). In the meantime, the lowest agreement was recorded for SV1 (83%). In terms of disagreement, SV2 recorded the highest percentage (2%), whereas SV1 recorded the lowest percentage (1%). Thus, all statements in Table 5.14 recorded over 83% agreement among participants, which indicates that the majority of participants agreed that SV11 and SV2 resulted in a lack of proper site investigation**.** Therefore, findings indicate that the ‘lack of proper site investigations’ represent a factor affecting the accuracy of cost estimates.

Table 5.14: Lack of proper site investigations

Coding	Lack of proper site investigations	SA	AG	NU	DA	SD
SV1	The failure to visit a project site may also lead to incorrect measurements and the preparation of inaccurate cost estimates.	33%	50%	16%	1%	0%
SV2	The estimator must have prior knowledge of site conditions such as ground condition, site access, etc to produce an accurate cost estimate.	34%	57%	7%	1%	1%

5.6 Ranks and RII Analysis for the major factors affecting the accuracy of pre-tender cost estimates.

After conducting the descriptive analysis for all the above factors and causes, it was possible to identify factors and the causes of each factor affecting the accuracy of pre-tender cost estimates. Accordingly, except for S1, "*Generic systems such as Microsoft Excel used for estimation is a major reason for reducing the accuracy of estimates*" the majority of participants agreed on the remaining statements. Thereafter, based on the findings in section 5.5, RII was calculated and the results were summarised in Table 5.15. However, as the majority of participants disagreed with S1, this was not considered in the findings for RII.

Table 5.15: Ranks and RII factors affecting the accuracy of pre-tender cost estimates

Factor Category	Statement Code	RII Value	Average RII Value	Rank
The Use of 2D Drawings	D1	0.796	0.806	06
	D2	0.829		
	D3	0.837		
	D4	0.792		
	D5	0.845		
	D6	0.755		
	D7	0.847		
	D8	0.788		
	D9	0.769		

Lack of Information	HI1	0.865	0.812	**04**
	HI2	0.835		
	HI3	0.810		
	HI4	0.765		
	HI5	0.786		
Software Issues	S2	0.769	0.786	07
	S3	0.788		
	S4	0.802		
Lack of Communication	COM1	0.869	0.770	09
	COM2	0.759		
	COM3	0.755		
	COM4	0.729		
	COM5	0.733		
	COM6	0.755		
	COM7	0.847		
	COM8	0.810		
	COM9	0.745		
	COM10	0.700		
Lack of Coordination	COO1	0.855	0.829	**03**
	COO2	0.820		
	COO3	0.798		
	COO4	0.816		
	COO5	0.855		
Limited Time	T1	0.792	0.778	08
	T2	0.786		
	T3	0.755		
Manual QTO	MQTO1	0.863	0.811	**05**

	MQTO2	0.841		
	MQTO3	0.800		
	MQTO4	0.796		
	MQTO5	0.755		
Estimator Knowledge and Experience	KNW1	0.873	0.872	**01**
	KNW2	0.873		
	KNW3	0.869		
Lack of Proper Site Investigations	SV1	0.831	0.838	**02**
	SV2	0.845		

As illustrated in Table 5.15, estimator knowledge and experience were ranked first with an RII of 0.872 and supported with three root causes that were identified through descriptive analysis. Ranked second was a lack of proper site investigation with an RII of 0.838, which was also supported with two root causes. The factor 'lack of coordination' was ranked in 3rd place with an RII of 0.829 and it was supported with five root causes. A lack of information was ranked in 4th place with an RII of 0.812, it was also supported with five root causes. MQTO was ranked 5th with an RII of 0.811 and supported with five root causes. The use of 2D drawings was ranked in 6th place with an RII value of 0.806 and supported with nine root causes. Software issues ranked in 7th place with an RII value of 0.786 and supported with three root causes. Moreover, at 8th place was time constraints with an RII value of 0.778, which was supported by three root causes. Finally, a lack of communication was ranked in 9th place with RII of 0.770 and supported by 10 root causes.

5.7 Summary and Link: Questionnaire A findings

An analysis of questionnaire survey A was conducted to achieve objective one of the study ('to identify the current status of pre-tender cost estimates and the factors affecting the accuracy of pre-tender cost estimates in Sri Lanka), and findings were presented in this section. A descriptive analysis was followed by RII and conducted to identify the affecting factors and their root causes, as initially identified through the literature. The results indicate that estimator knowledge and experience, a lack of proper site investigations, a lack of coordination, a lack of information, and manual QTO are the major factors affecting the accuracy of pre-tender cost estimates. However, findings also indicate that the use of 2D drawings, software issues, limited time, and a lack of communication also have an impact on the accuracy of cost estimates. Accordingly, findings also indicate root causes for each factor, and the majority indicated agreement by participants. However, participants did not agree (the majority disagreed) with S1 '*Generic systems such as Microsoft Excel used for estimation is a major reason for reducing the accuracy of estimates*', which indicates that the use of Microsoft Excel is not a major cause behind software issues. The next section of this chapter explains the analysis of questionnaire survey B.

5.8 Data Analysis And Findings From Questionnaire B – Section 01

5.8.1 Professional Background

The respondent's professional background was investigated in order to identify their current role within the organisation as it indirectly reflects the pattern of responses given for this survey. This survey mainly targeted Quantity Surveyors with a quantity surveying background, which was important given that most of their practice involves BIM-based construction cost estimating works. The survey results indicated that all respondents were from a quantity surveying background, at 100% from the overall percentage (refer to Table 5.1). This sample consists of Trainee QS (7%), Assistant QS (35%), Quantity Surveyors (27%), Senior QS (13%) and Charted Quantity Surveyors (18%), as illustrated in Figure 5.4. Therefore, the results suggest reliable and valid sources who can later provide adequate and useful data for the research.

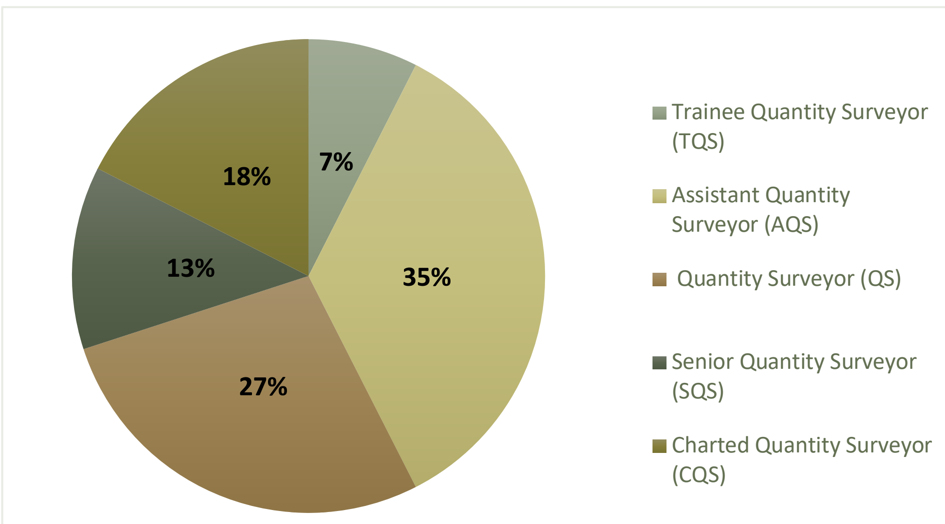


Figure 5.4: Distribution of respondents based on their professional background in their organisation

5.8.2 Business Nature of the Current Organisation

It is important to have an idea about the business nature and location of the respondent's current organisations as this research is limited to the Sri Lankan context. Therefore, to confirm that organisations are based in Sri Lanka, respondents were asked to indicate, 'In which geographical locations does your company carry out work?' The results indicate that all 40 (100%) respondents indicated that they work within organisations in the Sri Lankan construction industry. Apart from Sri Lanka, UAE (75%) and Australia (15%) are the other locations in which these companies work.

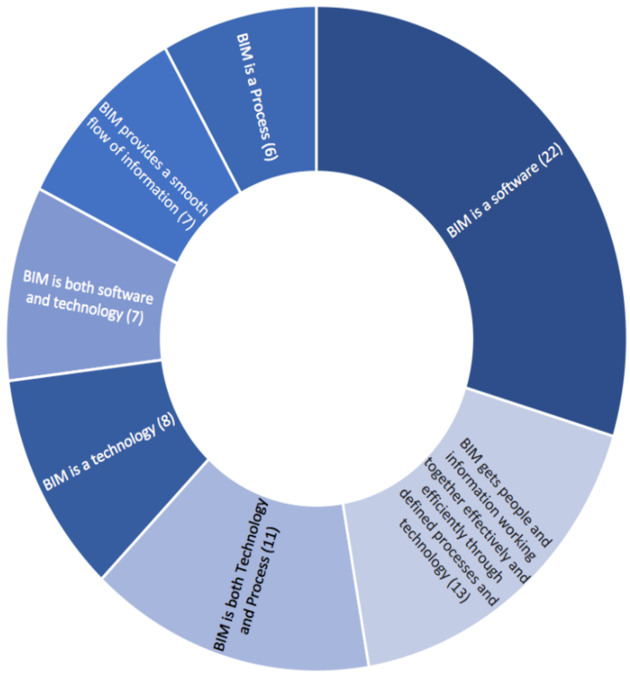
5.8.3 Respondents' BIM Adoption in the Sri Lankan Construction Industry

The background profile has demonstrated the characteristics of the group of respondents, hence verifying the appropriate responses for analysis. This section further investigates the context of BIM adoption in the Sri Lankan construction industry, from a quantity surveyor's perspectives. This consists of respondents' BIM awareness, current knowledge, and BIM usage. Moreover, respondents have further provided detail about the use of BIM software and its main application within their organisation.

5.8.3.1 Awareness of BIM

The level of BIM awareness amongst respondents was assessed based on their level of BIM knowledge and the way they defined BIM. According to Figure 5.5, 22 respondents defined BIM as just software, whilst 13 identified it as follows: "BIM gets people and information working together effectively and efficiently through defined processes and technology". Furthermore, eight respondents defined BIM as a technology, and seven identified BIM as both software and technology. In addition, seven respondents identified that BIM provides a smooth flow of information, whilst only six identified BIM as a process. As a whole, it can be concluded that the majority of respondents are aware of the BIM, even though it is not used that much in Sri Lankan QS practice.

Figure 5.5 Respondents' BIM awareness



Of 40 respondents, 30 (75%) respondents were aware of the benefits and drawbacks, of BIM while only 10 (15%) were not aware of such benefits and drawbacks. Moreover, respondents were also asked how they got to know about BIM and, according to the survey results (Figure 5.6), the majority (36) heard from professionals in the industry, while the rest mainly heard through workshops (17), seminars (13), conferences (4) and websites (10). Interestingly, no one had studied or attended a BIM course within this sample. This could be due to the lack of availability of BIM courses within the Sri Lankan education system.

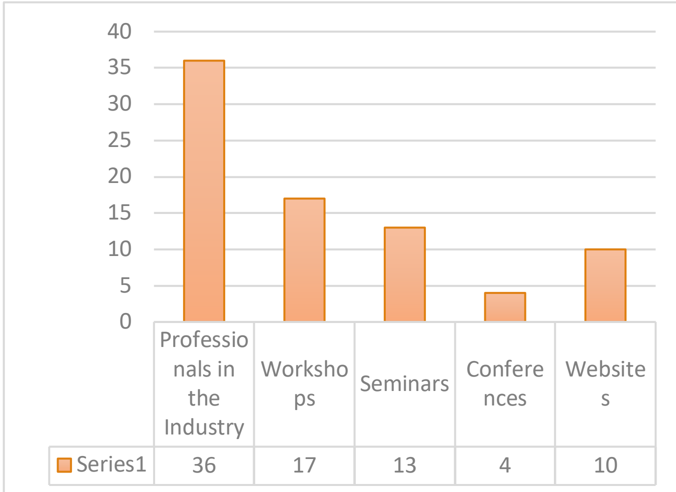


Figure 5.6: Respondents' BIM knowledge sources

5.8.3.2 BIM Software Usage and its Application

The level of BIM adoption amongst Sri Lankan quantity surveyors was initially assessed as a part of this survey. As shown in Figure 5.7, 85% of 40 respondents are engaged in a BIM-based practice, while 15% are in the process of adopting BIM.

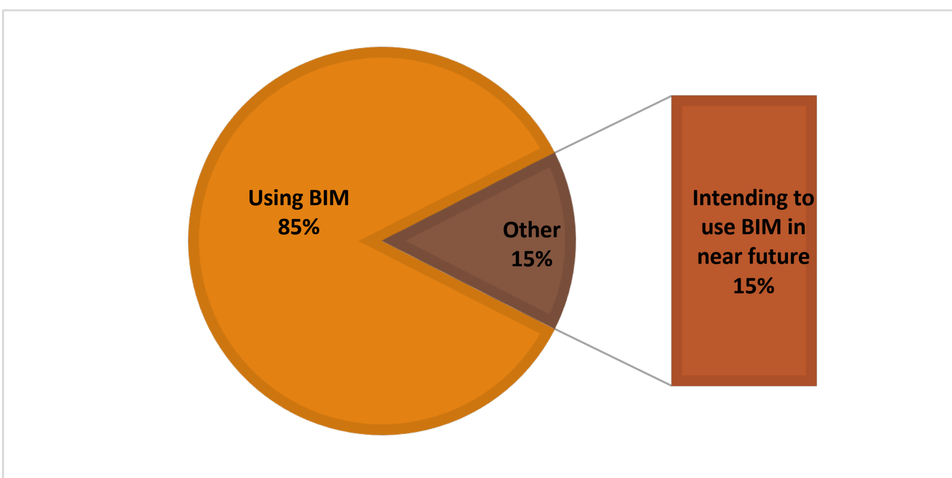
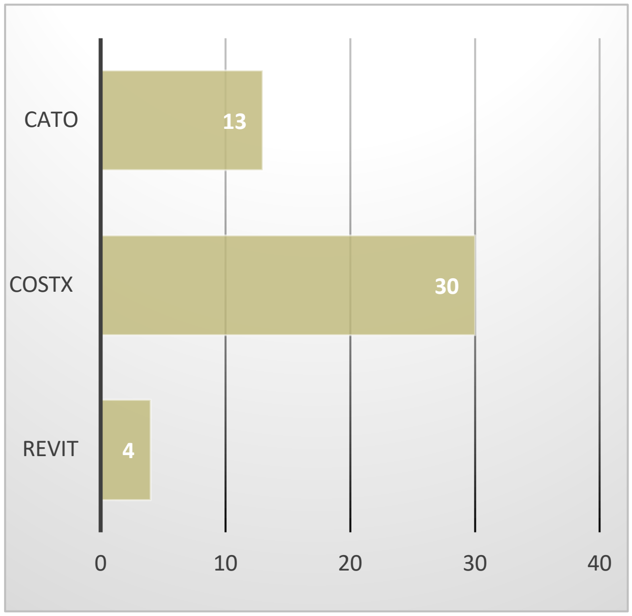


Figure 5.7: Respondents level of BIM adoption

The respondents' experience of BIM-based practice varied from 2-3 years (22%), 4-6 years (63%) and more than 6 years (15%), which indicates that some organisations are matured in BIM-based practice. The 34 survey respondents who are using BIM in their practice were questioned on the types of BIM software they adopt and the main areas in which they actively involved in BIM-based practice. These two categories of question were designed as multiple-responses, therefore the respondents could choose more than one answer in accordance with whatever relates to their practice.

According to Figure 5.8, the most commonly adopted software is CostX (100%). This software is specially designed for quick, BIM-supported quantity take-off, to suit the practice of Quantity Surveyors to enable accurate and efficient building cost estimation. Moreover, respondents also selected CATO (39%), which is also another BIM-based cost estimating software, whilst 12% of respondents also adopted Revit. However, no respondents selected Autodesk quantity take-off, Innovaya and Vico take-off manager, which were also included in the survey list.

Figure 5.8: Respondents most commonly engaged BIM software



According Figure 5.9, the majority of respondents (98%) use BIM mainly to prepare cost estimates. This process consists of quantity take-off and the preparation to estimates for particular projects. It can be seen that respondents used BIM software in this phase, as it was the most important stage in their practice, especially when considering pre-tender cost estimating, which is one of the most crucial tasks in the field of quantity-surveying. Quantity Surveyors play a significant role in this phase by ensuring that they produce accurate cost estimates for the project. Apart from cost estimating, respondents also adopted BIM technology to perform other roles, such as lifecycle costing (27%), valuation (13%), feasibility studies (33%) and risk management (8%).

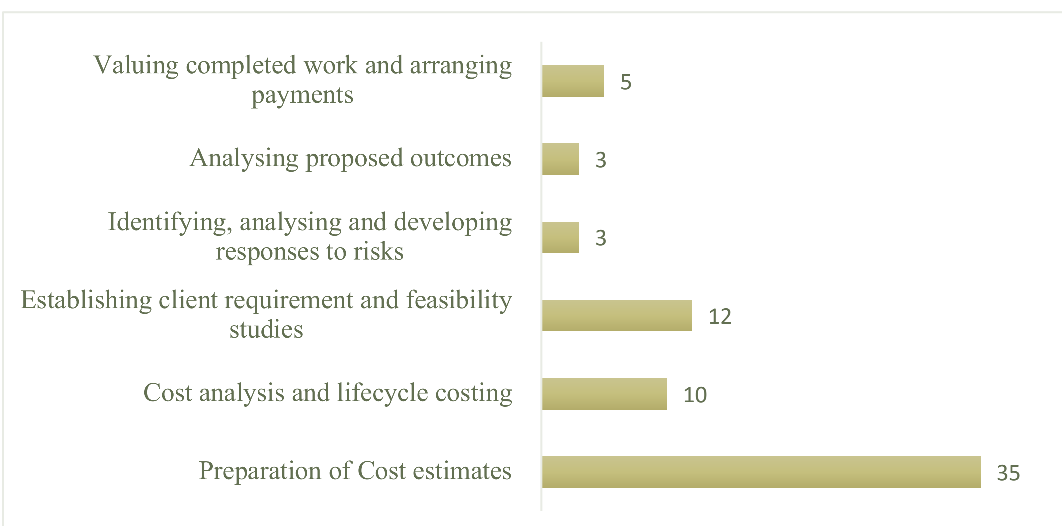


Figure 5.9: Respondents main involvement in BIM areas

5.8.4 The BIM Effect in Current QS Roles

The effect of BIM in respondents' current roles was also investigated. Figure 5.10 illustrates the survey results of the BIM effect. Accordingly, 27% believed that BIM will not affect their current role, although the majority (58%) believed that the application of within BIM quantity surveying will redefine the role of the QS. The remaining respondents (15%) believes that BIM application would make the role of the QS extinct.

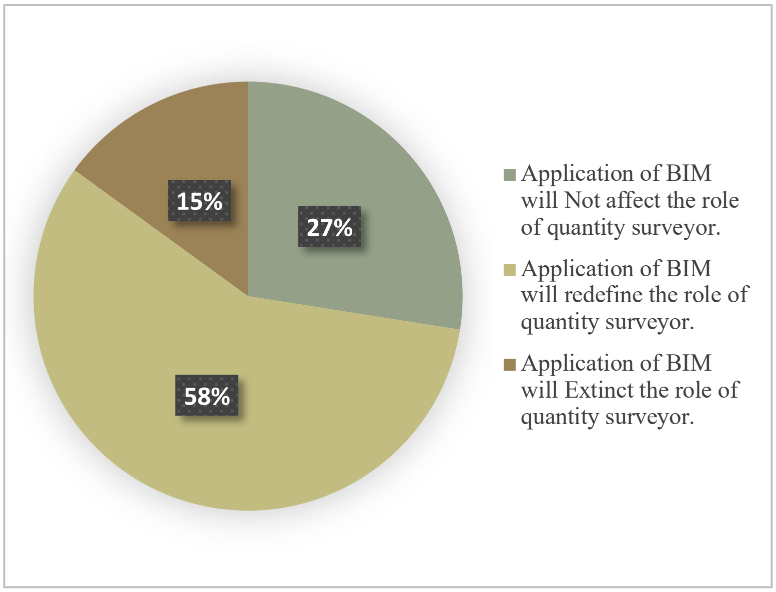


Figure 5.10: BIM effect in respondent's current role

5.8.5 BIM and its Productivity in Cost Estimating

The productivity of BIM usage was also examined as part of the survey. All respondents including users and non-users were asked, 'With the implementation of BIM, did your company experience, or do you anticipate it experiencing, a loss of productivity/ gain of productivity? According to the results, almost all respondents (100%) selected yes. This indicates that BIM users have already increased their productivity and that respondents who are going to use BIM in the near future strongly believe that it will increase productivity. Moreover, respondents were also asked 'The use of BIM generally improves the ability of the quantity surveyor to provide good cost advice during early design development?' Table 5.16 illustrates the responses obtained from participants.

Table 5.16: The BIM effect on providing early cost advice

The use of BIM generally improves the ability of the quantity surveyor to provide good cost advice during early design development.	Frequency	Percentage
SA	7	18%
AG	24	60%
NU	6	15%
DA	3	8%
SD	0	0%

Also, respondents were asked, ‘The use of BIM generally improves the accuracy of cost estimates’ and the results obtained are summarised in Table 5.17.

Table 5.17: The BIM effect on improving the accuracy of cost estimates

The use of BIM generally improves the accuracy of cost estimates	Frequency	Percentage
SA	4	10%
AG	32	80%
NU	4	10%
DA	0	0%
SD	0	0%

These results clearly indicate that the use of BIM has increased the accuracy of cost estimates through its benefits, especially in the early stages of a project. Therefore, it can be concluded that the use of BIM has improved the traditional process of cost estimating, by making the job of a quantity surveyor easier.

5.9 Data Analysis And Findings From Questionnaire B – Section 2: BIM Drivers

Section two of questionnaire B was developed to identify the drivers of BIM adoption. Accordingly, the questionnaire consists of 42 closed-ended questions (factors) under seven main headings which were based on the literature review (Chapter 3). Thus, BIM benefits, Client Demand, Government Drivers, Professional Bodies, Industry Demand, BIM-based Education, Organisational Pressure are the main headings. The factors were tested in the questionnaire using a five-scale approach, and results are discussed below.

Question: **Did any BIM benefit encourage you to adopt BIM/will any of the following BIM benefits encourage you to adopt BIM?**

Twenty elements were extracted from the literature and listed as BIM benefits factors. The frequency values of the responses for each statement are summarised in Table 5.18.

Table 5.18: BIM benefits: BIM drivers

Coding	BIM benefits	Root causes	SA	AG	NU	DA	SD
BM1	**The use of BIM model**	Improved design quality	38%	54%	7%	0%	0%
BM2		Reduced re-design issues	26%	47%	27%	0%	0%
BM3		The provision of a clear workable model for end users	19%	71%	8%	3%	0%
BM4		Design changes are reflected consistently in all drawing views.	37%	47%	15%	1%	0%
BM5		An improved, rich three-dimensional (3D) context that helps a QS to identify significant cost-sensitive design features	26%	47%	25%	1%	0%
BM6		Any changes made to the model, such as the editing of plans, sections or 3D views within the model are automatically made to all other documentation, drawings, and outputs, which saves time spent on manual revision.	40%	42%	17%	1%	0%
IV1	**Improved visualisation**	Earlier and more accurate design visualisation	31%	57%	9%	2%	0%
IV2		Improved clash detection	28%	59%	13%	0%	0%
IV3		QS can carry out a 3D virtual walk-through and ensure everything in the model is factored in the QTO.	23%	58%	16%	4%	0%
AI1	**Easy Access to Information**	QS can to extract and distinguish information from the 3D model	16%	75%	9%	0%	0%
AI2		QS can upload or download any information at any stage of the project from these models.	16%	66%	14%	4%	0%
AI3		Information can be filtered	16%	69%	13%	1%	0%
IM1		Efficiencies from the reuse of data	22%	65%	13%	0%	0%
IM2		Improved document management	29%	51%	19%	1%	0%

IM3	**Improved Information Management**	Intelligent information management allows data to be stored in a centrally coordinated model.	19%	59%	21%	0%	0%
ICOM	**Improved communication**	Improved communication between project parties	32%	49%	12%	6%	0%
ICOO	**Improved coordination**	Improved coordination	29%	44%	24%	3%	0%
AQTO1	**Automate Quantity Take-off**	Cost implications of design changes can be generated easily without manual re-measurement.	24%	70%	5%	0%	0%
AQTO2		Easily generated and accurate cost estimates for various design alternatives.	16%	65%	19%	0%	0%
AQTO3		Preliminary cost plan can be prepared by extracting quantities from the model.	27%	69%	4%	0%	0%

According to Table 5.18, the findings indicated seven BIM benefits. In term of the use of a BIM model, BM3 received the highest percentage of agreement (90%), whereas BM2 and BM5 recorded the lowest agreement (73%). In terms of disagreement with the factors, BM3 received the highest percentage (3%), whilst the lowest percentage of disagreement was recorded for BM1 and BM2 (1% each). Nevertheless, the findings indicate more than 73% agreement for all statements under the BIM model. Therefore, the findings confirm that the use of a BIM model offers key benefits for BIM adoption.

Findings also indicate that improved visualisation represents another BIM benefit. Accordingly, IV1 recorded the highest percentage of participant agreement (88%), whereas IV3 received the lowest agreement (81%). Besides, the highest disagreement was recorded for IV3 (4%) whereas IV2 recorded the lowest (0%). Thus, all statements under improved visualization recorded over 81% agreement amongst the participants, meaning the findings indicated that improved visualization is another key benefit of BIM adoption. Easy access to information is another indicated benefit; accordingly, AI1 recorded the highest percentage of agreement (91%) whereas AI2 recorded the lowest agreement (82%) while the highest disagreement percentage was 4%, and the lowest disagreement was for AI1 (0%). However, all statements recorded over 82% agreement by participants, which indicates that easy access to information is another BIM benefit that encourages them to adopt BIM.

According to Table 5.18 (showing IM1 at 87%, IM2 at 80%, and IM3 at 78%), improved information management was found to be another BIM benefit for participants. Accordingly, 'Efficiencies from the reuse of data' received the highest percentage of agreement. This suggests that, compared IM2 and IM3, IM1 contributes more substantially to improved information management. Besides, the highest disagreement was recorded for IM2 (1%) and the lowest was for IM1 and IM3 (0% each). However, all statements received more than 80% agreement, which indicates that improved information management is another BIM benefit that encourages participants to adopt BIM.

Findings also indicate the majority of participants agreed that improved information management (Ag, 81%; DA, 6%) and improved coordination (Ag, 73%; DA, 3%) are BIM benefits. Besides, findings also indicated that AQTO is another BIM benefit for participants that encourage the adoption of BIM. Accordingly, AQTO1, namely 'Cost implications of design changes can be generated easily without manually re-measurement' recorded the highest agreement percentage (94%), whereas AQTO2 recorded the lowest agreement (81%). In the meantime, no participants disagreed with the statements. However, all statements received more than 81% agreement, which indicates that AQTO is another BIM benefit (due to AQTO1, AQTO2, and AQTO3) and encourages participants to adopt BIM. Overall, the above findings indicate that BIM benefits have encouraged participants to adopt BIM. Therefore, it can be concluded that the BIM benefits are key drivers for its adoption.

Question: **Did any of the following factors encourage you to adopt BIM/will encourage you to adopt BIM?**

The purpose of this question was to identify the remaining BIM drivers, aside from the BIM benefits. Accordingly, Table 5.19 illustrates the frequency values of the responses that helped to identify the drivers related to BIM adoption. As the table illustrates, organisational intervention recorded the highest agreement percentage (96%) from participants. This indicates that organisational intervention has been a strong driver for BIM adoption, whilst the lowest agreement was recorded for government intervention (411%). In terms of disagreement with the factors, MD received the highest percentage (51%), whereas the lowest percentage was recorded for PBI and OI (0% each). In addition, BE and GI recorded 50% disagreement, whilst PBI and CD recorded 88% and 75% agreement respectively. Therefore, based on these results the majority of participants agreed only with OI, PBI, and CD. The majority of participants disagreed with the remaining factors (BE, MD, and GI). Therefore, findings indicated that OI, PBI, and CD are the BIM drivers for BIM adoption; thus BE, MD, and GI were not major influences for BIM adoption.

Table 5.18: BIM Benefits - BIM Drivers

Coding	Factor	**SA**	**AG**	**NU**	**DA**	**SD**
CD	Client Demand	20%	55%	24%	1%	0%
GI	Government Intervention	21%	20%	9%	20%	30%
PBI	Professional bodies intervention	38%	50%	12%	0%	0%
MD	Market Demand	21%	25%	3%	32%	19%
BE	BIM-based education	21%	26%	3%	30%	20%
OI	Organisational Intervention	38%	58%	4%	0%	0%

5.10 Ranks and RII Analysis for BIM Adoption Drivers

After conducting a descriptive analysis for the above factors, it was possible to identify 13 major drivers for BIM adoption in Sri Lanka. Thereafter, RII was calculated for all the filtered factors and the results have been summarised in Table 5.20.

Table 5.19: Ranks and RII Values of the BIM Adoption Drivers

BIM DRIVERS	Coding	RII Value	Average RII Value	Rank
The use of a BIM Model	BM1	0.845	0.798	06
	BM2	0.770		
	BM3	0.810		
	BM4	0.790		
	BM5	0.810		
	BM6	0.765		
Improved Visualisation	IV1	0.805	0.808	**05**
	IV2	0.810		
	IV3	0.810		
Easy Access to Information	AI1	0.800	0.780	08
	AI2	0.760		
	AI3	0.780		
Improved Information Management	IM1	0.800	0.786	07
	IM2	0.785		
	IM3	0.775		
Improved Communication	ICOM	0.770	0.770	09
Improved Coordination	ICOO	0.765	0.765	10
Automate Quantity Take-off	AQTO1	0.825	0.811	**04**
	AQTO2	0.775		

	AQTO3	0.835		
Client Demand	CD	0.845	0.845	**03**
Professional Bodies	PBI	0.855	0.855	**02**
BIM-Based Education	BE	0.660	0.660	11
Organisational Intervention	OI	0.860	0.860	**01**
Government Intervention	GI	0.650	0.650	12
Market Demand	MD	0.610	0.610	13

With an RII value of 0.860, the most influential driver for Sri Lankan quantity surveyors to adopt BIM seems to be organisational intervention. Secondly the intervention of professional bodies was ranked with an RII value of 0.855, whilst client demand was ranked third, with an RII value of 0.845. Automated QTO was ranked in fourth place with a similar RII value of 0.811 that was supported by three root causes. Improved visualisation was ranked in fifth place with an RII value of 0.808 (similarly supported by three root causes).

The use of a BIM model was ranked in sixth place with an RII value of 0.798 and supported by six root causes. Besides, improved information management was ranked in seventh place with a RII value of 0.786 and supported by three root causes. Easy access to information was identified as a driver for BIM adoption and ranked in eighth place with an RII value of 0.780, whilst improved communication was ranked in ninth place with an RII value of 0.770 and improved coordination ranked in tenth place with a RII value of 0.765. BIM-based education, Government Intervention and Market Demand took 11th, 12th and 13th places with RII values of 0.660, 0.650 and 0.610 respectively. Therefore, findings indicated that OI, PBI, CD, AQTO and IV were the key drivers for Sri Lankan QS organisations to adopt BIM. Moreover the use of a BIM model, Improved Information Management, Easy Access to Information, Improved Communication and Improved Coordination were among the top ten drivers. The ranking of BE, GI and MD indicated that these were less influential factors for BIM adoption; in other words, this indicates a lack of BE, GI and MD within the Sri Lankan context.

5.11 Data Analysis And Findings From Questionnaire B – Section 03: BIM Barriers

Section three of questionnaire B was developed to identify the barriers to BIM adoption. Accordingly, the questionnaire consists of 46 closed-ended questions (factors) under eight main headings developed from the literature review (chapter 3). Client Barriers, Industry Barriers, Legal Barriers, Educational Barriers, Lack of Resources, Lack of Professional Support, Financial Barriers and Cultural Barriers form the main headings. The factors were tested by using a five-scale approach in the questionnaire, and the results are discussed below.

5.11.1 Financial Barrier

The frequency values of the responses that identify the root causes related to financial barriers, and these are illustrated in Table 5.20. According to the table, FB2 received the highest percentage of agreement (81%), which indicates the cost of training is one of the barriers for BIM adoption. Besides, the lowest agreement was recorded for FB1 (57%). However, FB3 recorded 80% agreement among participants, which indicates that the majority of participants concurred with all factors. In terms of the disagreement, FB3 has received the highest percentage (12%) whilst the lowest percentage was recorded for FB2 (5%). Therefore, due to the results for FB1, FB2 and FB3, it can be concluded that financial concerns represent a barrier to the adoption of BIM.

Table 5.20: Financial Barrier

Coding	**Financial Barrier**	**SA**	**AG**	**NU**	**DA**	**SD**
FB1	Cost of new hardware and software	14%	43%	35%	7%	0%
FB2	Cost of training existing staff	20%	61%	14%	5%	0%
FB3	Cost of software updates	34%	46%	8%	12%	0%

5.11.2 Lack of BIM Awareness

As illustrated in Table 5.21, five root causes have been tested which were extracted from the literature and grouped under lack of BIM awareness. Accordingly, LBA5 received the highest percentage of agreement (84%), which indicates that a lack of BIM education programmes has resulted a lack of BIM awareness. Moreover, the lowest agreement was recorded for LBA2 (70%). In terms of disagreement with the factors, LBA1, LBA3, LBA4 and LBA5 received the highest percentage (3% each). Besides, the lowest percentage of disagreement was recorded for LBA2 (1%). Nevertheless, all statements in Table 5.22 recorded over 70% of agreement amongst participants, which indicates that the majority of participants agreed with the statements. Therefore, due to the findings for LBA1, LBA2, LBA3, LBA4 and LBA5, the lack of BIM awareness poses another barrier to BIM adoption.

Table 5.21: Lack of BIM Awareness

Coding	**Lack of BIM Awareness**	**SA**	**AG**	**NU**	**DA**	**SD**

LBA1	Lack of BIM-Related Continuous Professional Development (CPD), Seminars and Conferences	7%	70%	20%	3%	0%
LBA2	Lack of BIM Understanding About What it Will Actually Achieve	7%	63%	29%	1%	0%
LBA3	Lack of Understanding of BIM Benefits	20%	53%	24%	3%	0%
LBA4	Lack of BIM-Related Training	17%	59%	22%	3%	0%
LBA5	Lack of Education Programmes on BIM	10%	74%	14%	3%	0%

5.11.2 Legal Issues

The findings indicate that legal issues represent another barrier to BIM adoption, which is attributed to a number of root causes, as illustrated in Table 5.22. According to Table 5.22, LI5 received the highest percentage of agreement (69%), which indicates that a lack of interoperability has resulted in legal issues. Moreover, the lowest agreement was recorded for LI3 (21%). In terms of disagreement, LI4 received the highest percentage of disagreement (26%) whilst the lowest percentage was recorded for LI5 (4%). The findings also indicated that the highest percentage of the participants with a neutral opinion about the statements was recorded to the LI3 (63%), while the lowest neutral opinion percentage was recorded to the LI5. However, findings indicated that the majority of participants had neutral opinions on LI2, LI3 and LI4. This could be due to lack of understanding of, or experience in, BIM-based contracts and forms. Nevertheless, the majority of participants agreed with LI1 and LI5.

Table 5.22: Legal Issues

Coding	**Legal Issues**	**SA**	**AG**	**NU**	**DA**	**SD**
LI1	Data ownership is still being developing and therefore too risky.	8%	46%	34%	12%	0%
LI2	Design responsibility is still being developing and therefore too risky.	4%	35%	46%	15%	0%
LI3	The legalities in terms of contracts are still being developing and therefore too risky.	8%	13%	63%	15%	0%
LI4	Liabilities are still being developed and therefore too risky.	4%	31%	39%	26%	0%
LI5	Lack of interoperability	7%	62%	27%	4%	0%

5.11.3 Lack of Internal Pressure

The findings indicated that a lack of internal pressure is another barrier to BIM adoption, which was attributed to a number of root causes, as illustrated in Table 5.23. Accordingly, LIP2 received the highest percentage of agreement (90%), which indicates that a lack of support from senior management resulted in a lack of internal pressure. Besides, the lowest agreement was recorded for LIP5 (43%). In terms of disagreement, LIP3 received the highest percentage at 12%, whilst the lowest percentage was recorded for LIP1 (0%). The findings also indicated that the highest percentage of participants with a neutral opinion about the statements was recorded for LIP5 (46%), while the lowest percentage for a neutral opinion was recorded for LIP2 (14%). Nevertheless, except for LIP5, the remaining statements in Table 5.23 recorded over 51% of agreement amongst participants, which indicates that the majority agreed with the statements. Therefore, due to the findings for LIP1, LIP2, LIP3, LIP4, LIP5, LIP6 and LIP7, it can be suggested that a lack of internal pressure forms another barrier to the adoption of BIM.

Table 5.23: Lack of internal pressure

Coding	Lack of internal pressure	SA	AG	NU	DA	SD
LIP1	Lack of detail regarding BIM implementation	26%	51%	23%	0%	0%
LIP2	Lack of support from senior management	23%	58%	14%	4%	1%
LIP3	Fear of extinction of the QS role	11%	40%	37%	12%	0%
LIP4	People's refusal/reluctance to learn	19%	33%	38%	10%	0%
LIP5	Inflexible mind-set amongst staff	15%	28%	46%	11%	0%
LIP6	Weak cooperation between different disciplines	15%	36%	40%	9%	0%
LIP7	Strong resistance to change	11%	54%	32%	4%	0%

5.11.4 Lack of External Pressure

In the literature, it was revealed that a lack of external pressure could form another barrier to the adoption of BIM, which was attributed to various issues. Therefore, 11 elements were extracted from the literature and grouped under a lack of external pressure within the questionnaire. The results are summarised in Table 5.24.

Accordingly, LEP10 received the highest percentage of agreement (88%), which indicates that a lack of professional involvement resulted in less external pressure to adopt BIM. Besides, the lowest agreement was recorded for LEP9 (44%). In terms of the disagreement with the factors, LEP11 received the highest percentage (14%), whilst the lowest percentage was recorded for LEP2 (0%). The findings also indicated that the highest percentage with a neutral opinion about the statements was recorded to the LEP9 (52%), while the lowest percentage of those with a neutral opinion was recorded for LEP10 (8%).

Nevertheless, except for LIP9, the rest of the statements in Table 5.24 recorded over 52% agreement from participants, which indicates that the majority of participants agreed with the statements. Moreover, findings further indicated that clients, the government, market demand and professional bodies are the main influencers externally. Therefore, the findings from LEP1 to LEP11 indicated that a lack of external pressure forms another barrier to BIM adoption.

Table 5.24: Lack of external pressure

Coding	Lack of external pressure		SA	AG	NU	DA	SD
LEP1	Lack of client demand	Client	17%	55%	23%	5%	0%
LEP2	Client limitations due to high cost		13%	72%	15%	0%	0%
LEP3	Lack of client awareness		19%	62%	17%	1%	0%
LEP4	Lack of government direction	Government	26%	57%	14%	4%	0%
LEP5	Absence of BIM mandate		17%	55%	23%	5%	0%
LEP6	Insufficient BIM standards and protocols		16%	53%	21%	5%	5%
LEP7	Absence of BIM implementation plan		20%	44%	35%	1%	0%
LEP8	Perceived lack of industry adoption	Market Demand	7%	45%	40%	7%	0%
LEP9	None of the practitioners are on a BIM platform		8%	36%	52%	5%	0%
LEP10	Lack of professional involvement	Professional Bodies	10%	78%	8%	4%	0%
LEP11	Lack of professional body involvement		11%	66%	9%	14%	0%

5.11.5 Lack of BIM Resources

The findings also indicated that a lack of BIM resources represent another barrier to BIM adoption, which was attributed to a number of root causes, as illustrated in Table 5.25. Accordingly, LBR2 received the highest percentage of agreement (94%), which indicates that a shortage of experts in the BIM field signify a major lack of resource for BIM adoption. Besides, the lowest level of agreement was recorded for LBR4 (60%). Moreover, LBR4 received the highest level of disagreement amongst the factors (12%), whilst the lowest percentage of disagreement was recorded for LBR2 (0%). The findings also indicated that the highest percentage of the participants with a neutral opinion about the statements was recorded to the LBR3 (36%), while the lowest percentage was recorded to the LBR2

(5%). Nevertheless, all statements in Table 5.25 recorded over 60% agreement from participants, which indicates that the majority agreed with the statements. Therefore, the findings for LBR1, LBR2, LBR3 and LBR4 indicated a major lack of resources for BIM adoption; therefore, it can be concluded that this lack represents another barrier to BIM adoption.

Table 5.25: Lack of BIM resources

Coding	Lack of BIM Resources	SA	AG	NU	DA	SD
LBR1	Lack of resources within the organisation	29%	54%	15%	3%	0%
LBR2	Shortage of experts in the BIM field	27%	67%	5%	0%	0%
LBR3	Lack of internet facilities	11%	51%	36%	3%	0%
LBR4	Absence of a BIM implementation plan	22%	38%	28%	12%	0%

5.12 Ranks and RII Analysis of the Barriers to BIM adoption in Sri Lankan QS firms

After conducting a descriptive analysis for all factors, it was possible to identify six major drivers and associated root causes for BIM adoption in Sri Lanka. Thereafter, the RII value was calculated for all the filtered factors and results are summarised in Table 5.26.

Table 5.26: Ranks and RIIs of BIM Adoption Barriers

BIM BARRIERS	Coding	RII Value	Average RII	Rank
Financial Barriers	FB1	0.690	0.726	**03**
	FB2	0.755		
	FB3	0.735		
Lack of External Pressure	LEP1	0.730	0.720	**04**
	LEP2	0.780		
	LEP3	0.775		
	LEP4	0.775		
	LEP5	0.730		
	LEP6	0.595		
	LEP7	0.735		
	LEP8	0.670		
	LEP9	0.665		

	LEP10	0.765		
	LEP11	0.695		
Legal Issues	LI1	0.655	0.647	06
	LI2	0.690		
	LI3	0.595		
	LI4	0.580		
	LI5	0.715		
Lack of BIM Awareness	LBA1	0.740	0.745	**02**
	LBA2	0.730		
	LBA3	0.745		
	LBA4	0.750		
	LBA5	0.760		
Lack of Resources	LBR1	0.785	0.753	**01**
	LBR2	0.830		
	LBR3	0.710		
	LBR4	0.685		
Lack of Internal Pressure	LIP1	0.780	0.704	**05**
	LIP2	0.790		
	LIP3	0.655		
	LIP4	0.670		
	LIP5	0.650		
	LIP6	0.670		
	LIP7	0.710		

As per the results, the most influential barrier to the adoption of BIM amongst Sri Lankan quantity surveyors seems to be a lack of resources, which was ranked first with an RII value of 0.753 and four supportive root causes. A lack of BIM awareness is ranked in second place with an RII value of 0.745 and supportive 5 root causes, whilst finances are the third ranked another barrier to the adoption with an RII Value of 0.726 and three supportive root causes. A lack of external pressure is ranked in fourth place with an RII value of 0.720 and 11 supportive root causes; moreover, a lack of internal pressure is another barrier but ranked in fifth place with an RII value of 0.704 along and seven supportive root causes. Finally, legal barriers hinder the adoption of BIM by Sri Lankan QS firms, which are ranked in sixth place with an RII value of 0.647 and five supportive root causes. Therefore, the findings indicate that a lack of resources, lack of BIM awareness, financial barriers, a lack of external pressure and a lack of internal pressure are the top five barriers to BIM adoption. However, legal issues also have an impact on BIM adoption, which was ranked in sixth place.

5.13 Summary and Link Questionnaire B findings

This section presented an analysis of questionnaire survey B, which achieved objective three of the research, namely, to identify the drivers and barriers which impact on the adoption of BIM by Sri Lankan Quantity Surveying firms. A descriptive analysis was conducted followed by the calculation of the RII value, which enabled the researcher to identify the main drivers and barriers derived from the literature. The results indicated that 13 BIM drivers whilst organisational intervention, professional bodies intervention, client demand, automated quantity take-off and improved visualisation formed the key drivers. Moreover, six key barriers were also noted, namely: a lack of resources, lack of BIM awareness, financial barriers, lack of external pressure, a lack of internal pressure and legal issues. The next chapter explains the analysis of the case studies.

6 ANALYSIS AND FINDINGS FROM THE QUALITATIVE ENQUIRY

6.1 Introduction

This chapter presents the findings collected from three different Sri Lankan Quantity Surveying firms using semi-structured interviews. Accordingly, case studies A, B, and C were used to identify the factors affecting the accuracy of pre-tender cost estimates BIM adoption drivers, barriers, and mitigating actions. The chapter starts with a summary of the background to each case study; this is followed by the findings from the case studies from which themes and sub-themes are presented as suggested by the interview responses. Finally, the chapter ends with a summary of the findings.

6.2 Case Study Backgrounds

6.2.1 Firm A - Company History and Services

Firm A was established in 1994 as a grade-A consultancy quantity surveying firm in Sri Lanka. Firm A provides a wide range of quantity surveying services to national, state, and local government agencies, as well as private-sector owners and developers in Sri Lanka and abroad. The main headquarters are located in Colombo Sri Lanka, whilst they also operate two overseas branches in Qatar and India. The growing reputation of firm A meant it was able to extend its service to countries such as the Maldives, Oman, United Arab Emirates, Hawaii, USA, Australia, Qatar and India.

This firm is capable of offering a wide range of consultancy services focused on Quantity Surveying and Project Management. Furthermore, Architectural Services, Cost Management, Construction Management, Claims Management, and Dispute Resolution are also among their services. So far they have dealt with varieties of construction projects, such as hotels and leisure, commercial, institutional, housing, health, and infrastructure - both nationally and internationally. Therefore, the service scope of firm A range from complete pre and post contract quantity surveying services to partial and outsourced services, as follows:

Firm A quantity surveying services in the pre-contract phase include:

- Preliminary cost planning and procurement advice at the concept design stage;
- Preparation of tender documents, such as Bill of Quantities;
- Advice on alternative design solutions;
- Advice on relevant methods of procuring work and on the selection of contractors and specialists suited to the work;
- Feasibility Analysis - Initial cost estimates to establish feasibility, planning, and investment in construction work and to set a budget;
- Building Morphology Studies - Strategic advice on the economics of building shape, specification, and orientation, etc.

Firm A quantity surveying services post-contract phase include:

- Management of cost administration;
- Handling of the procurement process;
- Financial management of construction contracts;
- Timely financial statements projecting final cost;

- Settlement of the final account, upon completion and reconciliation.

Firm A is dedicated to providing professional services to their clients and, as a result, they have registered with the Royal Institute of Chartered Surveyors UK (RICS), the Australian Institute of Quantity Surveyors (AIQS) and the Institute of Quantity Surveyors, Sri Lanka (IQSSL). It thereby upholds the professional values, rules, regulations and ethical standards espoused by these institutions, and its principal officers are individual corporate members of one or more of the above institutions.

6.2.1.1 Current Status of BIM Application

Firm A started using BIM within their practice in 2014. So far so they have acquired more than 10 licenses for Costx-5D estimating and CATO and they are in a process of increasing these numbers shortly. In the year 2015, Firm A selected the Causeway CATO cost and program management software solution to support its BIM operation in both Qatar and Sri Lanka. Causeway Executive Vice President Paul Madeira said: "*We very much value the relationship we have formed with Firm A and her team and we look forward to working with them to ensure they gain the maximum benefit from their investment in Causeway.*" As a solution to integrating BIM tools into their practice, they are capable of providing BIM-related QS services, such as:

- The extraction of drawings from the 3D model;
- The automated measurement from Building Information Models (BIMs);
- Determining associated information, such as the Material Taking Off, Weight, Surface Area and Centre of Gravity (CostX, CATO);
- Preparing cost estimates using CostX and CATO;
- Cost Planning.

Firm A has highly experienced and skilled staff (mainly QS's) who can provide the quantity surveying services mentioned above for all project sizes and tiers of complexity for a solid spectrum of industries. Experienced Quantity Surveying specialists provide a pro-active, dedicated service from inception to completion, by combining reliable cost and contractual advice with effective execution. From establishing feasibility and preparing a Bill of Quantities to the financial management of construction contracts and understanding the final report, the company aims to guarantee maximum commercial value throughout the lifecycle of the task.

6.2.2 Firm B - Company History and Services

Firm B has operated within in the Sri Lankan construction industry since 1968 and carry out work as a limited company. In 2008, after changing ownership, the company came up with its new name. Firm B is a Chartered Quantity Surveying Company, which provides services in different areas, such as project management, contract administration, cost management, value engineering, and the increasing need for value that all clients will face against today's rapidly transforming construction industry.

Although firm B is a Sri Lankan based company, after they started a branch in Oman 2009, quantity surveyors have been able to deliver many government and private projects which include the multibillion U.S. Dollar landmark development of the Muscat International and Salalah Airports for the Ministry of Transport and Communication. Apart from Oman, they also deliver projects in many Middle East countries and Australia.

In terms of resources, the company has hired professionals to build a mix of cultural and professional backgrounds; this is based on the belief that diversity will increase the productivity of their company. The staff consists of Chartered Quantity Surveyors (RICS and MRICS), Project Managers, Engineers, Architects, Contracts and Claims Managers, Expert Witness, and the like. In the Oman office, they employ over 80 professionals and in Sri Lanka, they have 30 employees. The company regularly conducts carrier development programs, which allows them to share their knowledge and refresh current knowledge. Therefore, they are capable of going beyond traditional methods to produce practical, reliable, innovative, and cost-effective solutions that fit into the client's budget.

The firm B provides a wide range of cost consultancy services for both public and private clients. The services they offer cover both the pre and post contract stages. Firm B is dedicated to providing professional services to their clients and as a result, they have registered with the Royal Institute of Chartered Surveyors UK (RICS) to uphold the professional values, rules, regulations, and ethical standards espoused by this institution. Like form A, their principal officers are also individual, corporate members this institution.

6.2.2.1 Current Status of BIM Application

Firm B believes that, as long as they understand that change is the challenge, their future is secure. They state that they like to achieve this growth through dynamic change and by introducing new systems, methods, and technologies. As a result, in 2014, they started working with BIM and its tools. The main BIM tools that they currently use is CostX, and so far so they have obtained six licenses for their Sri Lankan office. The main BIM-based process area they are engaged in is cost estimation. Therefore, they are capable of providing the following BIM-based services for the clients,

- Extracting drawings from the 3D model;
- Automated measurement from Building Information Models (BIMs), and
- Preparing cost estimates using CostX

With the productivity they have gained after integrating BIM, they are shortly in the process of developing BIM-based QS services.

6.2.3 Firm C - Company History and Services

Firm C was established in 1984 as a grade-A quantity-surveying firm in Sri Lanka. Firm C provides a wide range of quantity surveying services to national, state, and local government agencies, as well as private sector owners and developers in Sri Lanka and abroad. The main headquarters are located in Colombo Sri Lanka.

This firm is capable of offering a wide range of services focused on Quantity Surveying. In addition, Architectural Services, Cost Management, Construction Management, Claims Management, and Dispute Resolution are also among their services. So far so they have dealt with a range of construction projects, such as hotel and leisure, commercial, institutional, housing, health, and infrastructure both nationally and internationally. Therefore, the service scope for firm C range from complete Pre and Post Contract Quantity Surveying services to partial and outsourced services as follows:

Firm C: Quantity Surveying services in the Pre-Contract phase include:

- Preliminary cost planning and procurement advice at the concept design stage;
- Preparation of tender documents, such as the Bill of Quantities;
- Advice on alternative design solutions;
- Advice on relevant methods of procuring work and on the selection of contractors and specialists suited to the work;
- Feasibility Analysis - Initial cost estimates to establish feasibility, planning, and investment in construction work and set a budget;

- Building Morphology Studies - Strategic advice on the economics of building shape, specification, and orientation, etc.

Firm C: Quantity Surveying Post-Contract services include:

- Management of cost administration;
- Handling of the procurement process;
- Financial management of construction contracts;
- Timely financial statements the projection of final cost;
- Settlement of the final account upon completion, and reconciliation.

6.2.3.1 Current Status of BIM Application

Firm C expects to provide more dynamic QS services to its customers in collaboration with modern technologies. As a result, they are in the process of adopting BIM and its tools into their organisation. So far, they have started using CostX in the first phase of their BIM adaptation. In the meantime, they have obtained 10 licenses and are expecting to increase the number of licenses soon. The main BIM-based process area they are engaged in is cost estimation. Therefore, they are capable of providing the following BIM-based services for their clients:

- Extracting drawings from the 3D model;
- Determining associated information, such as Material Taking Off, Weight, Surface Area and Centre of Gravity (CostX);
- The automated measurement from Building Information Models (BIMs), and
- Preparing cost estimates using CostX.

Along with the current productivity they gained after integrating BIM, they are in the process of developing BIM-based QS services (apart from cost estimating) shortly.

Accordingly, all the selected case studies have adopted, or are in the process of adopting, BIM into their organisations, especially in cost estimate practices. Nine semi-structured interviews were conducted for all three case studies and the respondent's profiles are illustrated in Table 6.1.

Table 6.1: Profile of Respondents

Respondent No	**Description**	**BIM adoption status**
CSA01	General Manager, XX Pvt Ltd, Charted QS, Member of RICS, and visiting lecturer for QS and Project Management, more than 17 years of experience	
CSA02	Senior Quantity surveyor, BSc in quantity surveying and construction and dip in arbitration, and team leader, more than 15 years of experience.	Adopted
CSA03	Managing director of XX Pvt Ltd, Charted consultant, FRICS, AIQS, charted manger from UK, Canada, more than 25 years of experience.	
CSB01	Senior QS, having more than 23 years of experience in both local and foreign construction projects.	

CSB02	Charted QS, having more than 45 years of experience in cost consultancy work in both local and foreign construction projects.	
CSB03	Senior QS, having 6 years of experience in both pre and post contract QS work.	
CSC01	Chief QS at XY Pvt Ltd, more than 26 years of experience in cost consultancy work.	In a process of adopting BIM
CSC02	Charted senior QS, more than 35 years of experience in both pre and post contract, in construction stage.	
CSC03	Assistant QS, RICS and CIOB, having experience more than 6 years in both pre- and post-contract work.	

6.3 Findings from the Interviews on the Factors Affecting the Accuracy of Pre-Tender Cost Estimates

6.3.1 Introduction

This section presents the themes and sub-themes extracted from nine in-depth face-to-face semi-structured interviews. The interviews were conducted with nine experts who deal with preparing pre-tender cost estimates within the selected firms (see section 4.8 in chapter 4). The data were analysed using thematic analysis (see section 4.10 in chapter 4) and seven main themes alongside sub-themes were extracted from the data. These themes and sub-themes are presented in Table 6.2.

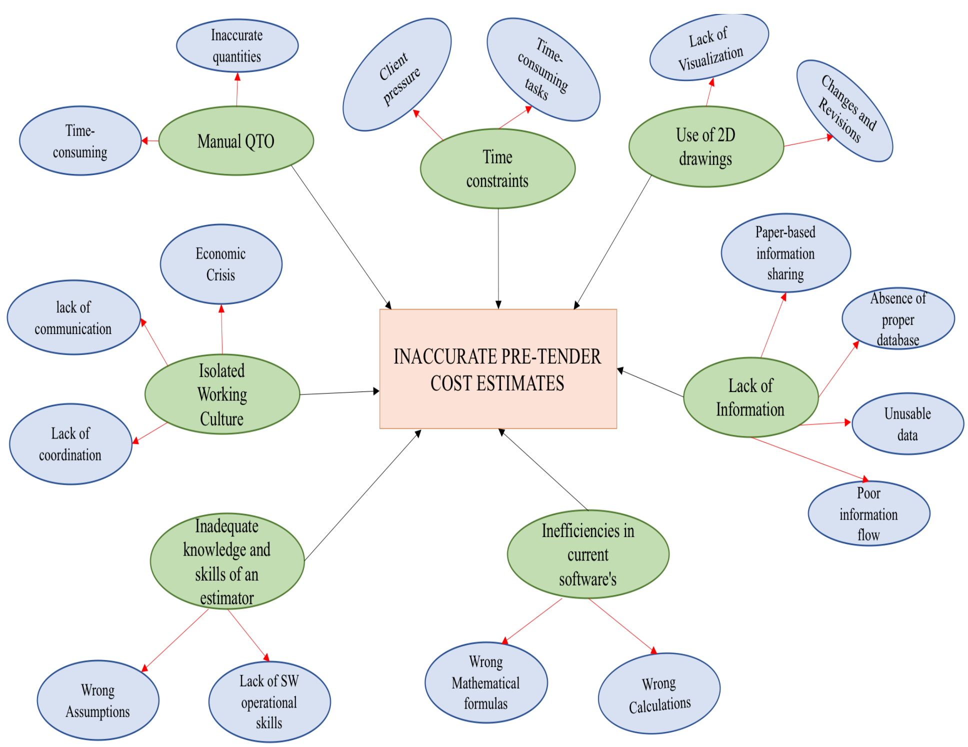
According to Table 6.2, different themes were extracted from the data collected from the semi-structured interviews. Underneath each theme different sets of sub-themes were identified. Moreover, Figure 6.1 illustrates the cognitive mapping of the main factors including their subfactors.

In the following sections, the themes and sub-themes will be presented alongside quotations extracted from interviews. It is vital to mention that the given codes (see Table 6.1) refer to the case study interview from which the evidence was extracted; thus the code indicates from which interview the quotation was taken from. For instance, if a quotation was extracted from case A and interview 01, the coding in the text will be as follows “*the quotation*"(CSA01).

Table 6.2: Themes and Sub-themes that extracted from the interviews

Factors affecting the accuracy of pre-tender cost estimates	
Themes	**Sub – Theme 1**
1. Use of 2D drawings	1.1. Lack of visualisation 1.2. Changes and revisions
2. Lack of Information	2.1. Paper-based information sharing 2.2. Unusable information 2.3. Absence of Common database 2.4. Absence of a rich information flow
3. Inefficiencies in current software	3.1. Incorrect Mathematical Formulas 3.2. Inaccurate calculations
4. Inadequate knowledge and skills of an estimator	4.1. Wrong Assumptions 4.2. Lack of software operational skills
5. Isolated working culture	5.1. Lack of communication 5.2. Lack of coordination 5.3. Economic Crisis
6. Manual Quantity Take-off (MQTO)	6.1. Time Consuming Tasks 6.2. Inaccurate Quantities
7. Time Constraints	7.1. Client Pressure 7.2. Time-consuming tasks

Figure 6.1: Cognitive mapping of factors affecting the accuracy of pre-tender cost estimates



6.3.2 The Use of 2D Drawings

The use of 2D drawings in construction works is the most common practice in the Sri Lankan construction industry. Even at a time when complex projects are prevalent, the use of 2D drawings within practice is inevitable. CSA01 endorsed this by stating "… *most of the cases we are getting drawings in 2D format, even for complex projects*". Furthermore, CSC02 and CSA02 expressed similar thoughts. However, the use of 2D drawings becomes more challenging when preparing accurate pre-tender cost estimates, especially for mega-scale complex projects. CSC02 explained, "*When it comes to a complex project, it's really hard for us to prepare accurate cost estimates using 2D drawings*". Nevertheless, even though the use of 2D drawings is more common in local construction projects, foreign contracts practitioners tend to use 3D drawings and BIM models, due to client requests. This indicates that, the majority of local projects still use 2D drawings. Nevertheless, there are a number of reasons, which make the use of 2D drawings more difficult.

6.3.2.1 Changes and Revisions

First of all, changes and revisions made to the drawings throughout the project are more challenging to deal with. During the design stage, an architect develops drawings without any participation by a QS Once the design is complete, the QS has access to the drawings to prepare the cost estimates. In most cases, these drawings are incomplete and subject to many changes and revisions. CSC02 endorsed this by stating "*The biggest issue is to deal with changes and revisions, Updated version of shop drawings*". Moreover, CSA02 indicated that "*We usually have to deal with 2000, 3000 drawings for a year, once a change is made, we have to identify changes drawing by a drawing which is very time-consuming*". As the QS has limited time to prepare pre-tender estimates, dealing with a number of revisions in a number of drawings is more challenging. Besides, obtaining accurate information related to drawing elements also resulted in changes and revisions. CSA02 agreed with this, stating, "*QS's face many difficulties when dealing with 2D drawings, as many drawings do not contain proper information*". Respondents complained that, due to isolated working cultures (discussed under section 6.3.5), no one wants to share any information. Moreover, responses also identified that the architect's last-minute submissions and client alterations also resulted in changes and revisions. Respondent CSA03 complained that "….*as QS's we should be the first part to be informed if there are any changes happen, hence no one does it as this is a designer lead construction industry*". Therefore, it is hard for a QS to deal with last-minute changes, especially within a tight schedule, as it takes considerable time to check drawings one by one, to evaluate the changes, and incorporate them within the estimates or the measurements already taken as there are no automatic updates. CSA02, CSA03 and CSC02 expressed similar thoughts. Therefore, it is clear that a QS's failure to identify the changes to drawings will increase the inaccuracy of cost estimates.

6.3.2.2 Lack of Visualisation

Another reason mentioned by respondents is the lack of visualisation in 2D drawings. As 2D drawings consist of lines, circles, etc, it does not provide a clear picture for the QS prior to the preparation of cost estimates. Therefore, in most cases, the QS has a blurred image of the final product while preparing the cost estimates. According to CSA01 *".... due to lack of visualisation, it's really hard to identify certain elements for measuring purposes*". According to many respondents, the lack of visualisation becomes more severe due to the complex nature of projects. The present nature of construction is more competitive in developing 'varieties of structure' that no one has seen before. CSA01 emphasized that, even for an experienced QS, it is hard to visualise the design and its elements, especially in complex projects. CSA02 agreed stating that "… *even if we go through all the set of drawings every section and elevations and to visualize how it's gone be in the final product, in most cases our visualisation might* *be wrong"*. Besides, even if a group of QS's assess drawings prior to the preparation of cost estimates, individuals could still develop entirely different images of the final product. As a result, many respondents indicated that taking off inaccurate quantities are inevitable as they depend upon their own visualisations. Moreover, responses also indicated that incomplete drawings also result in a lack of visualisation. Especially in the pre-tender stage, the QS receives incomplete drawings to prepare cost estimates, which provides insufficient background to enable an accurate idea of the final product. CSA03 endorsed this by stating "*If we can get more complete drawings, the cost estimates will be more accurate*". Therefore, respondents considered the use of 2D drawings more challenging due to the lack of visualisation they afford. Furthermore, many respondents believe that, rather that sticking with 2D drawings, the use of a model helps them to prepare more accurate cost estimates. According to CSA01 "*if we have a model, it'll always help to understand elements properly as it provides sufficient visualization for QS to get an idea about the final product"*. Besides, as the QS can depend upon one model rather their own imagination, it enables more accurate quantity take-off without omitting elements. Therefore, respondents prefer the use of models instead of 2D drawings, as they can support more accurate cost estimates without extra effort.

Consequently, responses indicate the use of 2D drawings has become more challenging due to changes, revisions and a lack of accurate visualisation in the 2D drawings. Accordingly, Figure 6.2 illustrates the cognitive mapping of 2D drawings and their difficulties.

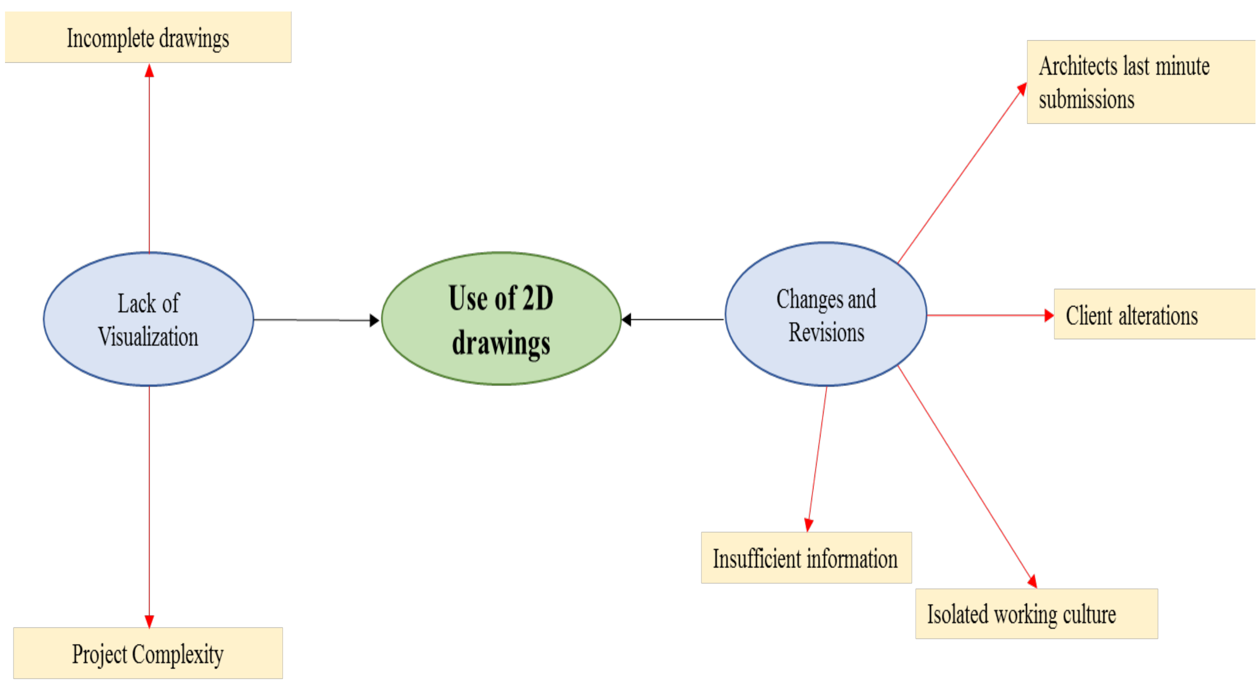


Figure 6.2: Cognitive mapping of the use of 2D drawings and its difficulties

6.3.3 Lack of Information

According to Figure 6.1, the interviewees' responses also revealed that the lack of information is another factor to affect the accuracy of pre-tender cost estimates. Particularly in the pre-tender stage, the availability of sufficient quality information is fundamental in the preparation of accurate cost estimates. However, CSA02 complained that "…*most of the time we are not getting sufficient information at the beginning of the project*". Although similar types of projects e.g. housing, could be undertaken based on previous (completed) project data, unique projects cannot be undertaken accordingly. However, the interviewees' responses indicate several reasons, which result in a lack of information.

6.3.3.1 Paper-Based Information Sharing

According to the interviewees' the majority of information in the Sri Lankan construction industry is shared on papers. As stated by CSA01, this practice is more common, especially in the government sector. Even though private sector firms have managed to share information electronically (e.g. emails), the government sector's traditional practices have hindered the efforts of the private sector. CSB03 endorsed this by stating "*…. as a company, we always trying to use a computer-based system, but when it comes to other parties, they always prefer a paper-based system*". This has resulted in a lack of information flow in many construction projects, where the QS cannot obtain information when needed. As paper-based information sharing is more time consuming, in most cases many QS's do not receive relevant information on time. Besides, respondents also indicated that the isolated working culture (section 6.3.5) also accelerated the use of paper for information sharing. Moreover, it was also found that the fear of using new technologies also promotes paper-based information sharing among practitioners. For example, CSA02 stated *"…… it's really hard to get a reply for an email, once we ask information's through emails responsible parties are not responding*". Moreover, most respondents said that many professionals do not opt for online meetings via Skype or any other online medium. According to CSC01 *"...many parties refuse their meeting to be recorded*, as *they don't want to highlight their errors, and they think that it's not good for their carrier*". However, respondents further emphasised that the use of a paper-based system is more suitable for small scale projects, such as houses, but once the project complexity increases, it becomes more challenging to manage this information on paper. However, according to interviewees, the majority of professionals prefer paper-based information sharing than modern methods and technologies, which results in a lack of information.

6.3.3.2 Unusable Information

Respondents also note that unusable data represents another reason for the lack of information. Accordingly, when the specification is misaligned with the general drawing or detail drawings, or it does not match each other, respondents find it difficult to use the given data to prepare accurate cost estimates. in such instances, as stated by CSA02, *"...in such discrepancies we have to write back to the designer and get the answer, then only we can finalize the estimate, which is very time-consuming".* CSC02 expressed similar thoughts. However, the interviewees' lack of communication (discussed under section 6.3.5.1) and lack of coordination (discussed under section 6.3.5.2) were two main reasons for unusable information. Besides, as discussed under section 6.3.2.1, loopholes in paper-based information sharing have also resulted in the production of unusable data. It is also important to keep contact with relevant parties to produce usable data. However, unfortunately, most of the project team members deal with charted accountants to obtaining data, rather than contact the QS. As a result, in most cases it is not applicable to obtain information. Therefore, unusable data results in a lack of information when preparing cost estimates.

6.3.3.3 Absence of Common Database

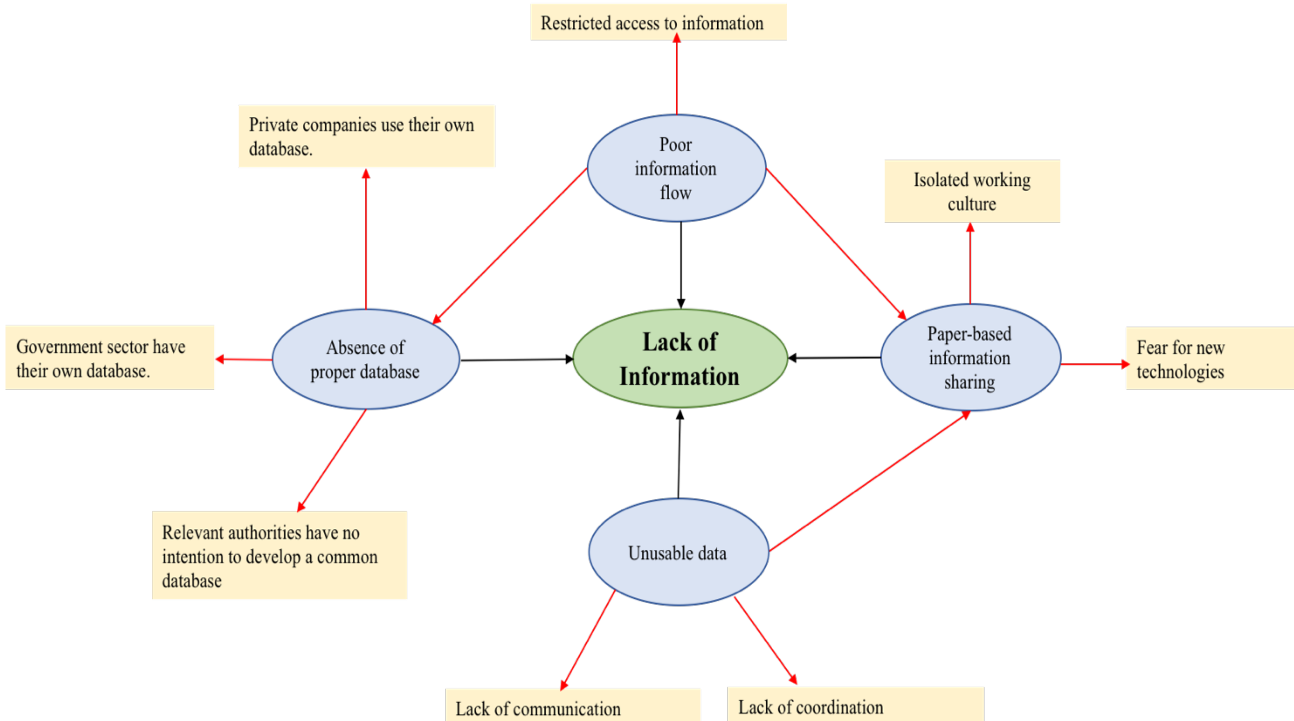
Another reason for the lack of information is the absence of a common database. Respondents mentioned that both the private and government sector have created databases for their individual use. However, CSA01 complained that *"either party does not provide any access to their databases, which have worsened the situation of getting proper information".* Moreover, some respondents believed that the formulation of a general database is the responsibility of relevant construction authorities and professional bodies. Nevertheless, according to CSC02, construction organisations, such as ICTAD, SIDA, have no intention of developing a common database for the construction industry. However, most respondents indicated the importance of having a common database for the Sri Lankan construction industry. Thus, responses confirm that the absence of a common database has resulted in a lack of information when preparing cost estimates.

6.3.3.4 Absence of a Rich Information Flow

Interviewee responses also identified the absence of rich information flow as another reason for the lack of information. As discussed in section 6.3.2.1 many organisations share information through paper documents. As a result, both private and government sector organisations have failed to maintain a proper database consisting of previously conducted project information for future use. This has resulted in the development of poor information flow, where the QS cannot obtain that much information when needed. Besides, CSA01 complained that "*even if they have proper database access to information is limited to the top management*". Therefore, the majority of access to project information has been denied in most organisations and construction projects. As a result, it is challenging to develop a rich information flow throughout the project, as not all the members are aware of the project information. CSB01 endorsed this by stating "*as QS's we should aware what's going on within the site, hence due to poor information flow we are updating in the last minute*". Respondents believe that, if organisations grant access to employees and project members, this could help to maintain a flow of rich information. On the other hand, this will increase the availability of information while improving its flow. Moreover, respondents noted the use of paper-based information sharing, which also results in poor information flow (see section 6.3.2.1). Therefore, it is clear that the absence of rich information flow has also resulted in a lack of information when preparing cost estimates.

Consequently, responses indicate that a lack of information is a factor that affects the accuracy of pre-tender cost estimates due to paper-based information sharing, unusable data, the absence of a proper database, and poor information flow. Accordingly, Figure 6.3 illustrates the cognitive mapping of the lack of information and its reasons.

Figure 6.3: Cognitive mapping for the lack of information and reasons



6.3.4 Inefficiencies in Current Software

As illustrated in Figure 6.1, the responses also revealed that inefficiencies in current software are another prevailing factor that increases the inaccuracy of cost estimates. As stated by CSA02, "*when you do TDS sheets manually you need to do the arithmetic in the calculator to get done the job"*. Moreover, respondents find that manual calculations are more challenging as a QS cannot easily repeat them. Besides, to change one-dimension, a QS has to carry out the entire process from the beginning. As a result, many QS's have tended to carry out their measurements with the help of different software. According to respondents, the most commonly used software among Sri Lankan quantity surveyors is MS. Excel due to its user-friendliness. Accordingly, Excel is mostly used to calculate quantities extracted from the drawings. According to CSC03 "*Excel helps QS by easily replacing one figure and to get the outcome*". However, due to various reasons, respondents indicated the use of Excel is not 100% accurate.

6.3.4.1 Incorrect Mathematical Formulas

The use of Excel compromises several mathematical formulas. Respondents noted that the use of incorrect mathematical formulas increases the inefficiencies of the software. As highlighted by the respondents, several mathematical formulas can be associated with Excel, which increases the inefficient use of the software. As highlighted by the respondents, the wrong assumptions of a QS represent a reason for incorrect mathematical formulas. CSA02 endorsed this by stating "*it's compromised with a lot of mathematical formulas like if command, where QS's have to do a lot of assumptions*". The use of wrong assumptions can result in incorrect formulas and subsequently incorrect measurements and cost estimates. For example, CSC01 stated, "*in SUM, we cannot see the range, so if we have 100 data, 99 will be calculated, and 1 will be missed*".

Respondents also indicated that the QS's lack of SW operational skills (discussed in section 6.3.4.2) is another reason for incorrect mathematical formulas. Besides, as Excel is not specially designed to calculate quantities, once a spreadsheet is created through the application of relevant formulas, it is hard for someone else to trace it to check whether the quantities are correct. According to CSA01 "*Sometimes* *the formulas I've created can't remember to me once I'm using*". Similarly, CSA02 stated, "*if you copied something else over there you will get the wrong answer as you cannot trace it unless otherwise, somebody has tracked it*". Therefore, many respondents suggested the use of unique software for quantity calculation and the preparation of cost estimates to enable more accurate cost estimates. On the other hand, it will save a QS time typically spent developing formulas.

6.3.4.2 Inaccurate Calculations

Inaccurate calculations are another reason for software inefficiencies, according to the interviewees. The use of Excel consists of a lot of hidden calculations, where need more careful attention, especially where changes are required. CSA01 emphasised this by stating "*coming back to the use of SW we need to be very careful because we've found many mistakes due to hidden calculations*". However, respondents also indicated that the use of software will increase the overall efficiency of the cost estimate process by 20% - 30%. Moreover, according to the respondents, missing elements or quantities when transferring measurements to an Excel sheet for calculation represent another reason for inaccurate calculations. As the automatic transferral of quantities does not happen, the QS needs to pay more attention to this process.

Therefore, responses indicate that the inefficiencies in current software affect the accuracy of pre-tender cost estimates due to incorrect mathematical formulas and inaccurate calculations. Accordingly, Figure 6.4 illustrates the cognitive mapping of inefficiencies in current software and its reasons.

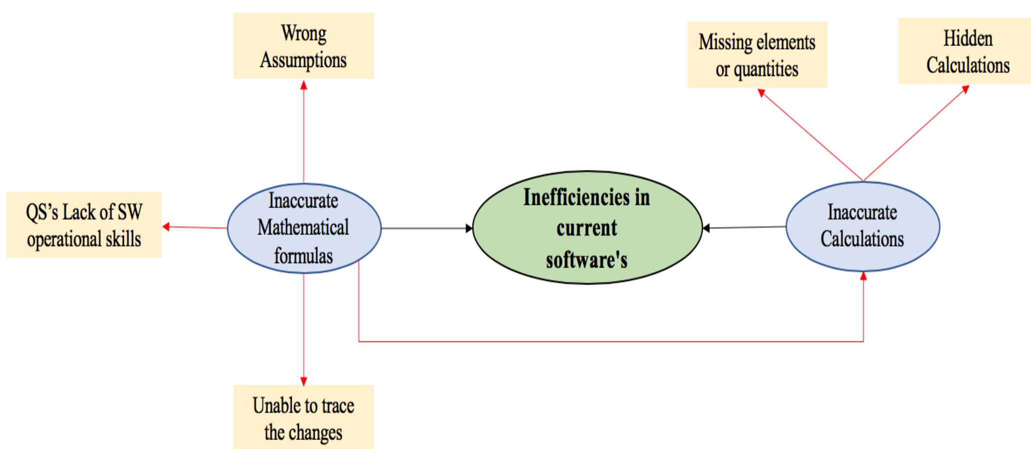


Figure 6.4: Cognitive mapping of the inefficiencies of current software and reasons

6.3.5 Inadequate Knowledge and Skills of an Estimator

According to Figure 6.1, the responses indicated inadequate estimator knowledge and skills as another factor that affects the accuracy of cost estimates. Moreover, the responses indicated that several reasons result in the inadequate knowledge and skills of an estimator.

6.3.5.1 Wrong Assumptions

Wrong assumptions were revealed as one of the main reasons behind the inadequate knowledge and skills of an estimator. In many instances, especially at the pre-tender stage, the QS has to make assumptions mainly due to a lack of available information to perform the tasks (cost estimation). According to CSA01 "*knowledge and experience of QS are vital to make reliable assumptions during* *cost estimation*". If not, it mainly affects the accuracy of cost estimates. Nevertheless, the responses indicate that a lack of awareness of current rates lead to the wrong assumptions. In the Sri Lankan context, the market prices fluctuate every day. Therefore, in many projects, escalations are inevitable. Although escalations are not problematic if payments can be claimed, according to CSC03 "*if you don't have any clause to claim for escalations*, *you have to predict for two years ahead by aligning prices with the market, specifications, drawings and pricing preambles*". Therefore, when updating current rates, it is fundamental for a QS to make reliable assumptions. Therefore, CSB03 suggested that "*a professional should always update themselves for the sake of their job and to deliver a good service*".

Moreover, respondents also believe that the QS's weaknesses in reading and understanding 2D drawings also result in the wrong assumptions. CSA02 endorsed this by stating "*as a QS you should be able to read the drawings properly, as every single line represents something*". A failure to properly identify the elements illustrated in drawings could result in an inaccurate understanding of a drawing and its elements. For example, CSC01 stated "*When it comes to interior works, once you measure the furniture the visualization of the entire design looks like. But in real life, different types of chairs are there with different costs*". Therefore, it can be concluded that the QS should have a reasonable level of knowledge and experience to read and understand drawings and thus make appropriate assumptions.

6.3.5.2 Lack of Software Operational Skills

Respondents also identified a lack of software operational skills as a reason for the inadequate knowledge and skills amongst estimators. The use of any software requires expert knowledge and experience as the software itself cannot sort the issues. For example, CSA02 stated "*certain contingencies and certain risks that you need to include when you do measurement using SW".* Thus, through his experience, the QS should know the percentage that needs allocating, which indicates the importance of QS awareness about the allocation of risk.

Likewise, the QS also has to foresee many things, such as ground conditions. Moreover, professional experience is also required for measurements especially when developing appropriate formulas (discussed in section 6.3.3.1). For example, CSB01 stated that, *"measuring concrete and formwork is different. Because concrete you have to measure by volume and formwork by area*". Therefore, the QS needs to have proper knowledge about measurement rules to effectively and accurately complete the job. Besides, as different SW requires various operational skills and knowledge, respondents emphasised the need for proper QS skills to prepare accurate cost estimates.

Therefore, responses indicated that the inadequate estimator knowledge and skills affect the accuracy of pre-tender cost estimates, due to wrong assumptions and the lack of software operational skills. Accordingly, Figure 6.5 illustrates the cognitive mapping of inadequate knowledge and skills of an estimator and its reasons.

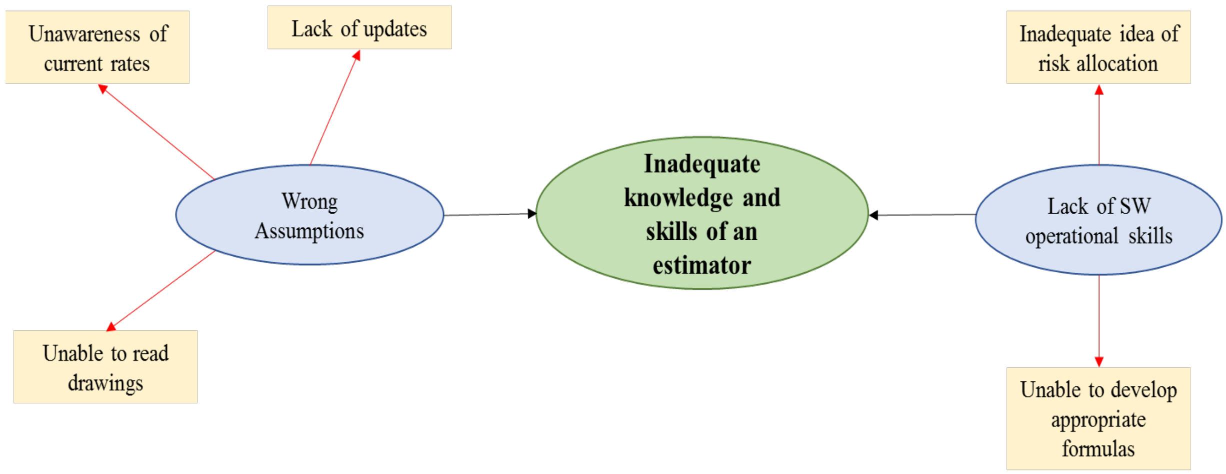


Figure 6.5: Inadequate knowledge and skills of an estimator

6.3.6 Isolated Working Culture

According to Figure 6.1, respondents identified isolated working culture as another prevailing factor behind inaccurate cost estimates. As stated by CSA01 "*…the Sri Lankan construction industry is mostly driven by the individuals rather than the organisations*". As a result, many practitioners (especially designers) prefer individual working practices, which has ultimately created isolated working practices within the industry. Respondents suggest many reasons have resulted in an isolated working culture.

6.3.6.1 Lack of Communication

According to respondents, poor communication among construction professionals is found to be a key reason behind isolated working culture. The most commonly stated reason for poor communication is paper-based information sharing, which is discussed under section 6.3.2.1. As a result, communication among professionals is at a lower level. Besides, many practitioners resist the use of electronic methods of communication, such as email. As a result, CSA02 stated that "*…… it's hard to get a reply for an email, once we ask information's through emails responsible parties are not responding*". Moreover, respondents also noted that freelance working professionals are another reason for poor communication, as they do not maintain an effective link between the industry and professionals. For example, CSB02 stated, "*Recently we have come across 300 quarries of a project, but still the majority of the quarries are outstanding due to poor communication*". This is mainly due to many freelance practitioners working within projects. However, respondents indicated that the risk of unsolved mismatches and discrepancies due to poor communication could result in inaccurate cost estimates. Therefore, CSC02 stated, "…even though *our responsibility is to produce error-free cost estimates, due to poor communication, it has become harder to produce error-free cost estimates*".

6.3.6.2 Lack of Coordination

Respondents also identified a lack of coordination as another reason for isolated working culture. Many respondents indicated that 95% of the areas were not properly coordinated before the tender documents were submitted. Accordingly, a lack of communication (discussed under section 6.3.5.1) was found to be the main reason for a lack of coordination. Moreover, as discussed under section 6.3.5.1, poor links among professionals is another reason for the lack of coordination. It was also noted by respondents that many practitioners refuse to coordinate with other professionals due to a lack of trust. CSA03 endorsed this by stating "*People refused to share anything with others thinking it's going to be a threat* *to them due to lack of trust*". Therefore, many respondents believe there is a need for a system to improve coordination. Accordingly, CSC02 suggested that "*…If we have a central system like BIM, it'll bring all the stakeholders working on the same platform, which ultimately improves the coordination*".

6.3.6.3 Economic Crisis

Respondents identified that the economic crisis are as another reason for isolated working culture. Accordingly, many respondents believe that the developing economy has resulted in an economic crisis in Sri Lanka. CSA01 endorsed this by stating "*due to a developing country, many clients expecting to get done the at the lowest cost"*. Even though quality is an important parameter, cost seems to be a prominent factor for clients due to the economic crisis. As a result, individual construction practitioners have experienced greater demand within the industry than large-scale organisations. As they can earn a lot more, many professionals work as freelancers rather than for an organisation. Moreover, as noted by respondents, political instability can also result in an economic crisis.

Hence, the responses indicate that an isolated working culture affects the accuracy of pre-tender cost estimates due to poor communication, lack of coordination, and the economic crisis. Accordingly, Figure 6.6 illustrates the cognitive mapping of isolated working culture and its reasons.

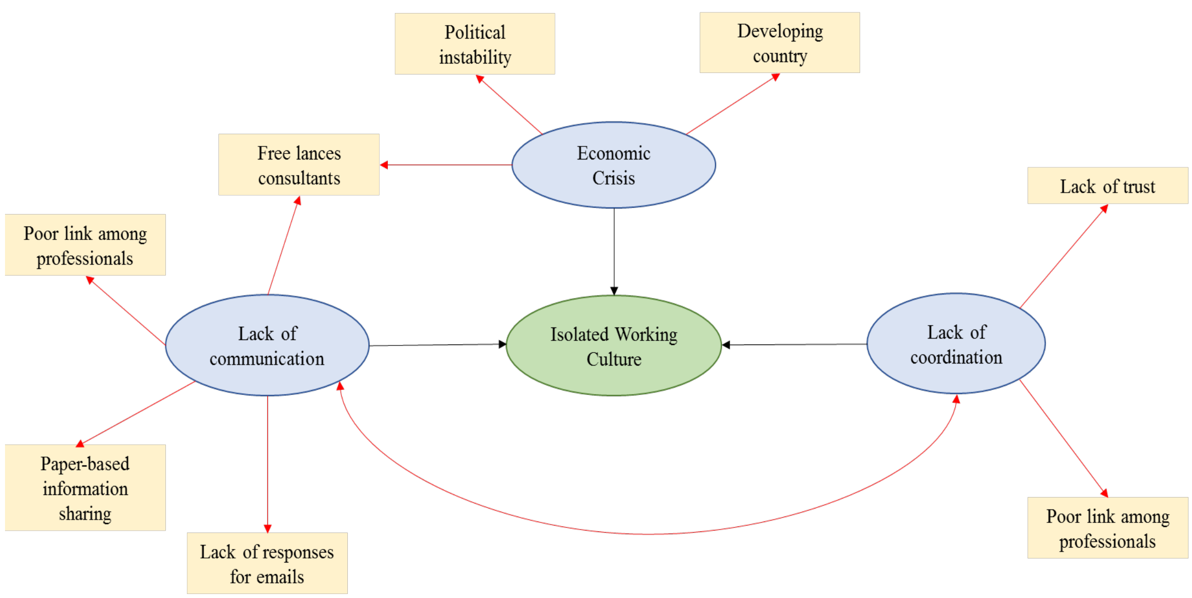


Figure 6.6: Cognitive mapping of isolated working culture and reasons

6.3.7 Manual Quantity Take-off (MQTO)

As illustrated in Figure 6.1, respondents identified that MQTO is another factor that hinders the accuracy of pre-tender cost estimates. According to the respondents, MQTO is more challenging due to various reasons.

6.3.7.1 Time Consuming Tasks

Accordingly, the interviewees' responses indicated that time-consuming tasks represent a key reason for the greater challenge of MQTO. MQTO was found to be the most time-consuming task in the entire estimation process. Accordingly, respondents identified poor visualisation as a time-consuming task. As stated by CSB01 "*QS needs to spend extra time on identifying the elements on 2D drawings due to poor visualization"*. Besides, respondents also indicated a lack of detail in 2D drawings, which is discussed under section 6.3.2 and resulted in the QS spending more time gathering appropriate information. Moreover, along with design updates (especially from the client) a QS is required to update estimates accordingly, as it does not update automatically. CSA02 stated, "*we have to waste our time for updating information based on the changes*". Not only that, but respondents also complained it takes a longer time to detect these changes and incorporate them with existing measures. Therefore, the responses indicated that MQTO is more challenging due to time-consuming tasks.

6.3.7.2 Inaccurate Quantities

It was also noted by respondents that MQTO is challenging due to inaccurate quantities. Respondents complained that missing elements and double counting are inevitable in MQTO, even for the well-experienced QS. This situation becomes more critical when the project complexity increases. According to CSA02, "*in AutoCAD drawings, you have to measure all the areas including floor finishes, skirting, wall finish, etc. it's like redoing the AutoCAD drawings which require manual deductions". If the deductions are disregarded, ultimately measurements or quantities become inaccurate. Moreover, respondents further noted discrepancies in software, such as AutoCAD, which also results in inaccurate quantities. For example, CSA03 stated, "… *in most cases, AutoCAD will not follow rules in Standard methods of measurements, therefore we cannot expect 100% accuracy in manual QTO*". Besides, responses also revealed that the limited time given to prepare cost estimates have also resulted in inaccurate quantities (discussed under section 6.3.7). Inaccurate assumptions (discussed under section 6.3.4.1) are the most frequently stated reason for inaccurate quantities by respondents.

Therefore, responses indicated that MQTO is a factor that affects the accuracy of pre-tender cost estimates due to its associated time-consuming tasks and inaccurate quantities. Accordingly, Figure 6.7 illustrates the cognitive mapping of MQTO and its reasons.

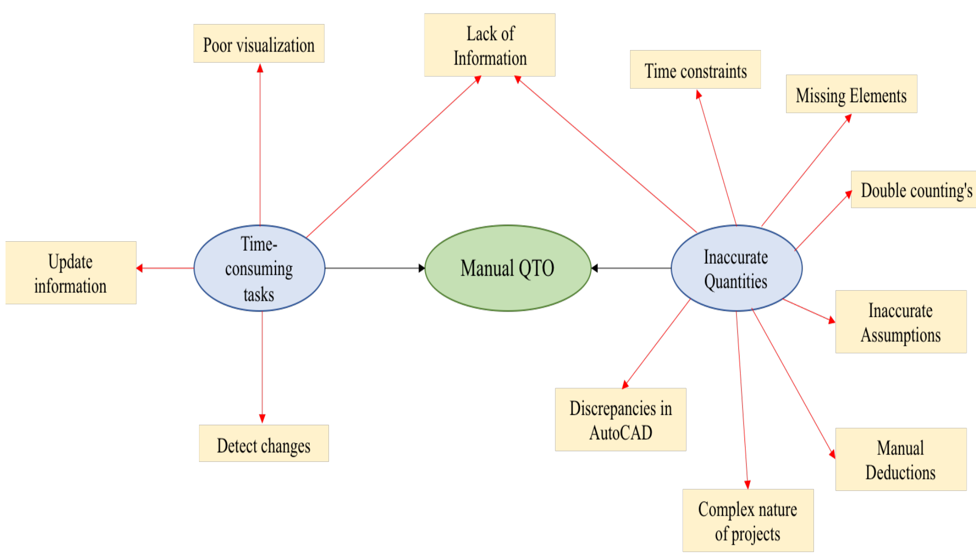


Figure 6.7: Cognitive mapping of manual QTO and reasons

6.3.8 Time Constraints

According to respondents the limited given time to prepare cost estimates also results in the preparation of inaccurate cost estimates (see Figure 6.1). Many clients and designers expect QS to complete the entire cost estimate within a shorter period. Therefore, respondents have identified that limited time is one of the major factors to affect the accuracy of cost estimates. Accordingly, respondents further stated the reasons behind time constraints.

6.3.8.1 Client Pressure

In most cases, the client has provided limited time for the QS to prepare cost estimates and this adds more pressure to the QS during the preparation of cost estimates. According to CSA01 "*...there's more tendency to make errors during manual QTO, due to substantial QS pressure*". As a result, in most cases, estimates do not provide accurate cost predictions. Respondents further identified that double counts and missing elements are inevitable due to increased QS pressure. Moreover, respondents also complained that clients and designers take plenty of time to undertake the design but expect the QS to complete the most important part, which is the cost estimate, within two or three days. For example, CSB02 stated "*, last two days we've submitted a BOQ, and it was a crucial one. they took almost five months to develop the design and gave us only one month to prepare the estimates".* This indicates that clients do not have any concern about the importance of preparing accurate cost estimates but only the cost of the project.

6.3.8.2 Time-Consuming Tasks

Time-consuming tasks, which are discussed under section 6.3.6.1, were also found to be another reason for time constraints. Accordingly, MQTO, drawing updates, and obtaining information requires extra time for the QS to prepare cost estimates. Moreover, it is essential to conduct site visits before preparing cost estimates in order to identify any restraints, site access, and ground condition. However, many respondents believed that site visits are time-consuming within the time available to them. As a result, many respondents stated that they are unable to conduct proper site investigations due to time limitations. As stated by CSA01 "*… failing to identify site conditions, the estimate gets inaccurate due to missing or extra elements being added*". For example, CSB02 stated*, "if the roads are too narrow, it's no point of adding pump cars within the estimate*". Therefore, even though many respondents agreed that site visits are important before preparing cost estimates, the limited time given prevents them from undertaking such investigations.

Therefore, responses indicated that time constraints are another factor that affects the accuracy of pre-tender cost estimates due to client pressure and time-consuming tasks. Accordingly, Figure 6.8 illustrates the cognitive mapping of time constraints and their reasons.

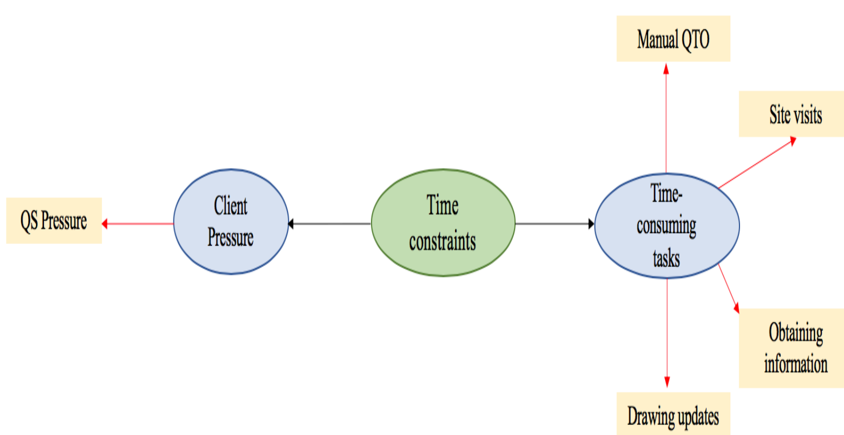


Figure 6.8: Cognitive mapping of time-constraints and reasons

According to the above analysis, the findings indicated seven significant factors that affect the accuracy of pre-tender cost estimates. The use of 2D drawings, lack of information, inefficiencies in current software, inadequate estimator knowledge and skills, isolated working culture, Manual Quantity Take-off (MQTO) and time constraints were the main factors affecting to the accuracy of pre-tender cost estimates. Moreover, these findings helped to identify the reasons behind each factor. The next section will demonstrate the findings related to the analysis unit of BIM drivers.

6.4 Findings from the Interviews Related to BIM Adoption Drivers

6.4.1 Introduction

This section presents the themes and sub-themes related to BIM drivers were extracted from nine in-depth face-to-face semi-structured interviews. The interviews were conducted with nine experts who are or have adopted BIM within their firms (see section 4.8 in chapter 4). The data were analysed using thematic analysis (see section 4.10 in chapter 4) and six main themes alongside sub-themes were extracted from the data. These themes and sub-themes are presented in (Table 6.3).

Table 6.3 Themes and sub-themes extracted from the interviews related to the BIM drivers

Drivers for BIM adoption	
Themes	**Sub – Theme 1**
1. BIM Benefits	1.1. Use of BIM model 1.2. Automate Quantity take-off 1.3. Information Management 1.4. Improved visualization 1.5. Clash detection
2. Client Demand	
3. Professional Bodies	
4. Organizational Pressure	
5. BIM Education	
6.BIM Trainings	

According to Table 6.3, different themes were extracted from the data collected from the semi-structured interviews. Underneath these themes, different sets of sub-themes were identified. Moreover, Figure 6.9 illustrates the cognitive mapping of the main drivers including their subfactors.

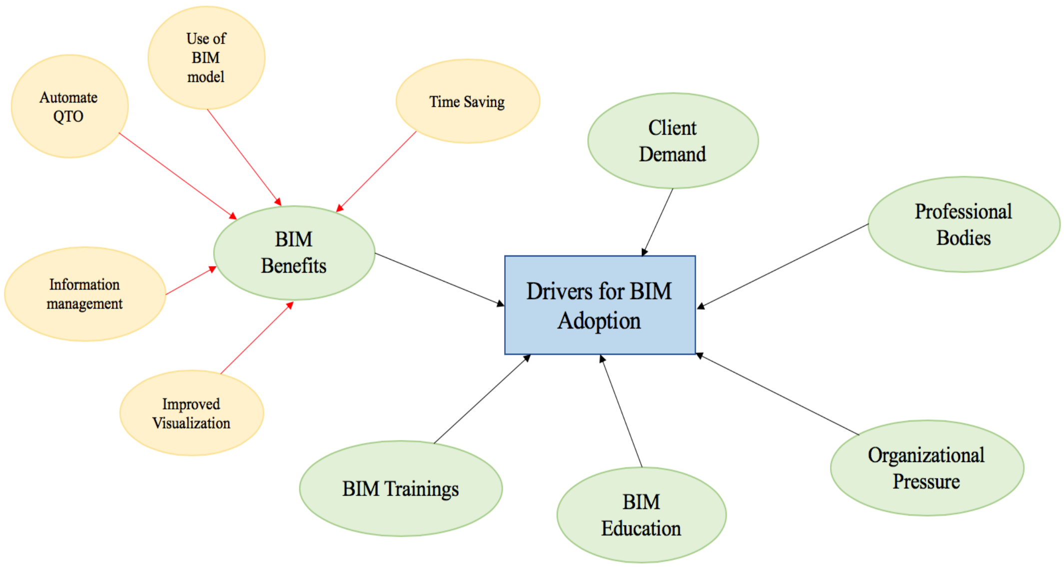


Figure 6.9: Cognitive mapping of BIM drivers for BIM adoption in Sri Lankan QS organisations

In the following sections, the themes, and sub-themes will be presented alongside quotations extracted from interviews. It is important to note that the given codes (see Table 6.1) refer to the case study interview from which the evidence was extracted thus indicating from the interviews from which a quotation was taken. For instance, if a quotation was extracted from case A and interview 01 then the presentation in the text will be such: "the quotation"(CSA01).

6.4.2 BIM Benefits

Many respondents indicated that the benefits of BIM accelerate the adoption of BIM within their organisations. Moreover, these benefits help them to overcome most of the difficulties they face during conventional practice. Accordingly, respondents stated that Automated QTO (AQTO) is the main benefit they gain by using BIM. In CSA02's words, "*AQTO does accurate measurements without spending time for manual calculations*". This indicates that AQTO saves plenty of QS time, which used to be spent on manual QTO. However, respondents also noted that accurate measurement can only be expected with the use of accurate BIM models. CSA01 endorsed this by stating "a *model with inaccurate information is like rubbish in rubbish out".* Whereas, a QS has to rely on their assumptions; for example, CSB02 stated, "*If we click one of the elements in the model if it not defined properly (for example 200mm thick) again you have to do many assumptions or to go back to the design team*". Therefore, the accuracy of the model is important for accurate measurement. With an accurate model, respondents emphasised that they could increase the accuracy of measurements as there is a lower tendency to miss elements in AQTO. CSC02 endorsed this by stating "*…it's easy to export it wherever you want, whatever the measurement you are giving or taking from it, automatically calculate and inbuilt into your software, so you won't miss any elements*"; as a result, a QS is able to get rid of the most time-consuming task in the entire cost estimation process, namely the MQTO. Moreover, CSB01, CSA02 and CSC03 offered similar views that also supported this.

According to respondents, a major difference compared to conventional practice is the use of models instead of 2D drawings in BIM-based cost estimation. The use of a BIM model provides better visualisation; indeed, respondents identified improved visualisation as another benefit offered by BIM. According to CSA01 "*Estimators can get a clear picture about the end product, as the use of the model* *has improved the visualization of elements*". The views of CSB04 also reflected this comment. Therefore, the QS does not need to put extra effort into visualising the final product or to depend on their imagination as before. Moreover, respondents also noted that improved visualisation increased the accuracy of measurements, as the QS can filter elements in the model. As stated by CSB01"*The improved visualization enhanced QS's take accurate measurements without any missing elements or double counting".* As a result, the overall accuracy of the cost estimate ultimately increases, whilst CSA02 and CSC02 also offered similar views.

According to the respondents, better information management is another BIM benefit that drives adoption. Respondents claimed that, with the use of BIM, they are able to maintain a proper database that consists of a large amount of data. According to CSB01, the "BIM *model allows us to easily grab any information given, at any stage of the project".* As a result, they can produce accurate cost estimates with the use of accurate information. Therefore, the use of a BIM model has improved the management of information as the model is integrated with necessary data, which means the QS does not have to trace back to the architects whenever they require any data. Besides, along with improved information management, they are able to minimize the use of paper documents for sharing information, especially with their foreign clients. For example, CSB03 stated, "*once we were having meetings, I observed that the many parties having separate documents sets such as drawings, specification, etc. Thus, now we are mainly relying on one resource which is the model".* Therefore, the responses indicated that they tend to share information electronically instead of by paper.

Another BIM benefit pointed out by respondents is time-saving. Accordingly, respondents identified that the ability to track changes in the model is one way of saving time, which used to be a very time-consuming task. CSA01 endorsed this by stating "*by comparing models the recent changes made to model can be easily identified*". Agreeing with this statement, CSC03 stated that, "*the use of 3D model automatically updates all the changes made to model as well as in the estimate".* As a result, the QS does not need to spend extra time identifying the changes and incorporating them in the estimate. Besides, respondents also noted that AQTO (as discussed above) is another way of saving time. For example, CSA02 stated, "*previously when we did the take-off, normally we give those measurements to be checked by someone else (arithmetic check)*". With the use of BIM, there is no need for someone else to check the quantities, which reduce both the time and resources required for one job. As a result, respondents noted that they were able to increase their overall productivity at the same time. Moreover, according to CSA01 and CSB02, the ability to detect clashes at the early stages has also resulted in time savings by reducing the need for changes and revisions. CSB02 endorsed this by stating *"... the use of model also enhanced to identify any clashes at the first stage of the project, which reduces the future changes and revisions by saving QS's time*". Therefore, based on the findings it can be concluded that the benefits of BIM represent a key driver for Sri Lankan QS organisations to adopt BIM.

6.4.3 BIM Training

As part of BIM adoption, organisations have organised training for employees related to BIM and its uses increase awareness of both its theoretical and practical uses. Therefore, respondents pointed out that training provided by the organisation is another driver to adopt BIM. CSB01 endorsed this by stating "*we had different pieces of training before we start using BIM and after we started using BIM*". Accordingly, organisations have used their senior professionals to train employees using tutorials and CPD. However, according to CSA02 "*…. a few months later experts came from Indonesia to train ourselves, by [that] time our people were more familiar with BIM use*". According to respondents, the training received by their clients also helped them to adopt BIM. In the meantime, some companies have used their strategies to train employees. For example, CSA01 said, "*I did a small kind of strategy by forming a small group of seniors and I've given them a task to study certain areas of costs for each* *individual and to do a presentation about their findings, and it worked very well*". Accordingly, training has been provided continuously throughout the BIM adoption process. As stated by CSB02 "*we have continuous training also when someone joining the company, we do a dedicated session for him/her*". Therefore, respondents also indicated that continuous training provided by organisations accelerate BIM adoption within their working places. Therefore, according to the findings, training represents another driver for BIM adoption.

6.4.4 Client Demand

Client demand is as another driver for BIM adoption. According to respondents, many organisations have adopted BIM due to demand from their foreign clients. The use of BIM is one of the main requirements of our foreign clients. CSA01 said, "…. *even though we don't get any BIM demand from the local industry, we do get demand for BIM foreign clients regularly*". This statement further reflects a lack of demand from local industry. However, according to respondents, many firms adopt BIM due to client demand, as they do not want to lose foreign contracts. Therefore, client demand is another driver for BIM adoption.

6.4.5 BIM-Based Education

Responses further indicate that BIM education is another driver to adopt BIM. Accordingly, some private sector institutions have started BIM-related courses. However, according to CSB01 "…*when it comes to private universities, they do provide just a BIM introduction, which is not enough to adopt BIM*". Moreover, the statement further indicates that government universities still lag behind in BIM education. In the meantime, many respondents believe that they require the practical use of BIM alongside theoretical knowledge, which is currently lacking in Sri Lanka. However, respondents indicated that seminars, CPD, and workshops conducted around the Colombo area have been beneficial in the adoption of BIM. Nevertheless, CSB01 and CSA01 complained that these BIM programs are still limited to Colombo, at a time where it needed island-wide. Therefore, CSB01 believes that "…*it is high time to introduce BIM to SL industry island wide*".

6.4.6 Professional Bodies

Responses also revealed that support received from professional bodies also helped them to deliver BIM within their practice. Accordingly, professional bodies have organised workshops, conferences, and CPD to increase BIM awareness. Respondents claimed that the efforts of professional bodies have increased BIM awareness, which has helped them, especially amongst professionals who are novices to BIM. Nevertheless, as stated by CSB01, "…*professional bodies are doing something, but it does not enough to implement BIM within the Sri Lankan context*", which indicates the industry is expecting more effort from professional bodies. According to CSA03, "*First professional bodies and universities should get together, and make standards, for BIM*". This indicates that there is poor linkage among universities and professional bodies and a lack of BIM standards within the industry. However, respondents noted that the University of Moratuwa has established a BIM group to promote BIM within Sri Lanka. However, respondents complained that most of the workshops are limited to the Colombo area. As CSC02 stated, "*They should organise seminars, CPDs, conferences, and workshops not only in Colombo but also island-wide, as many industry practitioners have traveling problems*". Therefore, findings indicate that professional bodies are another driver for BIM adoption, thus their efforts need to be extended.

6.4.7 Organisational Pressure

As mentioned in section 6.4.3, many organisations have started using BIM due to the demand they received from their foreign clients. As a result, many QS organisations have pressured their internal staff to use BIM. CSA01 endorsed this by stating "*Yes, we already implemented BIM in our firm since May 2017. We have mandated BIM within our organisation, we do cost estimation using BIM tools as per the client's request".* According to respondents, top management was noted as the most influential factor for their adoption of BIM. CSB01 expressed, *"our top management wants us to incorporate BIM, so as a result, we all have to learn more about BIM to make it happen".* Accordingly, top management has introduced strategies to implement BIM within their organisations. Respondents noted these were helpful for their BIM adoption journey. As stated by CSC01 "*As it ultimately creates BIM friendly environment, we didn't have no reasons to say no to BIM*". Moreover, as discussed under section 6.4.2, organisations have also organised continuous training sessions for employees to increase both their theoretical and practical knowledge. Therefore, respondents found that organisational pressure is another driver for their adoption of BIM.

According to the above analysis, the findings indicated six significant drivers that accelerate BIM adoption. BIM benefits, BIM training, client demand, BIM-Based education, professional bodies, and organisational pressure were found to be the main findings under the analysis unit of the BIM drivers. Moreover, findings have also helped to identify the reasons behind each factor. The next section will demonstrate the findings related to the analysis unit of BIM barriers and mitigating actions.

6.5 Interviews Findings Related to the BIM Adoption Barriers and Mitigating Actions

This section presents the themes and sub-themes related to BIM barriers were extracted from the nine in-depth, face-to-face semi-structured interviews (see Table 6.1). The interviews were conducted with nine experts who are adopting BIM within their firms (see section 4.8 in Chapter 4). The data were analysed using thematic analysis (see section 4.10 in chapter 4) and six main themes alongside sub-themes were extracted from the data. These themes and sub-themes are presented in Table 6.4.

Table 6.4: Themes and sub-themes concerning BIM barriers as extracted from the interviews

Barriers to BIM adoption	
Themes	**Sub – Theme 1**
1. Financial barriers	1.1. Cost of hardware and software 1.2. Upgrading costs 1.3. Training costs 1.4. Lack of goals
2. Organisational barriers	1.1. Lack of goals and processes 1.2. Isolated working culture 1.3. People mindset 1.4. Reluctant to change 1.5. Fear of sharing responsibilities
3. Regulatory barriers	1.1. Contractual Issues 1.2. Lack of policies 1.3. Lack of ethical behaviors 1.4. Legal Issues
4. Unawareness	1.1. Lack of BIM education 1.2. Absence of BIM initiator 1.3. Gap between industry and the academia 1.4. Knowledge sharing
5. Lack of Resources	1.1. Lack of trainings 1.2. Absence of BIM implementation plan 1.3. Limited number of software licences 1.4. Limited internet facilities 1.5. Lack of BIM experts 1.6. Lack of BIM models
6.Lack of BIM demand	1.1. Lack of government intervention 1.2. Lack of client demand 1.3. Unbalance BIM adoption 1.4. Scalability

According to Table 6.4, different themes were extracted from the data collected from the semi-structured interviews. Underneath the themes, different sets of sub-themes were identified. Moreover, Figure 6.10 illustrates the cognitive mapping of the main barriers including their subfactors.

In the following sections, the themes and sub-themes will be presented alongside the quotations extracted from the interviews. It is important to mention that the given codes (see Table 6.1) refer to the case study interview from which the evidence was extracted, thus indicating from which interviews the quotation was taken from. For instance, if a quotation was extracted from case A and interview 01 then the presentation in the text will be: "*quotation*" (CSA01).

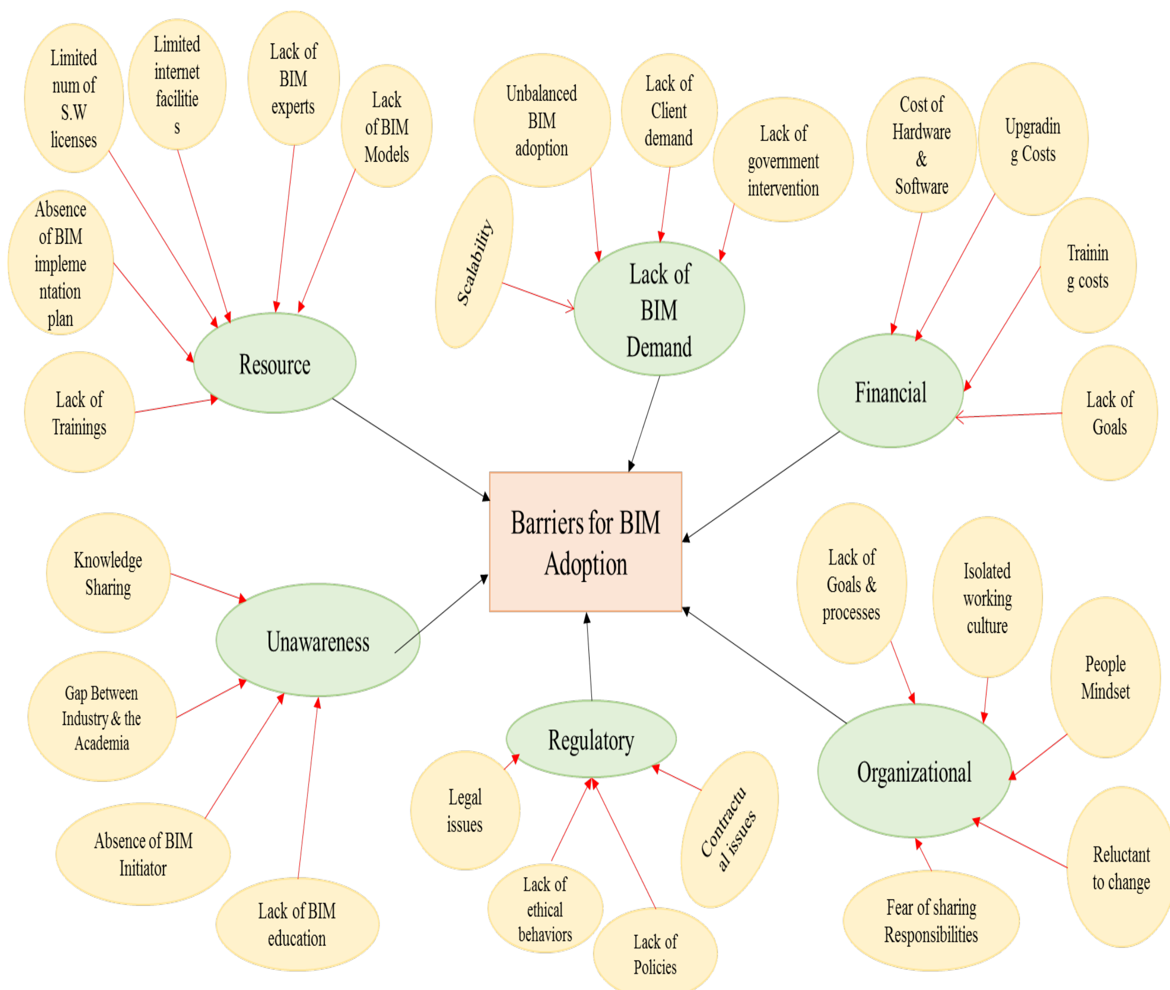


Figure 6.10: Cognitive mapping of the BIM adoption barriers of quantity surveying organisations in Sri Lanka

6.5.1 Financial Barriers

One of the most commonly stated barriers by respondents was the financial barrier. Even though many parties want to adopt BIM, high investment costs have hindered its adoption. However, according to CSA03 and CSC02 it is not just a waste but a long-term investment. According to CSB02, "*As it is expensive, I don't think individual practitioners can afford for it*", which indicates that BIM adoption would be limited to large-scale organisations but not for small or medium scale businesses due to the high cost. CSA01 endorsed this by stating "…. *Of course, it's expensive, but for large scale companies* *like us the cost is affordable, the company is willing to invest money because we've proved that the use of BIM is very productive, especially when we have tight schedules*". Supporting this, CSA02 and CSB02, also expressed similar thoughts. Therefore, it is fair to assume that large-scale QS organisations are willing to invest money to adopt BIM within their organisations. However, the responses indicate that, even for large-scale organisations, it is too expensive to bear due to various reasons.

6.5.1.1 Cost of Hardware and Software

Respondents identified that the purchase of new hardware and software is too expensive for organisations to bear. Accordingly, organisations have to purchase new hardware, software, and software licenses. However, CSA03, CSA01, and CSA02 complained that they were only able to get six software licenses due to the high cost, although they employ more than 30 people. Moreover, respondents also revealed that, due to the current situation in the construction industry, many organisations try to increase their profit margins by cutting down on unnecessary expenses. CSB02 said, "*So for them dumping money into additional SW is a question due to the low profit they are getting if the cost of BIM considerably has to come down, otherwise it's hard to afford*". This could result in low productivity, as many people cannot work on a BIM platform. Respondents further indicate that the lack demand for BIM by the industry has also resulted in organisations not investing in BIM. CSB01 endorsed this by stating "*At this moment if the BIM models getting more demand, we can spend money to get the software's*". Nevertheless, CSB03 had a different perception of this. He said, "my *perception is you don't need fancy software, just download the drawings on google drive, that is something lacking within the Sri Lankan professionals".* However, the majority of respondents indicated the cost of hardware and software results in a financial barrier.

6.5.1.2 Training Costs

Training costs were found to be another reason behind the financial barrier. Many respondents indicated that the costs too high to provide training for existing staff. It was also emphasised that some organisations lag behind on investing in training for people due to high labour turnover. CSA03 endorsed this by stating "*…. once we trained a person, there are many companies to recruit them*". Therefore, CSA01 believed that early BIM adopters have to make many sacrifices for BIM adoption. However, some organisations had to hire foreign BIM experts to train their local staff when they were introducing BIM-based software, e.g. CostX, which is very expensive. However, respondents suggested that collaborative training would minimize the training cost for organisations. For example, CSA01 stated that "*We had special discussions with designers, as a result, we had a lot of training on BIM use, for project XX. We got some suppliers to do some presentations on how to perform measurement work on a live model. So, we trained for uploading a drawing, making the dimension group, take-off, how the measurements are stored, to prepare a spreadsheet, and how to take final output*". Which costs them less than hiring experts. However, respondents indicated that training cost as another reason for the financial barrier.

6.5.1.3 Software and Hardware Upgrading Costs

Respondents also stated that the upgrade of licenses is another associated cost of BIM. Accordingly, many software packages require annual upgrades, which costs a lot. According to CSA01 "*once you entered a maintenance agreement you have to pay it annually*". Then, only software performance updates are required; moreover, without such updates, it is difficult to expect the maximum outcome. Therefore, respondents noted that, in most cases, organisations have to bear the annual upgrade costs of software and hardware as part of their BIM adoption.

Moreover, respondents also identified a lack of goals as another reason for the financial barrier, which is discussed under section 6.5.2.5. Therefore, findings indicated that finance is a barrier that affects the adoption of BIM due to its associated costs, such as hardware and software, training costs, upgrading costs, and a lack of goals and processes. Accordingly, Figure 6.11 illustrates the cognitive mapping of the financial barrier and its reasons.

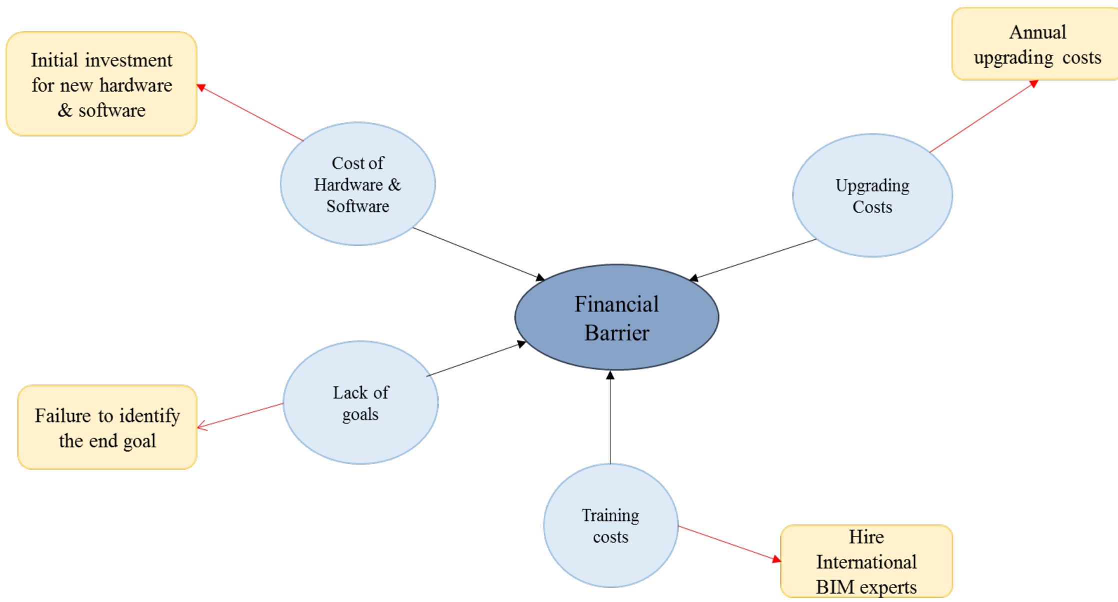


Figure 6.11: Cognitive mapping of the financial barrier and reasons

6.5.2 Organisational Barriers

Respondents also identified organisational barriers as another key deterrent to the adoption of BIM. As a result, only a few organisations have adopted BIM, but the majority have not. Respondents further indicate several reasons why organisations have not adopted BIM.

6.5.2.1 Isolated Working Culture

Accordingly, respondents indicated that the isolated working culture of the Sri Lankan construction industry prevents organisations from adopting BIM. Many practitioners work as individuals or as freelancers rather than for an organisation. According to CSA01 "*…they always try to work isolate, especially designers*". As a result, many professionals do not intend to share anything with other parties, which means a lack of transparency. Moreover, CSB03, CSA01, CSA02, CSA04, and CSB01 identified that the Sri Lankan construction industry is an architecture driven industry, and that architects do not want to be challenged by any other party due to their ego. Therefore, many professionals tend to work alone rather than collaboratively. However, the main rationale for BIM-based practice is true collaboration or working on the same platform, which includes architects, engineers, contractors, QS, and so forth. CSB02 endorsed this by stating "*As QS's we have to filter other mistakes, loopholes, discrepancies, so it takes a long time. These things would not happen if we can work on the same platform*". Thus, according to CSA03, CSB03 collaboration is still impossible due to freelance professionals. Respondents further emphasised that, even though - to some extent - collaboration could be seen in private sector organisations, it is still not a part of the culture of government sector organisations. Accordingly, CSA03 believed that "*Sri Lanka can change to BIM-based practice if the phycology and mentality of employees changed positively*". Therefore, CSA03 suggested that training university students and professionals on the industry on an ad hoc basis could overcome this. This indicates that such awareness should start at the university level before graduates step into the industry.

Another reason for isolated working culture as stated by respondents is an economic crisis. As part of a developing country in construction, Sri Lankan clients are more concerned with the economic aspect than the size of the project. CSA02 endorsed this by stating "*…. if I'm the client my aim to get the job done at the lowest cost".* As a result, many clients hire freelance professionals rather than employing a larger organisation. Therefore, respondents noted that many professionals work as freelancers to provide services at a low cost. Moreover, respondents further emphasised that individual working practices could earn a lot compared to levels experienced by organisations. Therefore, the economic crisis is another reason for the isolated working culture in the Sri Lankan construction industry. Therefore, based on the findings it can be assumed that isolated working culture is one of the reasons for the organisational barrier, as it has meant that collaboration between industry participants is hidden.

6.5.2.2 Fear of Sharing Responsibilities

The fear of sharing responsibilities was found to be another reason for the organisational barrier. Many employees refused to share responsibilities with their colleagues. According to CSB02 "…. *the core of the BIM is a collaboration, thus until people understand that we need to work as a team through shared responsibilities it's hard to adopt true BIM".* Respondents further noted that sharing responsibilities is another way of improving communication and coordination among project team members. However, respondents emphasised that people's mindsets have hindered the sharing of responsibilities. Thus, true collaboration is fundamental to work in a BIM environment. For example, CSB03 stated "…. *the current project we are dealing with architects are quick drawings all the mark-ups and changes, and they email them to India as soon after the meeting finished. The changes are made in India on the model and that will be emailed by the next morning*". This indicates true collaboration through shared responsibilities, while improving overall productivity at the same time. However, respondents identified that the fear of sharing responsibilities amongst employees has meant that some organisations have not transitioned to a BIM-based environment.

6.5.2.3 People's Mind-Sets

People's mindsets represent another reason for the organisational barrier. Managers indicated that many employees do not welcome any change, especially amongst senior-level employees who do not want to change traditional working practices. CSB01 endorsed this by stating, "*Many traditional QS's prefer to deal with standard TDS sheets and take-off".* However, responses also revealed that younger generations are more welcoming of industry changes. CSB01, CSA02, and CSB03 noted that new graduates prefer an easier way of working rather than sticking into conventional systems. As CSA02 stated, "*…...younger generation is very much into IT rather than senior professionals in the industry. So, they will very easily grab the change*". Nevertheless, according to some respondents, getting used to a new technology can be disastrous, as they believe once they get used to it, they would not perform traditional cost estimating or measurements if needed. Accordingly, CSB02 complained, "*most of the fresh graduates are used to electronic measurement methods because it's faster and more accurate, and they are trying to depend solely on a software"*. This indicates that getting used to new technologies hides the QS's capabilities to conduct manual take-off. Therefore, it is clear that the blend of both manual and automated ways of conducting quantities is important for a QS, particularly as the construction industry has not fully adopted BIM.

6.5.2.4 Reluctance to Change

Employees who are reluctant to change were found to be another reason for the organisational barrier. Many employees do not need any change in their day-to-day working practices. As CSA02 states, "*Sometimes people say I'm familiar with AutoCAD, so we don't want anything else*". Besides, some organisations are willing to adopt BIM-based practices; hence, the majority of the industry remains wedded to traditional practices, which means it is hard to implement BIM even within their organisations. For example, CSA04 stated "*.... we have some problems, especially with the government sector, as they still dominate with traditional practice. They don't want to update with new technology*". As a result, private sector organisations still lag behind in terms of BIM adoption, as they do not want to undertake two practices (conventional and BIM) at the same time. Respondents also noted that many employees do not want any change, as they believe that the adoption of BIM will mean they lose their job, which indicates a lack of BIM knowledge. Moreover, some do not want to change because they believe it is hard for them to learn, especially amongst senior-level professionals. CSB03 endorsed this by stating "*.... some people think the use of BIM is a big shift and a big change*". However, CSA01, CSC02 noted that the transformation to BIM is an enhancement to their role even though there are some slight changes in their working practice. Therefore, CSB03 suggested that "*you have to look at the use of BIM as an enhancement, if not you going to be stuck on Oh my god there's a lot of work to do*".

Besides, the responses further identified that employees refused to change due to selfishness and lack of trust, especially amongst seniors in the industry who do not want to share any information with other parties. Moreover, difficulties in using English were found to represent another reason for this reluctance to change. CSB03 endorsed this by stating "*I also think language is a barrier because all these things are developed in English; it caters more towards English speaking group and economies, but how does it transform to other languages?"* Amongst the majority of Sri Lankans, Sinhalese is their native language, meaning that BIM could be hard to deal with in a foreign language for some professionals. However, according to CSB02 "*I don't think there are any language barriers, as many of our employees can pick [up] anything very fast*". This is particularly the case for the younger generation as they are fluent in English; nevertheless, it could be more difficult for most senior professionals in the industry as they may not be as fluent in English. Nevertheless, CSA01, CSA02, and CSA03 emphasised that within their organisations they did not encounter any resistance to BIM, which they attributed to the existing culture of their organisations. CSA03 endorsed this by stating "*Our company maintains the very innovative culture, as a result, everyone wants to learn BIM. If someone learns something it'll be shared with everyone*". This indicates that organisational culture has a strong influence on an employee's phycology. Therefore, CSA01 suggested that the establishment of continuing innovative cultural environments helps to positively change the phycology of people, which makes the process of BIM adoption easy.

6.5.2.5 Lack of Defined Goals and Processes

The interview results show that the lack of defined goals and processes represent another reason for the organisational barrier. Respondents indicated that many organisations do not have proper goals concerning what to achieve through BIM. CSA01 endorsed this by stating "*if I'm to implement BIM within my organisation, my first step would be to identify the goals",* which is lacking at the moment. For example, CSC03 stated, "*If I need [to] start working on improving the accuracy of cost estimates or reducing my cost of construction or increasing profit, those should become my end goals*". This indicates it is important to know exactly what organisations want to fulfil through adopting BIM. Moreover, respondents also indicated that many organisations do not have proper processes to achieve their end goals. Therefore, CSB03 suggested that it important for organisations to identify appropriate processes to achieve BIM-related end goals. Moreover, according to respondents, having identified goals and processes will reduce the size of the investment. According to CSB03, "*…. this is going to be a solution for all the companies as a way of overcoming financial barriers*". Thus, defined goals help to identify exactly what BIM-related tools are requires and what technologies can help to improve workflow/goals. According to Sureman (2009) "*BIM is essentially like the survival of the fitters. Many* *numbers of years down the road people who use BIM and utilized BIM appropriately will sustain in the industry, those who want will fade off*". This indicates the adoption of BIM is possible for any organisation with carefully defined goals and processes. Accordingly, CSB03 suggested, "*we don't need fully BIM to be implemented, the understanding what BIM is and trying to improvise some of these processes and goals would lead the BIM adoption*", which indicates the importance of identifying the goals and process for organisations to enable better BIM adoption.

Therefore, the findings indicated that the organisation is another barrier to affect BIM adoption, and this is due to isolated working culture, fear of sharing responsibilities, reluctance to change, and a lack of defined goals and processes. Accordingly, Figure 6.12 illustrates the cognitive mapping of organisational barriers and their reasons.

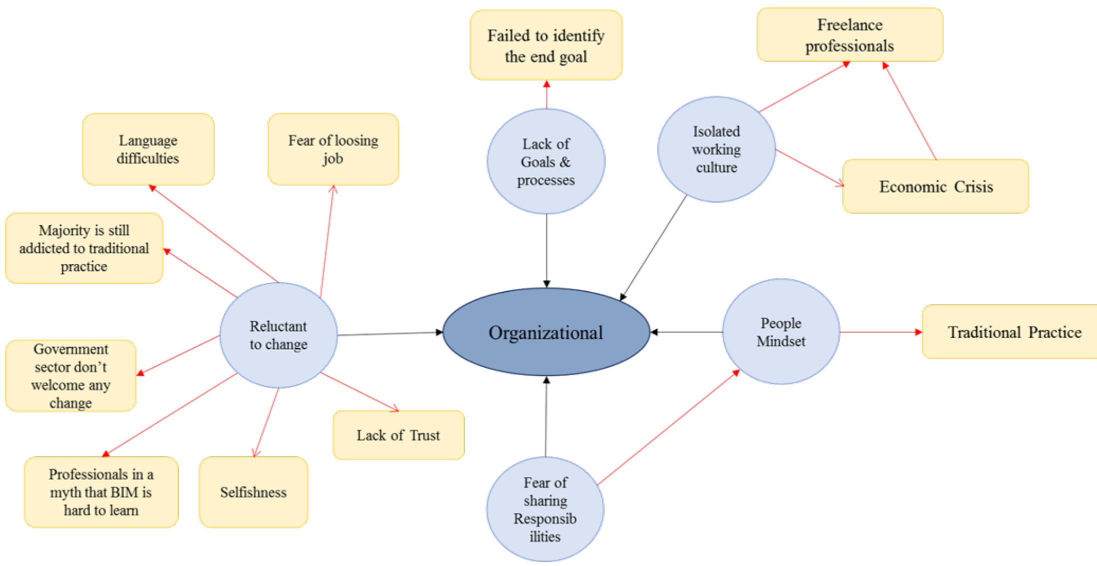


Figure 6.12: Cognitive mapping of organisational barrier and reasons

6.5.3 Regulatory Barriers

According to respondents, regulations were found to be another barrier to BIM adoption (see Figure 6.10). Accordingly, respondents identified several reasons which result in a regulatory barrier.

6.5.3.1 Legal Issues

Accordingly, legal issues were found to be the main reason for the regulatory barrier. Respondents revealed that the ownership of the model is the most significant legal issue for BIM adoption. CSB03 endorsed this by stating "*There are significant legal barriers in terms of who owns the models, as a result, that has created some challenges in a legal context, stakeholders are like who owns the model, who's the fault is that, who should take the responsibility if something goes wrong, etc*." This is not just affected by the Sri Lankan context, but the failure to define ownership of the model is recognised as a worldwide issue. Therefore, respondents believed that anyone could change the model at any time through cyber-crimes, which is highly risky. As a solution CSA03 suggested that, "*... in lump sum contract[s], [a] BIM model should freeze*". Hence, attention should be given to all types of contract, most importantly by defining the ownership of the model. Furthermore, the undefined responsibilities of the model were found to represent another legal issue that prevents a teamwork mindset amongst employees. Therefore, CSC01 suggested that, "*That is something as an industry we have to get over, we have to bring the employees mind-setters we all are working here as a team, so everyone is* *responsible for the work they do".* Without that mindset, it is more challenging to move BIM adoption forward.

6.5.3.2 Contractual Issues

Contractual issues were identified as another reason behind the regulatory barrier. Different countries use different forms of contracts; for example, in Sri Lanka SMM7 is used. Respondents complained that many BIM-based tools and software are created based on UK and USA construction contract forms, which means it is not capable of handling any other contractual forms. CSB03 endorsed this by stating "*….in SL context, all those Revit families and tools we are using to design or to model the building, doesn't accurately reflect with Sri Lankan standard contracts*". Therefore, respondents indicated the importance of developing BIM-based software following Sri Lankan contract forms. In CSB01 words "*if the BIM tools or software can integrate with SMM7, ... BIM adoption will be more accelerated among Sri Lankan practitioners*". CSA04 and CSA03 also offered similar comments to CSB01.

Respondents identified the absence of BIM-based contracts was another reason for contractual issues. Accordingly, many respondents noted that existing contracts do not cater to BIM requirements. As stated by CSA03, "*When we do taking-off on a BIM model we realized there are gaps, such as we don't have any BIM manager, as it's not stated in the contract to recruit a BIM manager*". This indicates the need at least to realign existing contracts following BIM. However, from a different perspective, CSA01 argued that, "*If you know your method of measurement, SW will give you quantities, and you can create your estimate aligned with your given standards. So, there's no need for realignment of standards*". Similarly, CSB02 stated "*Even if you are going to use BIM for the entire project process there no need for realigning. Because of the UK, Australia, and Canada, they have different standards. So, I don't think that the manufacturers will cater to all methods of measurements*". It should be noted that interviewees who believe that BIM is just a tool offered these responses. However, many industry experts define BIM as a process. Moreover, the use of internationally developed common contracts is fundamental. As a result, many professional bodies have introduced BIM friendly contracts, such as RICS which has introduced the International Construction Measurement Standards Coalition (ICMSC) for quantity surveyors and cost consultants to deliver cost estimates and financial reports in line with BIM (RICS, 2019).

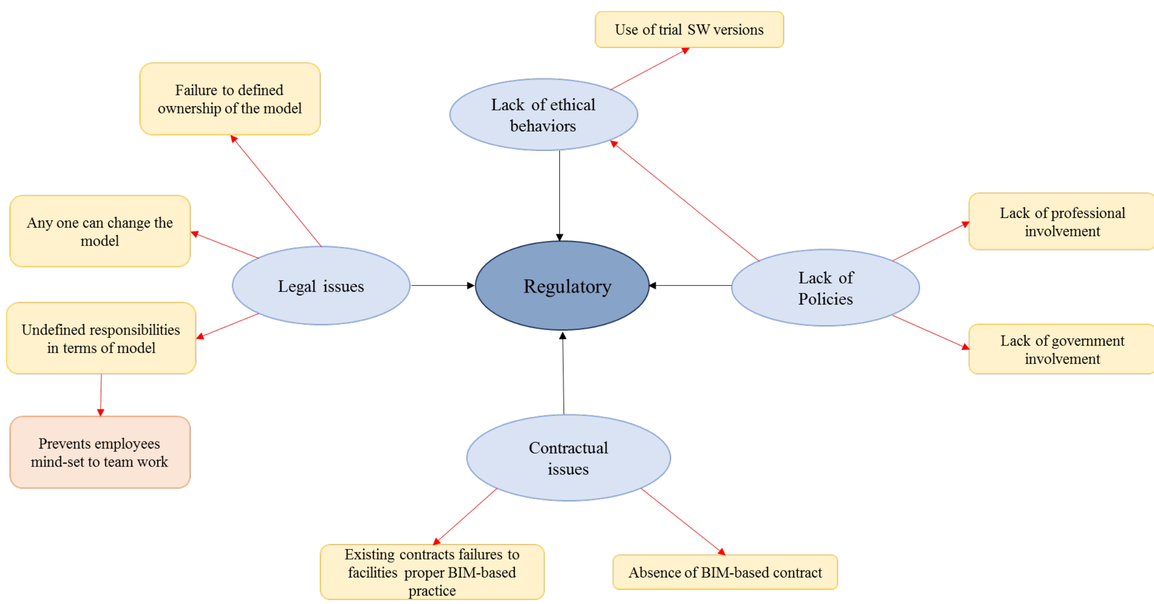
6.5.3.3 Lack of Policies

Respondents also indicated that the lack of policies form another reason for the regulatory barrier. According to respondents within the Sri Lankan construction sector, supportive, well-defined policies are lacking. According to CSA01 "*professional bodies and [the] government have to take lots of initiatives, especially for defining relevant policies*". This indicates the lack of professional government involvement in BIM adoption. However, many respondents believe that a properly defined set of policies would accelerate BIM adoption. As CSB03 states, "*It is one aspect that helps BIM adoption through defined policies such as mandates*". Respondents also emphasised not just the policies, but also that enforcement is essential to implement such policies. Accordingly, CSA02 endorsed this by stating, "*…. empty policies don't make any sense unless there's no empowerment to implement them*". Therefore, CSB02 suggested the consideration of issues and repercussions when developing policies, as they see policies as a strong BIM driver for the Sri Lankan construction sector.

6.5.3.4 Lack of Ethical Behaviours

The lack of ethical behaviours also highlighted another reason for the regulatory barrier. Respondents indicated that the use of trial software versions has resulted in a lack of ethics within the industry/ organisations. According to CSA03, "*In Sri Lanka, only a few companies are using licensed original software, but the majority of them are using trial versions*". This also could be attributed to a lack of financial resource. However, as BIM-based tools are not available in trial versions, organisations have to purchase original versions. However, respondents complained that the use of trial versions is unfair for companies who have purchased the originals. Therefore, CSB01 stated, "*…certain standards and guidelines should be introduced for organisations and individuals to use authorised BIM tools and software*". This also indicates that the lack of policies has also resulted in a lack of ethics within practice. Therefore, the findings indicated that regulations are another barrier that affects BIM adoption due to legal issues, contractual issues, a lack of policies, and a lack of ethical behaviour. Accordingly, Figure 6.13 illustrates the cognitive mapping of the regulatory barrier and its reasons.

Figure 6.13: Cognitive mapping of the regulatory barrier and reasons



6.5.4 Unawareness

Unawareness is another barrier noted by respondents. Accordingly, CSB03 said, "*At the moment BIM is in a very immature stage, little to non-existence within the Sri Lankan construction industry*". Similarly, CSA01 added that, "*many professionals have a fair knowledge about BIM, and it's not enough to implement BIM*". Supporting this, CSB02 stated that "*Many of the employees are having theoretical awareness, but they don't have the practical aspect of BIM*". Supporting this statement CSA01, CSB01 and CSA03 expressed similar thoughts. These statements indicated that BIM awareness among construction professionals is at a lower level and is limited only to the theoretical aspects of BIM but not the practical side. However, respondents indicated several reasons which have resulted in unawareness.

6.5.4.1 Lack of Knowledge Sharing

The interview findings revealed that loopholes in knowledge sharing between professionals and young professionals in the industry have resulted in BIM unawareness. CSB03 endorsed this by stating "*...in SL for some reason, many senior professionals hide everything only for themselves. There's is no spreading teaching from senior professionals to young professionals*". Agreeing to this CSB04 said: "*People are selfish, they don't want to share their knowledge with others*". This shows discrepancies in a working culture that has been practicing for a long time; as a result, in many organisations, seniors dominate young practitioners without offering proper opportunities to improve their skills. Accordingly, CSA01 stated: "*As a result, young professionals are not bold enough to learn, they are not innovative, and they are not pushing boundaries in the industry*". Respondents also stated that isolated working culture (section 6.5.2.1) is another reason for a lack of knowledge sharing. As a result of isolated working culture, many professionals do not communicate enough. Responses revealed that awareness should come from young professionals as they are the future of the industry; therefore, respondents consider that senior professionals should have more responsibility to increase BIM awareness through shared knowledge.

6.5.4.2 Absence of BIM Initiator

Respondents also noted that the absence of an initiator to implement BIM within the Sri Lankan context also has resulted in unawareness. CSA01 endorsed this by stating the "*Financial barrier is not the main barrier we have; hence, the initiation",* as there is no party responsible for initiating BIM within the industry. Supporting this statement, CSB03 and CSA02 expressed similar thoughts. According to respondents, named professional bodies and the government should be the initiators. Furthermore, many respondents identified that the involvement of professional bodies is fundamental to the adoption of BIM as it is the easiest way of increasing BIM awareness among industry professionals. In CSB01's words "*This should start with professional bodies like IQSSL, CIDA, ICTAD and Architectural institutes*". CSB03, CSA01, CSA03, CSB02, CSA02 and CSB04 expressed similar thoughts. Respondents also revealed that, at the moment, some professional body involvement can be seen. For example, CSB01 stated, "*…professional bodies are doing something, introducing BIM, BIM models, workshop, conferences but it does not enough to implement BIM within Sri Lankan context*". Therefore, CSA03 suggested that "*First professional bodies and universities should get together, and make standards, for BIM*", while CSA02 stated "*They should organise seminars, CPD, conferences, and workshops not only in Colombo but also island-wide, as many industry practitioners have traveling problems.*" However, even though anything is possible in this country, nothing is moving due to the silence of many professionals and professional bodies.

Respondents further identified that the government should also be responsible for the absence of BIM initiators, as they believe the government should also act as another initiator. Accordingly, respondents complained that they have lost large scale projects, such as Altaire, in which BIM could have been applied. Thus, they lost the chance, as the government has not taken the necessary action to support BIM adoption. CSB03 stated "*...If large scale projects are not using BIM, then it'll be a very few opportunities for Sri Lanka to involve in BIM-based projects*". Moreover, respondents further indicate that those requests should come from the professional level, such as architects, QS, or engineers, which is not happening. However, from the QS perspective, CSB01, CSA04, and CSB02 stated that architects should be the initiators of BIM adoption, as they are the first in the construction line. Accordingly, respondents have identified three main sectors - professional bodies, government and architects - who should be BIM initiators with the aim of increasing BIM adoption. Thus, CSB03 stated, "*if they don't do it, who will do it then?*".

6.5.4.3 Lack of BIM Education

Respondents also found that a lack of BIM education has resulted in unawareness. Accordingly, respondents indicated that a proper BIM education is still lacking in the Sri Lankan context. CSB03 stated that a "*Broader understanding of BIM, such as what BIM is, what it entails, is severely lacking"*. Those discrepancies can be seen in developed countries, such as the UK, the USA, and Scandinavia, but is significantly lacking in Asian counties. This has ultimately resulted in a lack of BIM experts within the country. CSA01 endorsed this by stating "*when we were to introduce CostX, we had to hire experts from Indonesia and Singapore to train our employees*". According to respondents, one of the main reasons for the lack of proper BIM education within SL is attributed to the fact it is still not part of the Sri Lankan education curriculum. CSA01 said "*Unfortunately BIM is not included in the education system*". CSB01, CSB02, CSB04 and CSA03 expressed similar thoughts. This indicates that, even though several government universities exist, BIM teaching is still at an immature stage. Moreover, CSB01 stated that "…*we don't have BIM courses within the Sri Lankan context to learn BIM*", which indicates the need to establish BIM-related courses. However, respondents noted that the only acting body at the government level for BIM is The University of Moratuwa. They organise BIM-related workshops and seminars to increase BIM awareness, but these do not cover the entire industry.

Hence, responses revealed that some private sector institutions conduct BIM-related courses. CSB04 endorsed this by stating, "*Few BIM-related courses are conduct[ed] in the private sector, but it does not fulfill the need of the industry*". This indicates there are only a few BIM education service providers in the private sector. Moreover, CSB01 stated that "…*when it comes to private universities, they do provide just a BIM introduction, which is not enough to adopt BIM*". Many respondents believe that they require practical use of BIM along with theoretical knowledge, which indicates that courses are not sufficient or appreciated. Therefore, responses indicate that universities have a big role in terms of BIM adoption. CSA01 endorsed this by stating the "*University has to take the first step of BIM adoption by introducing or updating existing curriculum with BIM*". Supporting this statement, CSA01 expressed similar thoughts. Moreover, CSB03 suggested that "…*the best way to teach BIM for SL students is to ask students to dream what BIM could be after giving them some idea about BIM. That kinda conversation is important for them to learn more*". This indicates the importance of providing the practical aspect of BIM. Besides, education should not only target students but also industry professionals, such as architects, engineers, quantity surveyors, etc.

According to CSB02, proper BIM education would be a driver for the Sri Lankan industry to adopt BIM. CSA03 suggested that, apart from standard BIM courses, workshops, live projects, CPD and conferences would also accelerate the use of BIM within Sri Lanka. Besides, respondents further identified a lack of demand from the industry as another reason to establish proper BIM education within the country**.** In CSB01's words "*In SL it's really hard to find a proper institution for proper BIM education, the reason for this at the moment we don't have any demand coming from the industry for BIM*". Respondents further noted a lack of BIM demand, especially during professional gatherings, as not many conversations relate to BIM. Hence, CSB02 had a different perspective; he stated that "the *first step would be to provide knowledge conducting CPD, seminars, conferences, etc., then only they will start thinking about BIM. Afterward, demand will come for it. Without knowing the product there's no demand coming from the industry*", which illustrates the need for proper BIM education to increase demand. Therefore, respondents believe that it is time to introduce BIM to the SL industry on an island-wide basis.

6.5.4.4 The Gap Between Industry and Academia

Respondents also revealed that the gap between the industry and academia is another reason for unawareness. CSB03 endorsed this by stating "…. *unfortunately, academics are not connected [to] the industry; they create ideas and thoughts, but there's no one to tested them*". According to respondents, the main reason for not connecting industry and academia is isolated working culture, as discussed under section 6.5.2.1. According to CSA01, "*There are some researchers who have done some research; hence, in the majority of papers only a few case studies have used compared to theories and models*". Therefore, respondents expressed dissatisfaction with the quality of research papers. In CSB03's words "*…when there are fewer case studies, how do you know what you are talking about will work or not? Until we test them within the industry, we cannot tell it will work or not*". Notably, most of the respondents drew attention to the lack of communication that worsens the gap between industry and academia. CSB03 said, "*Communication between industry and academics is in a very low stage in [the] Sri Lankan construction industry*". Agreeing with this statement, CSA01 stated "*If you send an email, you won't get a reply, so you have to contact them. They are more oriented towards the documentation*". Therefore, this is a cultural issue, which is discussed in section 6.5.2.1.

Therefore, findings indicated unawareness as another barrier that affects BIM adoption due to the lack of knowledge sharing, the absence of BIM initiators, a lack of BIM education, and the gap between industry and academia. Accordingly, Figure 6.14 illustrates the cognitive mapping of unawareness and its reasons.

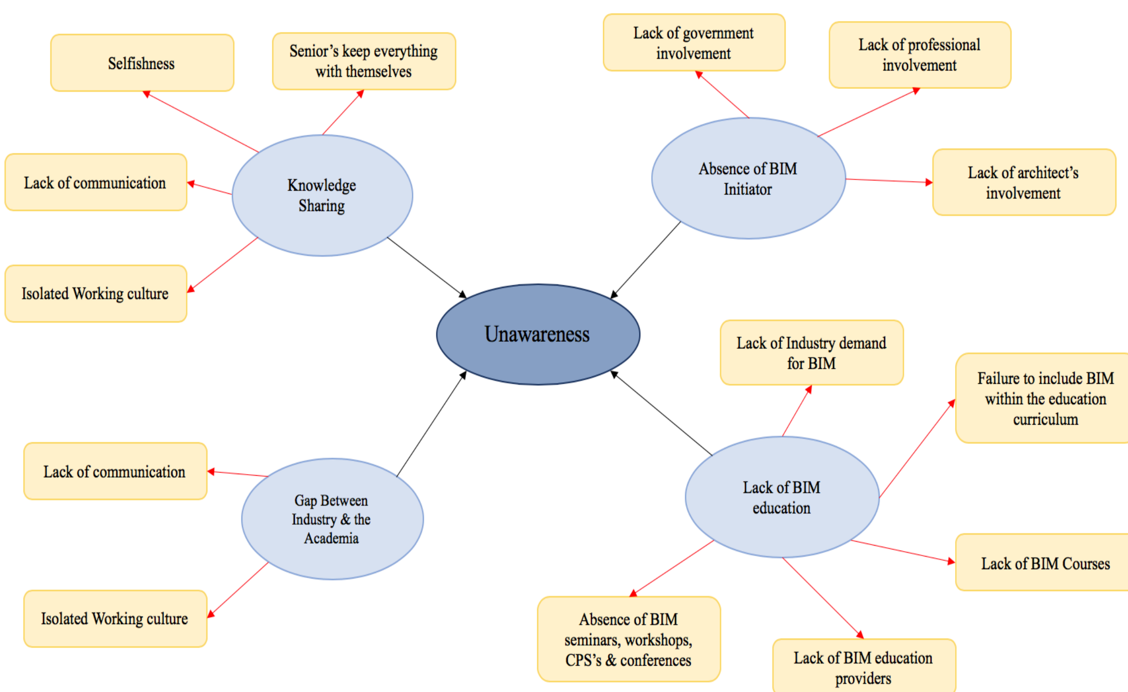


Figure 6.14: Cognitive mapping of unawareness and reasons

6.5.5 Lack of Resources

The lack of resources is another barrier noted by the respondents (see Figure 6.10). Accordingly, respondents identified the lack of various resources that prevent the adoption of BIM.

6.5.5.1 Lack of BIM-Experts

Respondents identified a lack of BIM experts as the main lack of resource for BIM adoption. CSB04 endorsed this by stating "*We don't have proper BIM educated people to launch BIM within our companies or in the industry*". CSA03 and CSA04 expressed similar thoughts, which indicates that BIM experts lack within the industry due to a lack of proper BIM education, as discussed under section 6.5.4.3. However, respondents highlighted the need for the role of a BIM manager, as he can coordinate with each party involved. As CSA03 states, "*Architects don't want anyone to meet the client. in case the client needs any change, no one would know what happened in that meeting, except client, if we have BIM managers, they can pass the information for the entire project team".* Nevertheless, respondents indicated that they had to hire international BIM experts to support BIM adoption within their organisations, which is highly expensive.

BIM experts can either be from academia or the industry. Although respondents noted that some academics have conducted some research on BIM, as many academics do not have proper links with the industry, it is unlikely that they can help to meet the need for BIM experts. According to CSB03 "*When talking about the BIM expert in SL, our experts are limited only to the academic sector; thus, we don't have any experts in the industry*". This indicates that experts are only limited to the academic sector, but none are based within the industry to develop the practical side of BIM. This further reveal that BIM education is still limited to theoretical aspects (as discussed in section 6.5.4.3), but there is a lack of opportunity to experience BIM in a real-life context. In other words, the lack of proper training has also resulted in a lack of BIM experts. Therefore, CSA04 suggested that hiring BIM experts would offer a solution; even though it is expensive, this could be a short-term solution. However, respondents also suggested the establishment of proper BIM education, as it could rapidly create local BIM experts.

6.5.5.2 Absence of a BIM Implementation Plan

The interview findings further indicated the absence of a BIM implementation plan is another fundamental lack of resource for BIM adoption. This seemed to be an issue organisationally and nationally. In CSB02's words "*We need a clear BIM implementation plan or a strategy/ framework for our organisation to adopt BIM*". In the meantime, CSA01 stated that, "*Let's say we use BIM up to some extent, that doesn't mean that we can implement full-scale BIM in a project, for that top management of the companies needs to step forward with a proper execution plan*". This statement implies that employees expect top management to develop a proper strategy for BIM adoption as the most responsible party. Besides, many countries have adopted BIM through nationally developed strategies or frameworks. Therefore, the responses also indicated that there's a need for a nationally developed implementation plan for BIM adoption in SL. Accordingly, many respondents believed that the lack of government intervention has resulted in the absence of a nationally developed BIM implementation plan. Therefore, CSB02 suggested that, "*for the development framework, we can use early adopters to share their experience about the use of BIM, its advantages, barriers they face during adoption, and the actions they have taken*".

6.5.5.3 Lack of BIM-Models

According to respondents, the lack of BIM models represents another key lack of resource. Thus, the most important requirement of a QS undertaking a BIM-based cost estimation is the BIM model. However, the responses revealed that the QS does not get a BIM model from the architects. CSB01 endorsed this by stating, "*The main reason not to find any local BIM projects is still the architects are not using BIM tools, so we don't get any BIM model to perform BIM-based cost estimation*". CSB01 and CSA03 expressed similar thoughts; moreover, CSB02 stated, "*if we are not getting any models, how come we do 5D cost estimation?*" CSC03 and CSA02 also expressed similar thoughts, which indicates that a BIM model is an important resource for the QS in BIM-based practice. Respondents complained that it is the architect's responsibility to design drawings in the BIM model. Furthermore, CSB01 guaranteed that, "*If architects start doing BIM models, definitely QS firms and other practitioners in the industry will start doing BIM-based practice*". Therefore, according to CSB01, CSA03 and CSB02, architects should be the initiators for BIM adoption. Responses also revealed that there is only one architect firm creating drawings in a BIM format, while the rest are not. For example, CSA03 stated the, "*Colombo city project they issued drawings in BIM format*". According to respondents, another reason for the lack of BIM models is unbalanced BIM adoption among professionals, which is discussed under section 6.5.6.1. Therefore, respondents suggested that the most important step for BIM adoption within the QS organisation would be to introduce BIM for architects in the industry. If not, CSB02 stated there is "*no point [for] QS's to adopt BIM, as we can't measure in BIM tools*".

6.5.5.4 Lack of BIM Training

A lack of BIM training was found to be another lack of resource in the Sri Lankan context for BIM adoption. Accordingly, respondents indicated that companies do not attempt to train employees, which is the main reason for the lack of BIM training. Many organisations find training costs them a lot. CSC01 endorsed this by stating "*…. training people going to be expensive as we don't have any BIM experts within the country*", so the organisation has to hire international BIM experts, which is expensive. Besides, labour turnover was also highlighted as another reason for the lag in training amongst organisations. CSA01 endorsed this by stating, "*once we trained an employee, there are many organisations to recruit him*". However, CSB03 had a different opinion, stating that "*My personal view is, if someone [is] interest[ed] in BIM, they'll learn by themselves, the thing is it's just not a teaching of SW as there are plenty of BIM SW available, what's the point of teaching just one SW? It's like telling them to go to the ocean and fish for just one type of fish*". As for some professions, there is specific software available, for example, QS's CostX for measurement and estimation. Moreover, there is no point for a QS to learn Revit as it is developed for designing. Another reason for the lack of BIM training, as highlighted by respondents, is the absence of proper BIM educational places to provide BIM training, which is discussed under section 6.5.4.3. Therefore, CSB03 suggested that, if all the construction organisations can organise a place to study and train, BIM would be more beneficial for all professions and more cost-effective. However, this should not be limited to a certain area, but rather based on an island-wide need.

6.5.5.5 Limited Internet Facilities

Responses also identified that limited Internet facilities represents another lack of resource that impacts BIM adoption. As CSA03's indicates, "*High-speed internet is essential for BIM-based cost estimation*"; furthermore, CSB02 expressed similar thoughts. In Sri Lanka, Internet facilities are very expensive and not fast enough. CSB02 said, "*…. if we are to use BIM, we need fast broadband for our offices for cheaper cost*". Therefore, respondents emphasised that government contribution is essential to reduce the cost of internet facilities at the organisational level.

6.5.5.6 Limited Number of Software Licenses

Another insufficient resource highlighted by respondents is the limited number of software licenses. Many organisations have only managed to get a limited number of software licenses. As CSA02 stated, "*We've got only six licenses for CostX, but 20 employees are working here, so at a time only one can* *use one software*". Agreeing with this CSA01 stated that "*We have purchased four licenses, but more than 30 employees are working, so the number of licenses is not enough*". These statements indicate that organisations have managed to get a few software licenses, but these do not cover the needs of all available staff. In the meantime, respondents complained that due to a limited number of licenses, productivity has decreased. CSB02 endorsed this by stating "*…once all the licenses are utilized, anybody else can log in to the system*". Due to the unethical behaviours discussed under 6.8.4, many organisations are using trial versions for various SW. However, it is hard to find trial versions for BIM-related SW; as discussed in section 6.6.1, one of the main reasons for a limited number of SW is the cost of SW. as CSB01's indicated, "*As it is very expensive, many local firms cannot bear that cost*". Furthermore, responses also indicated that the lack of demand for BIM from the industry has meant that organisations have not increased the number of software licenses, as it not profitable. Therefore, it can be assumed that a lack of demand has also resulted in a limited number of BIM software licenses.

Accordingly, the above findings indicated that a lack of resources is another barrier that affects BIM adoption due to the lack of BIM experts, the absence of a BIM implementation plan, the lack of BIM models, a limited number of software licenses, limited Internet facilities, and a lack of training. Accordingly, Figure 6.15 illustrates the cognitive mapping of a lack of resources and its reasons.

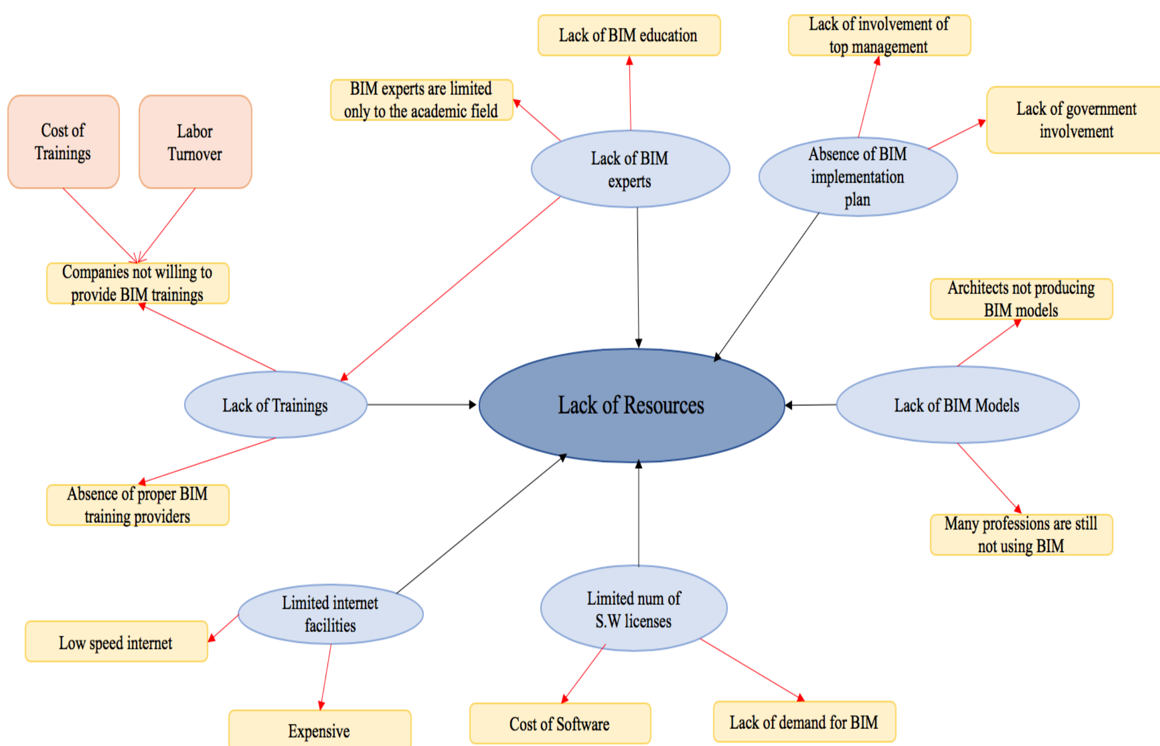


Figure 6.15: Cognitive mapping of lack of resources and reasons

6.5.6 Lack of Demand for BIM

Respondents identified that the lack of demand for BIM was as another barrier to its adoption. In CSC02's words "*At the moment we have no, or a very limited, demand coming from the industry for BIM-based projects*". Respondents noted that various reasons have resulted in a lack of demand for BIM within the industry.

6.5.6.1 Unbalanced BIM Adoption

Unbalanced BIM adoption was identified as the main reason for low BIM demand. Accordingly, CSB03 stated, "*In BIM adoption, people don't focus and concentrate on the equal development of all of the factors such as technology, process, and people*". This indicates there is not just one aspect to consider; thus, all factors need to be balanced equally. For example, CSA01 stated, "…*think you got the technology, and process, as you got all the fancy SW; from all these SW you can extract all the accurate information, your company has set out multiple processes, the government has defined policies, but if the people aren't trained to do it, it's not going to work*". Therefore, the adoption of BIM cannot be classified as just the use of technology, or process, but rather the combination and equal use of people, process, and technology (PPT). However, many respondents complained that unawareness (discussed under section 6.5.4) resulted in an unbalance adaptation of these factors.

Besides, respondents also noted that the lack of BIM use among professionals has also resulted in unbalanced BIM adoption. CSB01 endorsed this by stating, "*the current situation in Sri Lanka is only QS have started using BIM*"; however, not many architects or engineers are using it. However, according to CSA01 "*…. the earlier adopters should be architects, as architects are the initiators in the construction process, and they should prepare drawings using BIM*". Unfortunately, within current practices, only a few architectural firms are using BIM; moreover, it is not just QS's or architects who should implement BIM, but rather all parties in the construction process at the same time. Therefore, CSA03 suggested that "*we need to implement BIM, not just for one profession, but also every profession in the industry should be part of BIM*". Accordingly, findings indicated the uneven adaptation of PPT, and the lack of professional BIM use have mainly resulted in unbalanced BIM adoption. Furthermore, respondents identified that many professionals do not intend to use BIM due to the lack of client demand (discussed under section 6.5.6.2) and the lack of BIM training (discussed under section 6.5.5.4).

However, respondents noted the importance of government involvement to mitigate unbalanced BIM adoption. In CSA01's words *"…. many countries have made BIM a mandate, so they don't have any options unless using BIM if you want to do a project in a modern way; of course, the government will have to initiate this*". CSA02, CSA03, CSB01, CSB03 and CSC03 expressed similar thoughts while many respondents identified the BIM mandate as a major driver, which accelerates the use of BIM among construction professionals. Furthermore, some respondents suggested mandating the use of BIM for all foreign contractors. As CSA03's indicated "*if we have a mandate that foreign contractors to use BIM within projects going on Sri Lanka, with training for local industry practitioners, BIM adoption will be … accelerated among Sri Lankan construction professionals*". This also creates an opportunity for local practitioners to train themselves. However, as CSB03 stated "…. the *government has to be mindful in mandating BIM, as they need to consider certain aspects*", especially for local projects. For example, CSB01 stated*, "if it was mandated to utilise BIM for projects which exceed cost 15 million and above, that particular contractor is not engaged with many projects, sometimes the cost for BIM adoption doesn't justify. So, then what happen SL companies have to dig to get side-line, as they don't have enough resources*". This indicates it is not just about the scale of the projects considered, but also organisational capacity, which should be considered before introducing mandates.

6.5.6.2 Lack of Client Demand

Respondents also revealed that a lack of client demand has also influenced low BIM demand generally. Most organisations provide their services for foreign companies and projects due to demand from foreign contractors. As CSA01 explained, "*only a few organszations are dealing with BIM-based practices, and even them mostly provide BIM services for international clients*". This indicates that client demand is a significant BIM driver for construction organisations to adopt BIM. However, CSB01 stated, "*At the moment we don't get any demand for BIM from Sri Lankan clients*". CSB02, CSB03, CSB04, and CSA01 expressed similar thoughts, which indicates that client demand from local clients is almost non-existent. Therefore, it significantly affects the overall demand for BIM as not many organisations deal with foreign clients. Besides, according to respondents, the major reason why do not ask for BIM is unawareness (discussed in section 6.5.4). In CSA04 words, "*If clients know BIM and its benefits definitely, they will go for it*". CSA01 and CSA02 expressed similar thoughts. CSB01 suggested that "*….as a part of the BIM adoption process, the foremost step would be the raise client's awareness of BIM and its benefits*". The existence of the construction industry depends on clients. According to CSA01, BIM adoption also depends upon the client's decision as the individual who invests money on projects. Agreeing with this, CSB02 stated that, "*If clients don't have a proper idea about BIM, they will ignore the use of BIM*". Therefore, the client plays a significant role in BIM adoption.

6.5.6.3 Lack of Government Intervention

The lack of government intervention was another reason for the lack of demand for BIM; indeed, CSA02 said, "*even though the government intervention should be a must, I have no idea up to what extent its practical to expect government involvement*". CSA03, CSB01 and CSB02 expressed similar thoughts, which indicates it is hard to expect government intervention for BIM adoption. Accordingly, respondents indicated that political corruption is a major reason for the lack of government intervention. CSA02 stated, *"…if you are using e-tendering, once you upload quantities at the end it'll come as it is, so no one can edit the final figures or cheat…*" But in traditional practice, anyone can edit the final figures as they want. In terms of selecting contractors - especially for government sector projects - in most instances, political influences can be seen in the Sri Lankan construction sector. As a result, the government has no intention to go beyond traditional methods. Therefore, CSB02 asked, "*so how can we expect any government involvement?"*. Besides, an economic crisis represents another reason for the lack of government intervention. As a developing country government expectation are quite different to modern technological aspects. Nevertheless, respondents further complained that the lack of professional involvement (discussed under section 6.5.4.2) also result in a lack of government intervention. Respondents believe it is the responsibility of professional bodies to report the need for BIM within the construction industry to the government. Only then will the government pay attention to BIM adoption. Therefore, CSA03 suggested the involvement of government agencies on behalf of the government to encourage the implementation of BIM.

6.5.6.4 Scalability

Through the responses, scalability is also identified as another reason for the lack of demand for BIM. According to CSB03, "*it is important to decide whether the size of the Sri Lankan construction market will fit for BIM or not*". Furthermore, CSB01 said: "*As this is a scale game, it is important to consider how to increase the scale and how to get a better return when you run a larger incrementation*". This indicates the importance of determining the scale of BIM adoption. Therefore, CSB01 suggested that, "*if SL is … too small a market to adopt BIM, one way is to try to increase the scale, so then your approach is not just BIM adoption in SL but South Asia. Or it could be done through a comparative model; compare a small country where the scale is small, and if they have adopted BIM identify what they did and how they did*". Moreover, CSA01 suggested, *"as many large-scale local projects are done by international contractors, the best way to increase the scalability is through shared BIM adoption*", which indicates working with international contractors collaboratively to provide BIM services by covering certain areas, such as the development of the BIM model. In other words, this means outsourcing BIM services.

Accordingly, the above findings indicated a lack of demand for BIM as another barrier that affects the its adoption, due to: unbalanced BIM adoption, a lack of client demand, a lack of government intervention, and scalability. Accordingly, Figure 6.16 illustrates the cognitive mapping of the lack of demand for BIM and its reasons.

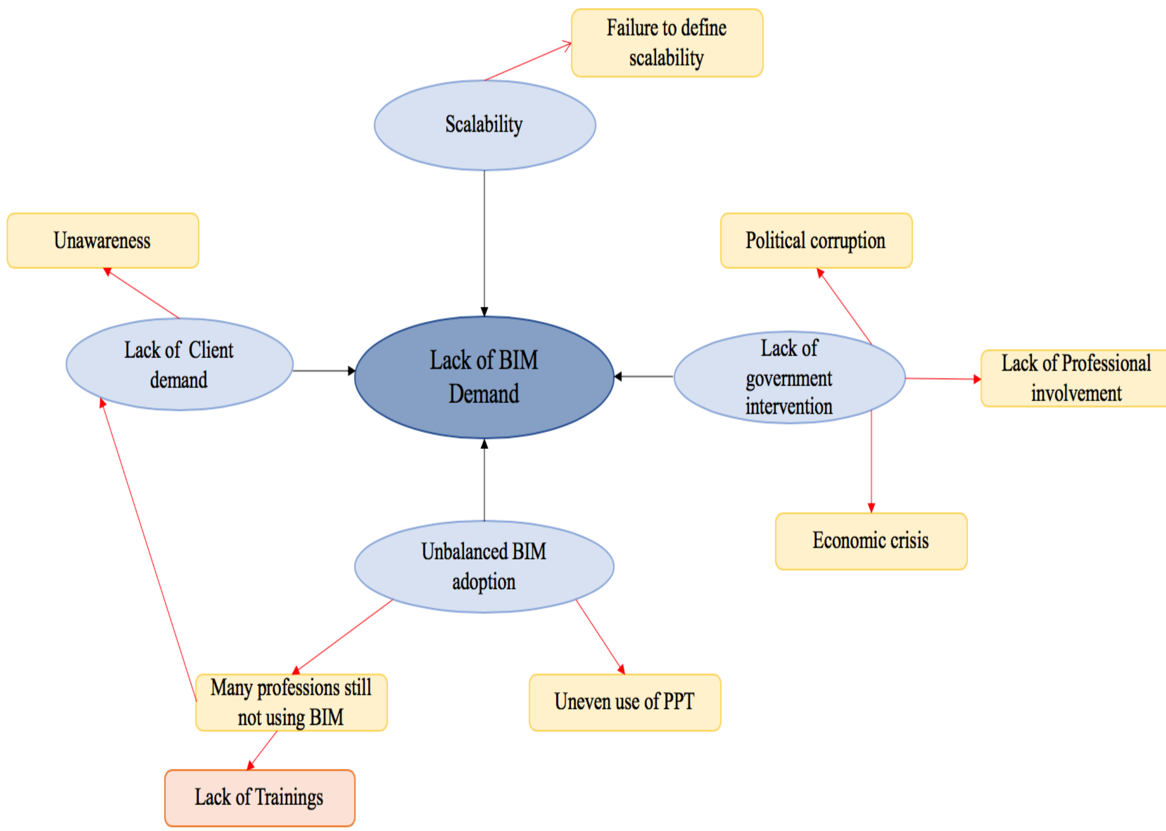


Figure 6.16: Cognitive mapping for the lack of BIM demand and reasons

According to the above analysis, findings indicated six significant barriers, which hinder the adoption of BIM. Financial barriers, organisational barriers, regulatory barriers, unawareness, lack of resources, and a lack of demand for BIM were found to be the main findings from the analysis. Moreover, the findings also indicated the reasons behind each barrier and the mitigating actions.

6.6 Summary and Link

A case study analysis is one of the principal methods of analysis used in this study and addresses the defined objectives. This chapter presented the factors affecting the accuracy of pre-tender cost estimates, the driving factors for BIM adoption and BIM adoption barriers, and the mitigating actions in Sri Lankan quantity surveying firms. Accordingly, the following chapter discusses the findings from both types of data analysis.

7 Discussion

7.1 Introduction

The purpose of this chapter is to conceptualise the research findings by evaluating the findings derived from the questionnaire survey, case studies (semi-structured interviews) and existing literature to develop a framework for BIM adoption in Sri Lanka. The chapter is divided into three sections. The first compares and summarises the findings from this study with current literature. The second section describes the development of the framework that was based on the findings. Finally, the third section presents the findings of the validation process.

7.2 Factors Affecting the Accuracy of Pre-Tender Cost Estimates

7.2.1 The Use of 2D Drawings

The results of this study indicate that the use of 2D drawings hinders the accuracy of pre-tender cost estimates. The use of 2D drawings is more challenging due to the lack of visualisation, changes, and revisions to the drawings. Findings from the case studies (qualitative) (see section 6.3.1) endorse this position, as many respondents find that the lack of visualisation results in the calculation of inaccurate quantities by QS's due to the difficulties they face in identifying certain elements, especially for complex projects. Furthermore, changes and revisions mainly occur due to last-minute submissions by the architect, client alterations, the isolated working culture, and insufficient information. Besides, results also indicate that changes and revisions are more time-consuming meaning that a QS has to spend considerable time detecting these changes and incorporating them within the existing cost estimate. Furthermore, respondents identified the lack of visualisation from 2D drawings (section 5.5 see Table 5.6); the majority agreed with this barrier by stating that it increases the inaccuracy of pre-tender cost estimates. Moreover, respondents further agreed that updates and changes made to 2D drawings hinder the accuracy of pre-tender cost estimates (section 5.5, Table 5.6). Therefore, the findings indicated that lack of visualisation, and changes and revisions are heavily impacted by the use of 2D drawings, meaning that it is more challenging for a QS when preparing accurate cost estimates. Accordingly, the factor "use of 2D drawings" was ranked in the 6^{th} place among nine main factors, as illustrated in Table 5.15. In agreement, GenieBelt (2019) mentioned that the preparation of accurate cost estimation using 2D drawings can be particularly challenging in complex projects. Autodesk (2016) positively supported this view indicating that lines and circles in 2D drawings provide poor visualisation for the QS with frequent revisions and changes. Therefore, it can be concluded that the use of 2D drawings is more problematic due to the lack of visualisation, changes, and revisions to drawings.

Thus, Sri Lankan QS organisations need to re-consider the use of 2D drawings when increasing the accuracy of pre-tender cost estimates. The world's top construction organisations have already made a transition from 2D design to 3D design due to prevailing issues with the use of 2D drawings (Mackay, 2016). Moreover, QS's have identified that the transition from 2D to 3D is the key to increasing the accuracy of cost estimates (Allplan, 2019). As noted in section 3.3.1 the use of 3D BIM models helps the QS to develop a clear picture of the project through a virtual 3D walk, which ultimately improves the visualisation (Azhar et al., 2008; BIM Talk, 2013; Haque & Mishra, 2007; Shen & Issa 2010; Underwood & Isikdag 2010; Viklund, 2011). Also, the ability to detect clashes has reduced manual revisions and changes (Thurairajah & Goucher, 2013) thereby saving the QS time. Therefore, the use of BIM models has improved the accuracy of pre-tender cost estimates through improved visualisation and by minimising the changes and revisions required within clash detection.

7.2.2 Lack of Information

The results from this study illustrate that the lack of information is another prevailing factor that hinders the accuracy of pre-tender cost estimates. The lack of information mainly occurs due to poor information flow, paper-based information sharing, unusable data and the absence of proper databases. Findings from the case study analysis (section 6.3.2) endorse this position, as many respondents find that poor information occurs as from: restricted access to the information provided for quantity surveyors; the absence of proper databases, and paper-based information sharing. In many organisations, top management is typically the only authorised party with complete access to company databases. This can limit employees' contributions to the entire information flow, as they do not have the right to upload or download any information. Moreover, as a result of limited access, the majority are reluctant to share information with other employees.

Findings also revealed that paper-based information sharing occurs due to the isolated working culture and the fear of new technologies. In the government sector, the use of email and the Internet is especially limited meaning a reliance on paper-based document sharing practices. As a result, many professionals refuse to adopt new technologies. Therefore, private organisations struggle to fully adopt new technologies, due to limitations in the government sector's current practices. This indicates that isolated working culture heavily influences the use of paper-based information-sharing among professionals.

In addition, the results from this study reveal that unusable data is another reason for the lack of information. Unusable data results from a lack of communication and coordination among project team members, and paper-based information sharing. Moreover, the study found that the absence of a general database similarly results in the lack of information. In particular, private organisations have their own databases, whereas the government sector uses their own databases. Thus, there is no generally developed database for the Sri Lankan construction industry, such as BCIS (British Cost Information Service). Moreover, the authorities responsible have not attempted to develop a general cost database for the Sri Lankan construction sector.

The results in quantitative section 5.5 (Table 5.7) revealed that respondents further agreed with the majority that the lack of information results in the preparation of inaccurate pre-tender cost estimates. Moreover, they believed that poor information flow, the absence of a proper database and unusable data are factors affecting on the lack of information. Besides, respondents also agreed that manual information exchange (paper-based information sharing) also results in a lack of information. As such, the findings indicate that the lack of information mostly occurs due to a poor flow of information, paper-based information sharing, unusable data and the absence of an appropriate general database. Accordingly, the factor 'lack of information' was ranked fourth among nine main factors, as illustrated in Table 5.15; this indicates that insufficient information has a significant effect on the accuracy of pre-tender cost estimates.

This view was further supported by the literature; according to the Muhammed et al. (2018), the use of accurate information from reliable sources is important to ensure accurate estimates. Therefore, obtaining accurate and sufficient information at the pre-tender stage can increase the overall accuracy of pre-tender cost estimates. Nevertheless, due to incomplete designs, in most instances the QS fails to gather sufficient, accurate information prior the preparation of pre-tender cost estimates. As a result, the QS receives incomplete design drawings with missing information, which ultimately results in a poor flow of information (Hiyassat et al., 2018). Moreover, Muhammed et al. (2018) confirmed the importance of access to a well-maintained database that could help the QS to develop accurate cost estimates. However, paper-based information sharing has resulted in the creation of poor databases for most organisations, as the information is not stored electronically. Braaf et al. (2016) positively supported this view by indicating that important information is sometimes buried in paper documents (such as 2D drawings), which the QS is not informed of, and is not verbally advised. Therefore, in order to improve the accuracy of pre-tender cost estimates, Sri Lankan QS organisations need to overcome the ‘lack of information’.

As noted in section 3.4.2 the use of BIM helps to overcome a lack of information through the use of 3D BIM models, which consist of rich information. Rather using series of 2D drawings, BIM model provide access to digital database where QS can gather accurate and reliable data during the early stage of the project. Moreover, the QS can share, download and manage any information at any stage of the project, which ultimately creates a rich flow of information throughout the project. This flow automatically generates a more reliable database for the entire project. As BIM allows all project participants to work on the same platform, it can improve communication and coordination among project team members by eliminating unusable data. Moreover, it also minimises paper-based information sharing as it prevents the maintenance of an isolated working culture. Therefore, the use of BIM has improved the accuracy of pre-tender cost estimates by overcoming the fact of lack of information.

7.2.3 Inefficiencies in Current Software

Results from the qualitative analysis illustrate that inefficiencies in current software also result in the preparation of inaccurate cost estimates in Sri Lanka. The results indicate that the majority (90%) of Sri Lankan QS’s use MS Excel for measuring purposes, which is attributed to its user-friendliness. However, the results also indicate the use of Ms Excel is not 100% accurate due to applications of incorrect mathematical formula and wrong calculations. Findings from the case studies (section 6.3.3) endorse this position as the many respondents find that the use of wrong assumptions, the inability to trace the changes, and a lack of SW operational skills represent as the main reasons for incorrect mathematical formulas. Excel is not specifically designed for QS measuring purposes; instead, it is a general software application that conducts calculations based on the formulas and commands which the user creates. Therefore, Excel can be compromised through the application of many mathematical formulas, on which the QS has to make assumptions when creating these formulas. In most cases, these assumptions are not accurate due to the lack of information, as discussed in section 7.2.2. Therefore, inappropriate assumptions result, which mean the development of inaccurate mathematical formulas, which ultimately result in inaccurate calculations.

Responses also indicated that QS’s lack of software (SW) operational skills represents another reason for incorrect mathematical formulas. Many QS’s are not skilled enough to develop their own formulas, as they are not sufficiently familiar with Excel. Even though some professionals have a degree of skill to use Excel, they do not update their system with the latest versions so miss the advantages offered by new SW features. In addition, once a formula is developed it is hard to remember the commands used, and it is hard for a third party to track them if they are not familiar with the development of formula or use of Excel.

Moreover, in most cases these files are shared among professionals in a secured version (non-editable), to prevent fraud or corruption, which could result in million-pound losses. This also prevents the traceability of changes undertaken by different parties outside from the person who developed the file. Even if it is possible to pinpoint the location of every related file, tracing the logic of formulas from one related cell to another can be time-consuming. Similar problems will be encountered when troubleshooting any questionable data. Therefore, responses illustrated that the inability to trace changes as another reason for wrong mathematical formulas. Findings from the qualitative data also revealed that hidden calculations, missing elements or quantities, and wrong mathematical formulas are the main reasons for wrong calculations. Accordingly, responses indicated that many mistakes arise due to the hidden calculations made within Excel. Thus, when a change is made to a formula, all hidden calculations might not automatically change, which means that manual checks are required. Moreover, according to the respondents, missing elements or quantities can also result in wrong calculations. The respondents indicated that this occurs when transferring measurements to an Excel sheet for calculation. Missing one element will result in entirely incorrect calculation. It can be also seen from the results that wrong mathematical formulae also result in wrong calculations. Therefore, even when a QS conducts an accurate take-off of quantities or measurements, the use of wrong mathematical formulae will result in incorrect calculations.

Furthermore, this is similar to the results for the quantitative analysis (section 5.5, Table 5.8), where participants agreed with the majority of inefficiencies in current software results in inaccurate pre-tender cost estimates. Moreover, respondents believed that human error from manual programming increases the use of wrong mathematical formulae, which also indicates inefficiencies in the current software. On average, due to human error, a spreadsheet will contain one error for every 20 cells containing data (Worthington, 2016). Besides, respondents also confirmed that wrong calculations occur when the SW unrealistically overestimates, meaning that higher risk allowances are added compared to those included by human interaction. The results of both findings indicate that wrong mathematical formulae and incorrect calculations are the leading factors for inefficiencies in current software. Accordingly, the factor "inefficiencies in current software's" was ranked seventh among the nine main factors, as illustrated in Table 5.15 which indicates that this also has a significant effect on the accuracy of pre-tender cost estimates.

This view was supported by the literature; according to Hook (2018), it is challenging to maintain a standardised approach to estimating when using Excel for cost estimating as it does not offer estimator specific functions. Moreover, QS mistakes within embedded formulae can mean significant inconsistency in the calculations, as it difficult and time-consuming to pinpoint the mistake (Blog, 2019). Besides, formulae can be easily changed – either on purpose or by mistake. According to Baio and Anna (2016), the use of dedicated software reduces such errors by applying predefined cost formulae and calculations. Therefore, rather than using generic software like Ms Excel, to increase the accuracy of pre-tender cost estimates, Sri Lankan QS organisations have to re-consider the use of specific software that is specially designed for cost estimating purposes.

As noted in section 3.3.3, BIM has its own developed software, such as CostX, Vico Take-off, Zuzia, etc, which are designed for cost estimation. This means such SW is specially designed for estimation purposes, and therefore conducts automated quantity take-offs. Moreover, it generates accurate cost estimates without the need for manual programming. The QS does not need to spend extra effort creating mathematical formulas for calculations. Therefore, with the effective use of the right BIM software for cost estimating increases the accuracy of the final cost estimate.

7.2.4 Inadequate Estimator Knowledge and Skill

The results from this study illustrate that inadequate estimator knowledge and skill form another factor hindering the accuracy of pre-tender cost estimates. The lack of SW operational skills and wrong assumptions are the main factors that illustrate inadequate knowledge and skill. Findings from the case studies (section 6.3.4) endorse this position, as many respondents find that the wrong assumptions occur from the lack of updates, a lack of awareness of current rates, and the difficulties in reading 2D drawings. Many QS's are not up to date with the current business side of the construction industry; as a result, they are not capable of identifying important circumstances, such as price escalations during the preparation of cost estimates. Therefore, in most cases the assumptions made by the QS are inaccurate due to lack of updates and awareness about current rates. Wrong assumptions also occur due to difficulties in reading 2D drawings, which was discussed under section 7.2.1. If the QS is not skilled enough to read drawings properly, they could add extra or miss items in the cost estimate. Besides, qualitative findings also revealed that the QS is unable to develop appropriate formulas (discussed in section 7.2.3) and inadequate knowledge of risk allocation has also resulted in a lack of SW operating skills. As SW does not manually calculate risk, the QS needs to decide the amount of percentage that should be allocated for risk.

Furthermore, this finding is similar to participants' responses for the quantitative analysis (section 5.5, Table 5.12), to which the majority of participants agreed that the accuracy of pre-tender cost estimates heavily depends upon the knowledge and skills of the estimator. Moreover, they believed that the wrong assumption and lack of SW operational skills are the prevailing factors for the inadequate knowledge and skill of an estimator. Besides, the majority of participants agreed that the QS's knowledge and skills are highly important in preparing accurate cost estimates even though plenty of tools and technologies are available.

Accordingly, the factor "inadequate knowledge and skill of an estimator" ranked first among nine main factors illustrated in Table 5.15, indicating that inadequate knowledge and skill amongst estimators have a strong effect on the accuracy of pre-tender cost estimates. Similarly, Lim et al. (2016) identified that cost estimation is an experienced-based process, which indicates the importance of estimator knowledge and experience for accuracy. Muhammed et al. (2018) positively supported this view by indicating that the experienced QS plays an important role in the assumptions that the estimator uses to calculate an accurate estimate. Moreover, the ability to generalise information based on limited design data was suggested as a skill that has been developed through experience (Brendon et la, 2016). According to Lim et al. (2016), 15 years of experience as a QS could enable the development of a great QS or estimator; this indicates the importance of QS experience and knowledge. A lack of experience does not indicate that a QS is unable to prepare accurate estimates, hence experience matters a lot in terms of operating SW and preparing estimates as it reduces the risk associated with preparing inaccurate cost estimates. Nevertheless, a more experienced QS tends to solely depend on their knowledge and experience rather accept modern technological aid. As human errors are inevitable - even for a highly experienced professional - the use of new technologies would make their job more accurate and risk-free. Therefore, in order to improve the accuracy of pre-tender cost estimates, Sri Lankan QS organisations need to overcome the issues associated with inadequate estimator knowledge and skill.

However, as discussed in section 7.2.3, the use of BIM-based SW, such as CostX, eliminates the use of wrong assumptions, as the BIM model (as pointed out in section 3.3.1) mostly consists of relevant information. Moreover, as these types of SW are specially designed for cost estimating purposes, the QS does not need to put in extra effort by making assumptions. For example, Cubicost TAS can overlay the BIM model with PDF/DWG drawings, so the QS can reduce the risk of inheriting errors from the model. In addition, it also has an error analysis function that enables the QS to interrogate the model and auto-process the overlaps. Moreover, as it conducts automated quantity take-off and generates accurate cost estimates, it eliminates manual programming or the need to develop mathematical formulae for calculations. Therefore, the QS does not require in-depth SW operational skills, and can thus be concluded that the effective use of BIM and its tools results in improved accuracy of pre-tender cost estimates by overcoming the issue of inadequate estimator knowledge and skill.

7.2.5 Isolated Working Culture

The results of the qualitative analysis (see section 6.3.5) illustrated that isolated working culture in Sri Lanka also results in the preparation of inaccurate cost estimates. Results indicate that the Sri Lankan construction industry is mostly driven by individuals rather than organisations. The results of the qualitative analysis also illustrate that isolated working culture mainly occurs due to a lack of coordination, lack of communication and the economic crisis. Findings from the case studies (section 6.3.5.1) endorse this position, as many respondents find a lack of communication through: the use of freelance consultants, poor links among construction professionals, paper-based information sharing, the lack of response to emails, and a lack of coordination. Rather discussion, face-to-face meetings or the minimal use of email, paper-based processes (discussed in section 7.2.2) seem to be the prominent way of sharing information among Sri Lankan construction professionals.

This situation has worsened due to freelance working consultants in the industry. It can be seen that many consultants are working individually within the industry as they can earn more than working in an organisation. In a way, freelance consultation is a way of overcoming the economic crisis, as many clients want to get their job done at a lower cost. As a result, many freelance consultants are working in the industry. Nevertheless, even though some freelancers work collaboratively with other parties, some have weak interaction with other parties, which ultimately results in a lack of coordination among professionals. Findings also revealed that the lack of coordination mainly occurs due to the lack of communication, lack of trust and lack of linkages among professionals (section 6.3.5.2). Many professionals refuse to share information with other parties, as they are not sufficiently trusting of them; moreover, this is perpetuated through poor links among professionals. Therefore, even if the tender is submitted, many areas are not properly coordinated. Apart from that, findings also revealed that economic crises (in general) mainly occur due to political instability and Sri Lanka's status as a developing country (section 6.3.5.3). As a developing country, its economy fluctuates most of the time, and this worsens due to political instability within the country. The political situation has always had a strong impact on the country's economic growth. Therefore, many Sri Lankan clients are still locked within the mentality of getting a job done at a lower cost than clients in developed regions.

Furthermore, this is similar to findings for the quantitative analysis (section 5.5, Table 5.9) in which the majority of participants agreed that the accuracy of pre-tender cost estimates heavily depends upon the type of working culture. Hence, they believed that the lack of communication and coordination are the main reason for the isolated working culture but not the economic crisis. Accordingly, aside from the findings from the qualitative analysis, the quantitative results further indicated that selfishness, a lack of trust, and intense competition among professionals also result in a lack of communication. Besides, as illustrated in Table 5.10, the majority of respondents agreed that repetitive work arises due to the poor links among professionals, which is attributed to the lack of coordination. Participants believed that the lack of coordination occurs as a result of poor linkages among professionals, which arise due to isolated working practice. Indeed, GC (2017) mentioned that one third of employees have no strong relationship with employees at work, due to isolated working culture. ICE (2019) further supported this view by indicating that due to poor relationships, employees do not tend to demonstrate strong communication and coordination. This is particularly important between the designer and QS where communication is crucial for the preparation of accurate cost estimates in order to resolve differences between the designer's drawing copies and those used by the QS. Some organisations operate in this isolated working culture (paper-based information sharing) while many employees try to work in isolation due to personal issues, a lack of fit within organisations and a lack of interpersonal trust.

Besides, political considerations and the economic climate were also identified as strong drivers, which accelerate the isolated working culture (Silicon, 2018). Therefore, it can be concluded that a lack of communication, lack of coordination and economic crises are factors that create an isolated working culture within the construction industry. Indeed, it is clear that an isolated working culture affects the accuracy of pre-tender cost estimates in Sri Lanka; thus, QS organisations need to overcome the issues associated with an 'isolated working culture'.

Nevertheless, many leading organisations are working hard to promote teamwork and employee relationships as it brings considerable benefits (GC, 2017). Golaszewska and Salamak (2017) suggested that introducing processes like BIM help to improve teamwork. As pointed out in section 3.3.4, maintaining good communication is vital when working in a BIM environment. The use of a BIM model requires continuous communication and coordination among team members (Popov et al., 2008) - especially between the designer and the QS - as it helps to build strong, long-lasting relationships among team members. This makes the QS job easier to prepare accurate cost estimates as they receive instant information when sudden changes and updates occurs. Improved collaboration also results in improved communication amongst working parties. The communication improves due to better access to information, which thereby reduces the level of work carried out in isolation (Marsh, 2017). Therefore, the use of BIM improves the accuracy of pre-tender cost estimates through improving the team working culture.

7.2.6 Manual Quantity Take-off (MQTO)

The results of this study identified that MQTO is another factor that hinders the accuracy of pre-tender cost estimates. The respondents identified that, due to inaccurate quantities and extensive time requirements, MQTO is the most challenging task in the entire cost estimate process. Findings from the qualitative case studies (see section 6.3.6) endorse this position, as many respondents found that the lack of information, time constraints, missing elements, double counting, inaccurate assumptions, manual deductions, project complexity and discrepancies in 2D drawings are the main reasons for generating inaccurate quantities in MQTO. Although the QS spends considerable time on the QTO, missing elements, double counting, and manual deductions are inevitable due to the complex nature of projects. Therefore, professionals agreed that, even amongst highly experienced QS's, it is hard to expect 100% accurate quantities in MQTOs. Results also indicated that poor visualisation, changes detection and information updates in MQTO required an extensive amount of time. Thus, the QS has to invest extra effort in carrying out these tasks in a pressurised situation.

The results in section 5.5 (Table 5.13) revealed that respondents further agreed with the above findings. They believe that double counting, missing elements and wrong assumptions are the main reasons for the production of inaccurate quantities. Moreover, they also believed that a MQTO is more challenging, as it does not allow for the preparation of various cost estimates for different design alternatives without substantial rework. Besides, respondents further agreed with the majority that, due to the lack of visualisation in 2D drawings, substantial amounts of time are required for MQTO, as the QS needs to update information and detect changes.

Accordingly, the factor "Manual Quantity Take-off (MQTO)" was ranked fifth among the nine main factors, as illustrated in Table 5.15, which indicates that it has a strong effect on the accuracy of pre-tender cost estimates. Similarly, Gołaszewska and Salamak (2017) identified that MQTO is a time-consuming process that is prone to human error. Tops (2019) similarly indicated that the accuracy of a MQTO solely depends upon the estimator's knowledge and experience. The accuracy of cost estimates heavily depends upon the accuracy of quantities taken during the QTO process. Thus, an accurate take-off can only be undertaken if properly developed designs and details are available. As discussed, in pre-tender stage many designs are incomplete and as such, even an experienced QS cannot guarantee the accuracy of the quantities taken due to high risk of human error. Thus, MQTO is a major issue that needs to be considered by Sri Lankan QS organisations when improving the overall accuracy of pre-tender cost estimates.

Nevertheless, as noted in section 3.3.3, BIM has the ability to accelerate QTO for a construction project while increasing the accuracy of cost estimates by overcoming deficiencies associated with MQTO (Olsen & Taylor, 2017). Automated QTO was the most significant benefit offered by BIM that was identified by QS's, who specified cost estimate programs such as CostX (Eastman et al., 2008; Meerveld, 2009; Wong et al., 2014). This can speed up the QTO process and thereby lead to fewer mistakes and omissions caused by human misunderstanding (Marsh, 2017). However, the use of automated QTO has created new problems; for example, data relating to the take-off must be input during the design stage and the take-off only shows the material quantity included in the 3D model instead of the quantity of used materials (Olatunji et al., 2014). According to Gołaszewska and Salamak (2017) these issues could be overcome by maintaining close cooperation between the design team and quantity surveyors at every stage of the project. Therefore, automated QTO speeds up the process by generating accurate quantities over a shorter time period with fewer miscalculations and omissions due to human error.

7.2.7 Time Constraints

The results of this study indicate that time constraints represent another factor to affect the accuracy of pre-tender cost estimates. Especially in the pre-tender stage, limited time is given for the QS to prepare cost estimates. Findings from the case study analysis (see section 6.3.7) indicated that client pressure and time-consuming tasks are the main consequences of time constraints. Accordingly, findings in section 6.3.7.1 pointed out that limited time given by the client to prepare cost estimates pressurise the QS. Hence, in most cases, the QS has to work under pressure to meet the given deadline without considering the accuracy of cost estimate. Apart from that, the findings in section 6.3.7.2 indicated that time-consuming tasks are another reason for time constraints. Accordingly, the MQTO, site visits, obtaining information and drawing updates were identified as the most time-consuming tasks. Respondents further indicated that the QS does not get enough time to conduct site visits before preparing cost estimates and as a result the QS can fail to identify and include some items, such as accessibility (roads), to the estimate. This indicates a strong relationship between site visits and the accuracy of pre-tender cost estimates.

Furthermore, these findings are similar to participants' responses from the quantitative analysis (section 5.5, Table 5.11) to which the majority agreed that the limited time given for the preparation of cost estimates reduces their accuracy. Accordingly, they believed that, due to the time constraints, the QS has to carry out a substantial workload under pressure, and as a result, they tend to take shortcuts - such as guess estimation - which increases the inaccuracy of cost estimates. Moreover, the findings in Table 5.14 illustrated that the majority of respondents agreed that the lack of site investigations were due to limited time, and that this led to inaccurate cost estimates. They confirmed that the QS's awareness of site conditions is essential to prepare accurate cost estimates. Accordingly, the factor 'time Constraints' was ranked eighth among nine main factors, as illustrated in the Table 5.15; thus, indicating that time constraints have a strong effect on the accuracy of pre-tender cost estimates. Therefore, it can be concluded that client pressure and time-consuming tasks, such as site visits, are consequences of time constraints, which affects the accuracy of pre-tender cost estimates. Torp and Klakegg (2016) identified that the limited time given to prepare cost estimate is a crucial factor that affects the accuracy of pre-tender cost estimates. Hatamleh et al. (2018) indicates that accurate estimates can only be prepared if the estimator considers the site constraints (access, storage, services) during the preparation of cost estimates. This indicates the importance of conducting site visits prior to the preparation of cost estimates.

Moreover, as pointed out in section 3.3.6, the replacement of automated QTO saves the significant amounts of time that the QS had to otherwise spent on counting things, which subsequently increases the pressured environment. Therefore, to overcome 'time constraints' Sri Lankan QS's need to find more efficient ways to address time-consuming tasks, such as MQTO, which will save considerable time to spend on other tasks, such as site visits. The use of BIM will save extensive time through the application of automated QTO (Ajibade & Aibinu, 2012); this means reducing QS time spent on collecting information from various sources and stakeholders (Mattsson, 2013). Therefore, saved time can be used to conduct site visits and prevent the QS from taking shortcuts, such as guess estimations, which increase the accuracy of cost estimates.

The above discussion summarises the factors affecting the accuracy of pre-tender cost estimates and the use of BIM to improve the accuracy of pre-tender cost estimates by overcoming the identified affecting factors. Figure 7.1 illustrates the updated version of the conceptual framework for objectives 1 and 2 based on the discussion within section 7.2.

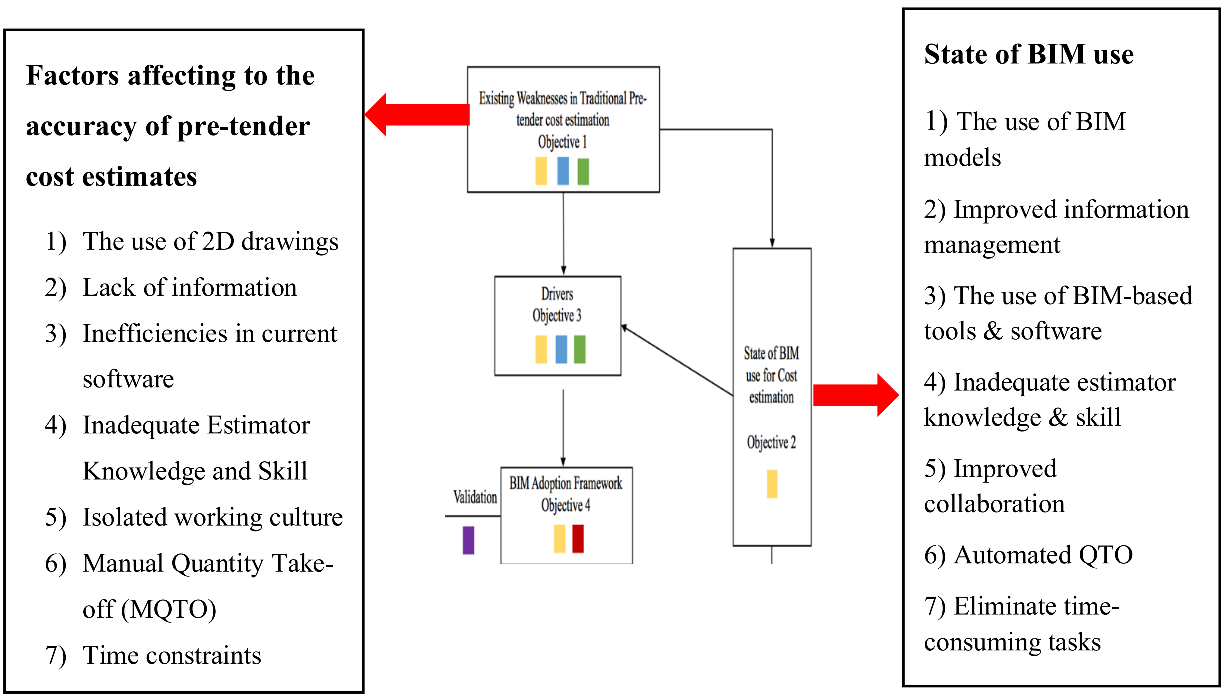


Figure 7.1: Updated conceptual framework for objectives 1 and 2

7.3 BIM Adoption Drivers

The study results indicated that BIM benefits, client demand, challenges in traditional cost estimation, government intervention, BIM education, and BIM training are the key drivers for BIM adoption that were recognised by respondents as drivers for BIM adoption.

7.3.1 BIM Benefits

The study results indicate that BIM benefits are the main key driver for Sri Lankan QS organisations to adopt BIM within their current practice. The case study findings (qualitative) (see section 6.4.1) endorsed this position, with many respondents finding that the use of a BIM model, automated quantity take-off, improved visualisation, improved information management, clash detection and time-saving are the main benefits that BIM has to offer to improve the accuracy of cost estimates. Respondents indicated that the BIM-model denotes a major difference between traditional cost estimation and the BIM-based cost estimation. As a result, the use of BIM models has made the job of a QS easier by saving time which they used to spend on tracking changes, manual QTO, etc. However, respondents also noted the importance of the accuracy of the BIM model and its embedded information. As every measurement taken is based on the model and its given information, the model must be accurate from the outset to ensure a better outcome. Moreover, automated QTO was found to be the major driver amongst respondents for the adoption of BIM, as it generates accurate quantities and estimates by saving the QS time. Improved visualisation has also resulted in BIM adoption by offering early clash detection due to the use of a BIM model. As a result, the QS can easily identify the elements in the model without any misinterpretation. Besides, as every element in the model consists of all the information the QS needs, they can easily grab the data at any stage of the project without any disturbance. Therefore, it can be concluded that respondents were able to increase visualisation, automated quantity take-off and improved information management with the use of a BIM model. Therefore, there is a relationship between the use of BIM models and increased visualisation, automated quantity take-off and improved information management (see Figure 7.2). Besides, respondents also agreed that the use of BIM has improved productivity by minimising the demand for resources and the time needed for one task.

Furthermore, it is similar to the participants' responses from the quantitative analysis (section 5.9, Table 5.18) in which the majority agreed on the following benefits of BIM use: the use of a BIM model (ranked sixth, Table 5.20), improved visualisation (ranked fifth), information management (ranked seventh), automated QTO (fourth), improved communication (ninth) and coordination (tenth). Moreover, they further agreed that easy access to information (ranked eighth) also offers a strong benefit to adopt BIM. Accordingly, respondents confirmed with the majority indicated that BIM benefits are a key driver for BIM adoption. Besides, Mohammad et al. (2018) indicated that the advantages of BIM would influence its adoption among quantity surveyors. Moreover, BIM enables estimating capabilities, such as visualisation, coordination and communication, automated QTO, information management and time saving which also encourages its BIM adoption (Anifowos et al., 2018; Rathnayake et al., 2018). As the use of BIM eliminates most of the major challenges in the traditional cost estimating process, many QS organisations tended to use BIM as a solution. Therefore, it can be concluded that the benefits of BIM act as a main driver for Sri Lankan QS organisations to adopt BIM within their current cost estimating practices.

7.3.2 Client Demand

The study results indicate that client demand is one of the main key drivers for Sri Lankan QS organisations to adopt BIM. The qualitative case studies findings (see section 6.4.3) endorse this position, as many respondents find they tend to use BIM due to the requests from foreign clients. Accordingly, as they do not want to lose future contracts, organisations have started to implement BIM within their practices. This indicates a strong relationship between client demand and organisational pressure (see section 7.3.6) as clients requests pressurise organisations to adopt BIM. Respondents from the quantitative data collection further supported this finding (section 5.9, Table 5.19), by strongly agreeing that client demand drives the adoption of BIM. Moreover, client demand was ranked third out of the ten driving factors (see Table 5.20). These findings reflect those of Siriwardhana et al. (2018) who indicate that some local clients (Sri Lankan) have requested BIM for apartment projects. This indicates that both requests from foreign clients and those from local clients have driven BIM adoption. Moreover, according to NBS (2019), clients have proven to be the key driver in BIM adoption. Therefore, it can be concluded that client demand can act as a main driver for Sri Lankan QS organisations to adopt BIM.

7.3.3 BIM Training

BIM training was found to be another key BIM driving factor for Sri Lankan QS organisations. Generally, it was noted that many organisations have provided training by using foreign BIM professionals. Besides they have also used their own strategies to provide training, such as tutorial sessions, workshops, CPD and group discussions. The qualitative case study findings (see section 6.4.2) endorsed this position, and many respondents find that training provided by organisations have really helped them to adopt a BIM-based working environment. Besides, they also believed that continuous training is important, not only for the current employees but also for new staff joining the organisation. Some organisations have asked their employees to undertake on-going training courses conducted by educational providers and professional bodies, which indicates that BIM training has a relationship with organisational pressure, BIM education and professional bodies (Figure 7.2). This view was further supported by the literature; according to Epasinghe et al. (2018), many BIM training programs have helped the implementation of BIM in the Sri Lankan construction sector. Hamma-adama (2019) positively supported the view that trained professionals easily deal with BIM tools within their practice. Ideally, proper training helps employees to improve their confidence in using BIM. Therefore, BIM training was found to be another BIM adoption driver for Sri Lankan QS organisations.

7.3.4 Professional Bodies

Results also illustrate that professional bodies are another BIM driver for Sri Lankan QS's to adopt BIM. The qualitative case study findings (see section 6.4.5) endorse this position as many respondents indicated that conferences, workshops, training and seminars organised by professional bodies supports them to adopt BIM by increasing awareness. Moreover, it also helped many project stakeholders - e.g. clients - to increase their BIM knowledge. As a result, many clients tend to request BIM for their projects. Therefore, professional bodies indicate a strong relationship between BIM education, organisational pressure and client demand, as professional bodies can enhance client demand and organisational pressure through BIM educational programs and BIM events (Figure 7.2). Besides, respondents from the quantitative research phase further supported this (section 5.9 Table 5.19), by strongly agreeing that the involvement of professional bodies drives BIM adoption. Also, professional bodies were ranked second based on its RII value, by indicating that professional bodies are a strong BIM driver. However, the results also revealed that current support from professional bodies do not facilitate successful BIM adoption. Therefore, industry professionals expect greater involvement from professional bodies towards BIM adoption. According to Gajendran and Gof (2012), the involvement of professional bodies in the AEC sector have promoted BIM adoption through developing BIM agendas and professional BIM development activities for members. Consequently, a professional body would offer a springboard for the construction industry to implement BIM by a larger number of professionals in different disciplines. Thus, in Sri Lanka, the only acting body for BIM is the University of Moratuwa (Suranga et al., 2014). However, according to Wedikkara (2018), the Institute of Quantity Surveyors Sri Lanka (IQSSL) actively promotes BIM among quantity surveyors and other professionals through BIM symposiums, technical sessions and CPD events. This elaborates the contribution of other professional bodies towards BIM adoption. Therefore, professional bodies were found to be another BIM adoption driver for Sri Lankan QS organisations.

7.3.5 BIM-Based Education

BIM-based education was found to be another BIM adoption driver by respondents. Qualitative case study findings (see section 6.4.4) endorse this position as many respondents find that BIM related courses conducted in the private sector help them to learn about BIM in depth. Accordingly, it helps to increase the awareness of BIM benefits for most construction clients, which ultimately increases demand for BIM use. This illustrates that the education driver has a strong relationship with client demand driver due to increased awareness of BIM (Figure 7.2). However, results also reveal that many BIM-based courses are only designed to cover the theoretical aspects, but not the practical aspects of BIM. Besides, the majority of government universities are not engaged with BIM-based courses and have limited BIM learning facilities to local students. Nevertheless, respondents believed that the intervention of professional bodies (see section 7.3.4) to conduct BIM courses, conferences, workshops and CPD have made the path to BIM adoption easier. This revealed a relationship between the education driver and the professional bodies driver (Figure 7.2). Moreover, some education providers have started to provide BIM training as part of their range of courses to fulfil industry needs. This was further enhanced with requests made by particular organisations due to client demand (see section 7.3.2), which motivated their employees to obtain external training on BIM use. In the meantime, client requests also increased the number of BIM events. Therefore, it is clear that client demand and organisational pressure have increased BIM education, which indicates that the BIM education driver has a strong relationship with client demand and organisational pressure.

Respondents to the quantitative data collection supported this finding section 5.9 (Table 5.19), by strongly agreeing that BIM-based education is a strong driver for construction professionals to adopt BIM. Moreover, according to Table 5.20, this factor was ranked eleventh out of 13 identified factors. According to Weddikkara (2018), in Sri Lanka the majority of degree programs have now introduced BIM as a module alongside specific training for 5D BIM enabled software. Moreover, according to Rathnayake et al. (2018), short BIM courses conducted in the private sector are well-liked among young QS's. It was also noticed that the number of BIM-based publications increase day-by-day in Sri Lanka, which implies that BIM education is there up to some extent. Therefore, BIM-based education was found to be another BIM driver for Sri Lankan QS's.

7.3.6 Organisational Pressure

The study results indicate that organisational pressure is another major BIM driver for Sri Lankan QS's to adopt BIM. The qualitative case study findings (see section 6.4.6) endorse this finding, as many respondents find that with increased foreign client demand some organisations have mandated the use of BIM within their organisation. This indicates that organisational pressure has a strong relationship with the client demand driver. Moreover, the findings further reveal that increased BIM awareness about the benefits and intervention of professional bodies (discussed in section 7.3.4) also resulted in organisational pressure to adopt BIM. Therefore, it can be concluded that the organisational pressure driver has a significant relationship with the client demand driver, BIM benefit driver, BIM education driver and professional bodies driver (Figure 7.2). Moreover, decisions taken by top management have placed extra pressure on employees to learn and adopt BIM. Respondents from the quantitative data collection further supported this finding (section 5.9, Table 5.19), by strongly agreeing that organisational pressure accelerates the adoption of BIM. Also, this factor was ranked first according to the RII value (Table 5.20), which indicates that organisational pressure is the major driver for a QS to adopt BIM. This view was further supported by the literature; according to Ahamed et al. (2017), formal organisational pressures, such as mandates and regulations, lead to successful practices among employees which thus overcome beliefs, norms, and conventions. Therefore, it can be concluded that organisational pressure is another BIM driver identified by Sri Lankan QS's.

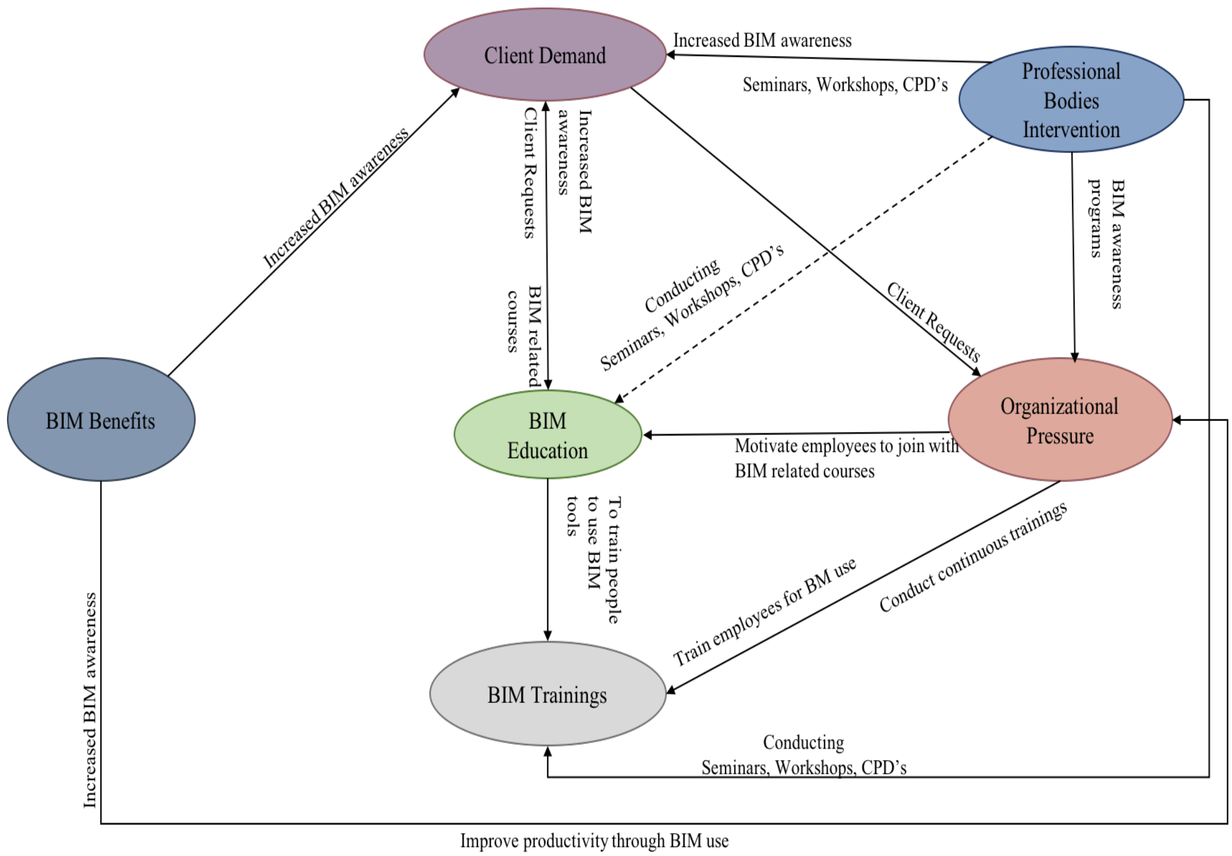


Figure 7.2: Schematic diagram of the significant relationship between BIM adoption drivers

The above discussion summarises the factors that drive the adoption of BIM within Sri Lankan QS organisations. Accordingly, Table 7.1 lists the BIM drivers that emerged from the analysis.

Table 7.1 BIM Drivers

Drivers	Cases Studies	Questionnaire survey	Literature review
BIM Benefits	✓	✓	✓
Client Demand	✓	✓	✓
BIM Trainings	✓	✓	✓
Professional Bodies	✓	✓	✓
BIM-based education	✓	✓	✓
Organizational Pressure	✓	✓	✓

Figure 7.3 illustrates the updated version of the conceptual framework for objective 3 (BIM drivers) based on the discussion in section 7.3.

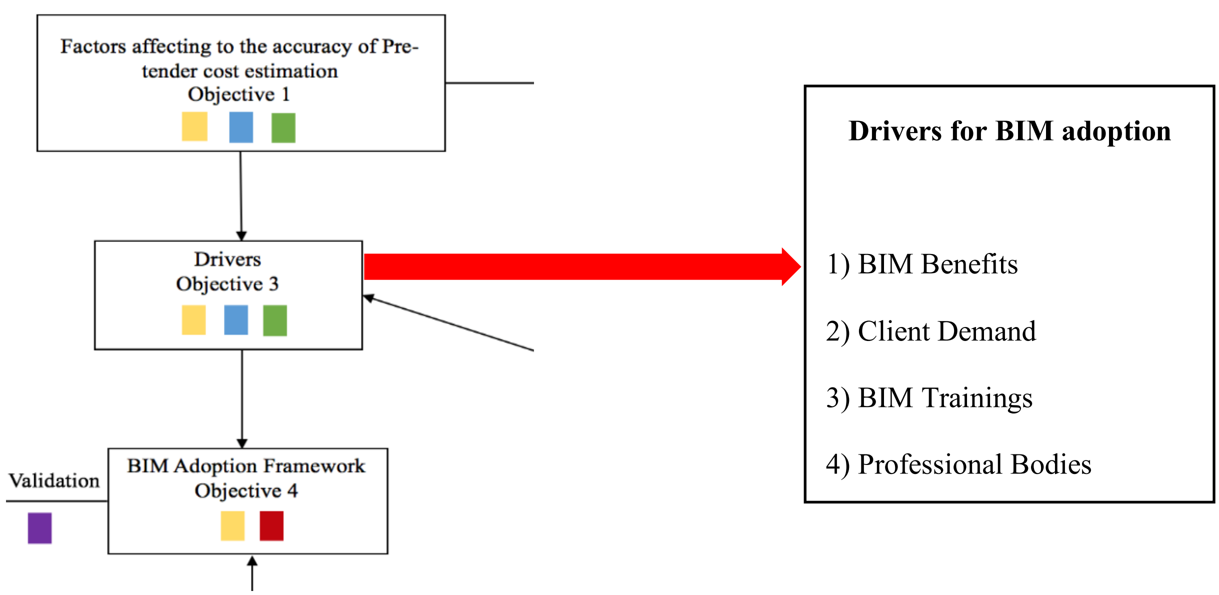


Figure 7.3: Updated conceptual framework for objective 3 - BIM drivers

7.4 Barriers to BIM Adoption

The study results indicate that financial, organisational, regulatory, lack of awareness, minimal resources and a lack of market demand for BIM are key barriers for its adoption.

7.4.1 Financial Barriers

Respondents considered the financial capability of an organisation as a barrier to BIM adoption. As illustrated in Table 5.27, financial barrier was ranked third (as per the calculated RII value) among the six major barriers. Most individual practitioners refuse to invest in BIM as it is not affordable for them. However, so far, only large-scale QS organisations have started to use BIM, which indicates their financial affordability. The qualitative findings from this study (see section 6.5.1) indicate that the cost of hardware and software, upgrade costs, training costs and the lack of goals (discussed in section 7.4.2) are the core issues underpinning the financial barriers. The qualitative case study findings (Qualitative) (see section 6.5.1.1) endorse this position, as many respondents find that the initial investment for hardware and software is too high. Software, such as CostX, does not exist in any duplicate versions. Therefore, it is necessary to get the original version, which is extremely expensive. Due to the lack of demand for BIM from the industry many organisations lag behind in investing in new software and hardware. This indicates a lack of market demand for BIM, which has resulted from financial issues. Therefore, a strong relationship exists between the financial barrier and the lack of market demand barrier, which is attributed to the initial investment for new hardware and software (Figure 7.4). However, results also indicate that the cost of hardware and software can be minimised if organisations can identify appropriate processes to implement. Moreover, defined goals would help to minimise the initial investment for hardware and software. This indicates that the lack of goals has resulted from increased of hardware and software costs. Therefore, it can be concluded that the costs of software and hardware have a strong relationship with the lack of goals.

Furthermore, these are similar results to the participant responses from the quantitative phase (section 5.11.1), in which the majority confirmed that financial barriers affect the adoption of BIM. Accordingly, as indicated in Table 5.21, the majority of respondents agreed that cost of new software and hardware have resulted in the financial barrier. Indeed, Epasinghe et al. (2018) also identified that computer hardware and software are key requirements for the successful adoption of BIM. According to Siriwardhana et al. (2018), there are some technological companies in Sri Lanka with the capability of providing BIM hardware and software for a reasonable cost. Jayasena et al. (2018) indicate that FOSS (Free and Open Source Software) support is available to Sri Lankan QS organisations through many methods, such as online forums, purchase vendor support from third party companies, support software by the company itself and project sponsor support. Besides, according to Weddikkara (2018), organisations should discuss their needs with software service providers to negotiate the software cost, which would offer a solution to the high costs. Therefore, there are plenty of ways that Sri Lankan QS organisations can fulfil their hardware and software requirements at a lower cost.

As pointed out in section 6.5.1.2, training costs are another core issue underpinning the financial barriers. As Sri Lanka does not have any industry BIM experts, many organisations have to hire international BIM experts to provide training for employees, which is extremely expensive. High training costs have a strong relationship with the unawareness barrier due to the lack of BIM education within the country (Figure 7.4). Moreover, the risk of providing training for employees is that once training is provided, many organisations like to hire BIM trained QS's. As a result, many organisations do not want to invest in people's training. Moreover, the lack of organisational intervention has also resulted in high training costs due to the lack of goals and processes, which indicates a strong relationship between the financial and organisational barriers (Figure 7.4). Furthermore, it is quite similar to the participants' responses from the quantitative data collection (section 5.11.1); they agreed with the majority that the cost of training existing staff would be an expensive process for BIM adoption. However, it will be cheaper than hiring additional external staff (BIM specialised). Kumara et al. (2017), suggested that, to overcome the high cost of training and the associated risks, organisations should ask software vendors to provide training for their existing staff, rather than hire external professionals.

As pointed out in section 6.5.1.3, software and hardware upgrade costs also represent another issue for the financial barrier. Organisations also have to bear the annual maintenance and upgrade costs for BIM software and hardware, which adds another cost to any BIM adoption. This was further supported by the quantitative findings (section 5.11.1, Table 5.21) for which the majority agreed that upgrade costs result in financial issues. Epasinghe et al. (2018) similarly mentioned that hardware and software require expensive annual upgrades to ensure bug fixing and the installation of new features to meet project requirements. Although some upgrades can be carried out for free, this depends upon the vendor. To summarise, in Sri Lanka the transition to BIM is hard and expensive, mainly due to training, hardware and software, maintenance and upgrade and the recruitment of additional staff. Consequently, for many construction organisations, cost represents the main internal barrier, which prevents the adoption of BIM (NBS, 2018, 2019). Unless the aforementioned issues are supported with solutions, the financial barrier persists for BIM adoption amongst Sri Lankan QS organisations. Nevertheless, Siriwardhana et al. (2018) noted that collaboration with funding agencies, such as the government, and private and leading companies, would offer a key solution to overcome the financial barrier for Sri Lankan QS organisations.

7.4.2 Organisational Barriers

Organisational issues were found to be another barrier to BIM adoption. As noted in Table 5.27 organisational barriers (internal pressure) were ranked fifth out of six main barriers. The qualitative case studies findings (see section 6.5.2) endorse this position; many respondents find that only a few organisations have already started using BIM. Thus, the majority are not using, or are not in the process of adopting, BIM and this is due to several organisational issues. Results indicate that isolated working culture, people's mind-sets, the fear of sharing responsibilities, reluctance to change, and a lack of goals and processes are the main reasons for the organizational barrier. Qualitative findings (section 6.5.2.1) revealed that the isolated working culture prevents true collaboration which is required for BIM adoption.

As discussed in section 7.2.5, the isolated working culture arises from an individually driven industry and an economic crisis. Accordingly, many individuals work alone to earn a good profit, which offers a solution to the economic crisis. This reveals a relationship between the organisational barrier (isolated working culture) and the lack of market demand barrier (economic crisis) (Figure 7.4).

Many parties - especially architects - do not maintain proper relationships with other industry stakeholders due to ego and selfishness. BIM requires all stakeholders to work on the same platform, which brings a number of benefits, as discussed under section 7.3.1. Nevertheless, existing isolated working culture does not facilitate true BIM collaboration, unless there is a phycological change in employees. Therefore, suggestions indicate that positive changes to employees' phycology and mentality are required. Moreover, training students and professionals on an ad-hoc basis would offer another solution to overcome the isolated working culture. Furthermore, this outcome is similar to participants' responses from the quantitative data collection (section 5.11.4, Table 5.24), the majority agreed that weak corporation between different disciplines result in isolated working. According to Hughes and Ferrett (2016), a positive collaborative culture should be implanted within the industry. Moreover, PAS1192-6:(2018) emphasised the use of structured processes, techniques and advanced digital technologies to support collaboration issues (BSI, 2018).

Findings in the qualitative analysis (section 6.5.2.2) revealed that a fear of sharing responsibility also affects true collaboration. BIM demands more teamwork than individual practice. However, due to people's mind-sets, they are not ready to work as a team and to share responsibilities, which prevents the sharing of information and effective communication. Nevertheless, suggestions indicate that, encouraging employees to think they are working as a team could help to reduce fear and promote the sharing of responsibilities. To achieve this, organisations should encourage the development of a supportive culture. Furthermore, these findings are similar to the results from the quantitative analysis (section 5.11.4, Table 5.24) in which they agreed with the majority that the inflexible mind-set of staff has resulted in employees not sharing any responsibilities.

Besides, results in section 6.5.2.3 indicate that people's mind-sets prevent changes within the organisation due to on-going traditional practices. However, it is also noted that the young generation welcomes change, while senior employees do not expect to change their traditional working style. Moreover, the majority of respondents agreed (section 5.11.4, Table 5.24) that people refuse to learn new technologies due to traditional mindsets. According to Kumara et al. (2017), for over two decades Sri Lankan QS's have used 2D drawings, which are embedded with traditional methods and procedures. Epasinghe et al. (2018) also mentioned that 76% of Sri Lankan construction companies use MS Office packages and Autodest AutoCAD, while less than 6% of QS's using CostX. This indicates that, even if more advanced and relaxed technologies are available for use, the prevailing mindset of QS's tends to close the doors to new methods and processes. Therefore, suggestions indicate that top management is responsible for changing existing individualistic working culture to teamwork through shifting employees' mind-sets.

Reluctance to change (in section 6.5.2.4) was found to be another issue within the organisation, and this was attributed to language difficulties, traditional practice, the lack of welcome from the government sector to change, the fear of job loss, the lack of trust, selfishness, and the myth that BIM is hard to learn. Respondents revealed that unawareness about BIM has resulted in the above consequences, which reveals a relationship between unawareness (lack of BIM education) and the organisational barrier (reluctance to change) (Figure 7.4). According to Sardroud et al. (2018), many companies do not intend to use BIM, as they believe it is complicated to adopt either within their organisations or in projects. As many organisations do not have any experience of dealing with BIM, they assume that BIM is an immature technology with limited competences. However, results also indicate that some organisations have overcome employees' reluctance to change by maintaining an innovative culture in which anyone can share anything that motivates them to learn about BIM. Moreover, Monyane and Ramabodu (2017), indicated that the use of BIM will reduce the need for the traditional QS role by giving such opportunities to emerging roles, such as advising on procurement measures or suggesting the best building materials for use, including sustainable options. Instead, BIM can strengthen the role of the QS by securing their place within the construction industry.

Findings in section 6.5.2.5 revealed that the lack of defined goals and processes is another organisational issue for BIM adoption. Many organisations fail to identify what they are going to achieve by adopting BIM. Identifying the end goal, for example improving the accuracy of cost estimates, and reducing the size of the investment as it helps to determine the exact tools and technologies required. Moreover, respondents believed that understanding BIM and trying to improvise some of the processes identified to achieve the end goal would be the best way to adopt BIM. According to Mayo et al. (2012), many clients want to mandate BIM within their projects and organisations without knowing the end goal. Nevertheless, results suggest that organisations should start with BIM adoption to figure out the end goals and processes. Therefore, it is fair to assume that the adoption of BIM among Sri Lankan QS organisations has been affected by the aforementioned issues; thus, organisational barriers need to be overcome for the successful adoption of BIM.

7.4.3 Regulatory Barriers

Respondents also recognised that regulatory issues represent another barrier to prevent BIM adoption. The qualitative case study findings (see section 6.5.3) endorse the same position as many respondents find that the lack of policies, contractual issues, legal issues and the lack of ethical behaviours are the main issues underpinning the regulatory barriers. Findings in the qualitative section 6.5.3.1 reveal that a failure to define the ownership of the model and undefined responsibilities within the model are the main reasons for legal issues. Therefore, as a solution, it was suggested that the BIM model should be frozen in lump sum contracts. This was further supported by the results in the quantitative section 5.11.3 (Table 5.23), in which respondents agreed with the majority that, as the ownership of the model is undeveloped, and it is too risky to use the model, anyone can make changes at any time. Moreover, if the architect is given the wrong dimensions when designing the model, the QS carries out their work based on the information given in the model, which is not accurate. Thus, it deters an employee from developing a teamwork mindset, as there is no one to take the responsibility for the model. Therefore, Sardroud et al. (2018) identified intellectual property rights as determiner of BIM adoption. Ghaffarianhoseini et al. (2016) positively supported this view by indicating that model ownership, copyright, legal and illegal use of the models, and the extent to which trade information should be disclosed as important provisions in the intellectual property rights of contracts. Moreover, it is important to establish ground rules for using the model and its data, such as who is permitted to use the data and the penalties when it is used inversely (Miller, 2019).

Findings in the qualitative analysis section (6.5.3.2) indicate that contractual issues are another reason for the absence of BIM-based contracts and the failure of existing contracts to facilitate proper BIM-based practice. Many respondents complained that a lack of support from professional bodies has failed to develop a suitable BIM-based contract for the Sri Lankan context. This further reveals the relationship between regulations and the lack of market demand (Figure 7.4). Suggestions indicated the need for BIM friendly contractual standards that consider the Sri Lankan construction industry context. Moreover, this was further supported by the findings in the quantitative section (5.11.3, Table 5.23), which confirmed that incompatibility with current standard measurements prevent the QS from adopting BIM. Hence, the RICS has introduced International Construction Measurement Standards (ICMS), which provides the parameters for both BIM software vendors and users (QS) in terms of cost estimating (ICMS, 2018). Therefore, new standards will eliminate the gap between contractual issues and BIM adoption. Hence, a recent survey revealed that the majority of the professional BIM users are not aware of BIM standard forms of contract (Abdirad, 2015), which indicates that the use of BIM contracts - such as ICMS – are still not popular among QS's worldwide.

Besides, qualitative results also identified a lack of policies, which is due to the lack of professional and government involvement (section 6.5.3.4). Although many BIM-adopted countries have their own policies for its adoption, in the Sri Lankan construction industry there are no policies to drive BIM adoption. This indicates a strong relationship between the lack of market demand and the regulatory barrier (Figure 7.4). Therefore, the government and professional bodies are responsible for defining and executing policies for BIM adoption. However, suggestions indicate that policies should be developed according to threshold, issues and repercussions. Moreover, enforcement is also essential to ensure the execution of developed policies.

The findings from the qualitative analysis section (6.5.3.5) also identified that the lack of ethical behaviour is also another issue for the regulatory barriers. As a result, many organisations have tended to use trial and duplicate versions of software, such as AutoCAD. Many organisations and individual practitioners have tended to use trial versions due to the high cost of software. This indicates a relationship between the regulatory barrier and financial barrier, which is attributed to ethical behaviours (Figure 7.4). Therefore, respondents indicate the importance of having certain standards and guidelines to improve ethical behaviours, as many BIM software providers do not offer duplicate or trial versions. Epasinghe et al. (2018) mentioned that it is essential to have standards for technology usage in order for each user to equally experience success or failure. Therefore, it is reasonable to assume from the above issues, that regulations represent a main barrier for the adoption of BIM by Sri Lankan QS firms. Thus, to encourage successful adoption, it is important to address these issues.

7.4.4 Unawareness

Unawareness was found to be another barrier that hinders BIM adoption within Sri Lankan QS firms. As pointed out in Table 5.27, unawareness was ranked second out of six main barriers. As a result of this issue, BIM is at a very immature stage in Sri Lanka, categorised as 'little to non-existence'. The results in the qualitative section (6.5.4) noted the following are the main reason for this unawareness: lack of knowledge sharing, the absence of a BIM initiator, the lack of BIM education, and the gap between industry and academia. Findings in the qualitative section (6.5.4.1) identified that selfishness, the lack of communication, isolated working culture and the ego of senior professionals within the organisation have resulted in a lack of knowledge-sharing among employees. In other words, the existing organisational culture has a strong impact on knowledge-sharing. Therefore, it can be concluded that a relationship exists between the organisational barrier (isolated working culture) and unawareness (lack of knowledge sharing) (Figure 7.4). However, suggestions indicated that teaching and learning should be part of organisational culture for both senior and junior employees, which accelerates knowledge sharing. According to Gunaratne et al. (2016), the individualistic organisational culture in Sri Lanka plays a vital role in terms of creating and sharing knowledge. Moreover, Pushpamali (2016) indicates that individualistic organisational culture has result in: a lack of communication and a lack of trust among employees, which impacts on knowledge sharing. Unfortunately, in many organisations, knowledge sharing is not embedded within the organisation's culture.

Findings from the qualitative analysis section (6.5.4.2), indicates that the lack of government and professional involvement are main reasons for the absence of BIM amongst much of the industry. Although no government involvement can be seen, professional bodies (such as ICTAD, IQSSL, and CIDA) have a minimal involvement in increasing BIM awareness, through workshops and conferences, which indicates they have done something. However, this further indicates a relationship between the lack of market demand barrier (lack of government intervention and lack of professional bodies intervention) and unawareness (absence of a BIM initiator) (Figure 7.4). However, suggestions indicate that universities, professional bodies, and the government should develop standards to initiate BIM and offer island-wide BIM workshops, CPD and conferences. This was further supported by the majority of respondents from the quantitative data collection (section 5.11.5, Table 5.25), who confirmed that the that lack of support from professional bodies and government meant the failure to identify a BIM initiator. However, results also suggest that architects should be the BIM initiators, although only one architectural firm is practicing BIM at the moment. Indeed, Kumara et al. (2017) identified that encouraging architects to use BIM should be the first step towards its adoption in Sri Lanka. Moreover, Jayasena et al. (2017) suggested that the establishment of training programs, lecture sessions, and piloting Revit on selected small projects (such as houses) would accelerate the use of BIM among Sri Lankan architects.

The qualitative analysis in section 6.5.4.3 identified that a lack of BIM education also results in unawareness. The lack of industry demand for BIM, lack of BIM experts, lack of BIM courses, absence of BIM within the education curriculum, lack of BIM education providers and lack of BIM seminars, workshops and conferences were noted as the main reasons for a lack of BIM education. Findings further indicated that the lack of industry demand (from clients) has resulted in the lack of BIM seminars, workshops, CPD and conferences, which indicates a strong relationship between the lack of market demand and unawareness (Figure 7.4). Moreover, due to lack of BIM expertise (as discussed in section 7.4.5), unawareness has another relationship with the lack of resource (Figure 7.4). These results were further supported by the majority of respondents within the quantitative analysis section

(5.11.2, Table 5.22), who confirmed that the lack of BIM seminars, workshops and conferences, lack of BIM related training and lack of BIM courses results in the lack of BIM education. Moreover, due to the absence of on-going live BIM projects, education providers struggle to provide practical BIM-based education programs. In agreement, Sardroud et al. (2018), noted that access to run-time BIM-based projects offered another way of encouraging stakeholders to use BIM.

Moreover, Epasinghe (2018) indicated that the lack of BIM-based projects in Sri Lanka represents a major problem for BIM adoption, whilst Siriwardena et al. (2018) suggested that the government should take the initiative for BIM education due to the absence of proper BIM education programs in both the private sector and the government. Therefore, according to Wijeywickrama et al. (2018), the Sri Lankan government has to play the role of educator for the BIM adoption strategy. Besides, Rathnayake (2018) identified that incorporating BIM into the education curriculum is another way of increasing BIM awareness. Besides, professional institutions (such as IQSSL, SLIA and RICS) should continuously promote BIM programs with the help of foreign institutions and the University Grant Commission (UGC) (Wedikkara, 2018). Moreover, Weddikkara (2018) states that Masters and PhD level BIM-based programs and exchange programs should be introduced to government universities in collaboration with foreign universities.

Besides, findings from the qualitative analysis section (6.5.4.4) indicate that a lack of communication and an isolated working culture were the main reasons for the gap between industry and academia, which also impacted on BIM unawareness. Therefore, this also reveals a relationship between the organisational barrier (isolated working culture) and unawareness (gap between industry and academia) (Figure 7.4). Awareness should come not only from academia but also from industry. Hence, according to Odubiyi et al. (2019), there is an identifiable gap between construction industry academics and practitioners. Therefore, certain competencies expected by the industry cannot be seen in present-day QS graduates (Perera, et al., 2011); for example, many QS's struggle to work with BIM tools. However, in many countries - including Sri Lanka - the role of the BIM demonstrator within the BIM adoption strategy is unclear. According to Siriwardene et al. (2018), the absence of an organisation to test and demonstrate new technologies increases the gap between industry and academia. Suggestions indicated that the Sri Lankan government should perform this role. Furthermore, the continuous promotion of BIM practices amongst academics and industry practitioners would help to address this gap (Weddikkara, 2018), which confirms that connections between academics and industry professionals are significant. Hence, isolated working culture in the Sri Lankan construction industry has created a huge gap between industry and academia, which makes BIM adoption more awkward. Accordingly, unawareness is among the barriers that affect BIM adoption within Sri Lankan QS organisations.

7.4.5 Lack of Resources

Respondents recognised that the lack of resource is a serious barrier to the adoption of BIM. As noted in Table 5.27, this factor ranked first among the six major barriers. Results from the qualitative analysis (section 6.5.5) indicated that the following are the main resource issues for BIM adoption in Sri Lanka: a lack of BIM experts, the absence of a BIM implementation plan, a lack of BIM models, the limited number of SW licenses, limited internet facilities, and a lack of training. As pointed out in section 6.5.5.1, many respondents find that the lack of BIM education (discussed in section 7.4.4) and few industrial BIM experts are the main reasons for the lack of BIM experts. Accordingly, the findings indicated that the lack of BIM courses has a substantial impact on the development of BIM experts. This further reveals a strong relationship between the unawareness (lack of BIM education) barrier and the lack of resources (lack of BIM experts) (see Figure 7.4). Besides, respondents believe that BIM experts are a fundamental requirement for the coordination among project stakeholders. Therefore, suggestions indicate the need to formulate the role of a BIM manager within the Sri Lankan construction industry. Besides, experts should not be limited to academia, as industrial BIM experts accelerate its usage within the industry. Therefore, the interviewees believed that the hiring of international BIM experts offers a solution for the current lack of local BIM experts. However, as it more expensive to hire international BIM experts, properly established BIM education should aim to develop local BIM experts for the Sri Lankan construction industry. Besides, the quantitative analysis in section 5.11.6 supported this point, that the lack of suitable BIM skilled staff and the lack of BIM experts hinder its adoption. The RICS (2019) identified that the lack of BIM skilled people is a key obstacle to BIM adoption, which has meant that many organisations have outsourced this role to other countries. Similarly, Kushwaha (2016) mentioned the lack of BIM-skilled staff makes the AEC industry vulnerable to adhering to traditional practices. Therefore, Weddikkara (2018) suggested that the continuous promotion of BIM programs would offer a solution by increasing the number of BIM experts within the industry.

As pointed out in qualitative analysis section 6.5.5.2, the absence of a BIM implementation plan/strategy is another resource issue for BIM adoption. The need for its adoption has to be identified at the management level, which indicates that organisational intervention is required by top management. Therefore, it can be concluded that there is a relationship between the organisational barrier (top management intervention) and the lack of resources (absence of BIM implementation plan), as illustrated in Figure 7.4. Suggestions indicate that management is responsible for identifying goals and developing their own strategies and processes to implement the goals identified to encourage BIM adoption. Furthermore, interviewees also believed that a nationally developed BIM framework with the aid from early BIM adopters would accelerate its uptake among Sri Lankan construction practitioners. This was further supported by the findings in quantitative section 5.11.6 (Table 5.26), in which the majority of respondents positively agreed that a BIM implementation plan is one of the fundamental resources required for BIM adoption. Rathnayake and Hamed (2019) indicate that a nationally developed BIM framework that reflects the BIM drivers and barriers would be key to the adoption of BIM. According to Siriwardhana et al. (2018), few Sri Lankan organisations have mandated the use of BIM within their businesses. Hence, the majority have not used any strategies or frameworks for BIM adoption; this indicates the lack of involvement by top management to support BIM adoption. Nevertheless, many early BIM adopters are ready to provide their support to develop a local BIM implementation strategy (Epasinghe, 2018).

Findings further revealed that the lack of BIM models is another major resource issue for the adoption of BIM by QS's. The qualitative case study findings (see section 6.5.5.3) endorse this position, as many respondents find that architects do not producing BIM models and this has implications for the adoption of BIM (discussed under section 7.4.6). They state that this is the main reason for the lack of BIM models within the Sri Lankan construction industry. Respondents indicated that the use of a BIM model is one of the main differences between traditional cost estimation and BIM-based cost estimation. Therefore, the QS cannot start a BIM-based cost estimation if the architect has not produced a BIM model. Thus, requesting that architects produce BIM models for selected projects would offer a solution. However, the lack of demand has resulted many professionals not using BIM; therefore, the adoption of BIM among professionals is not steady. This indicates a strong relationship between the lack of market demand (unbalanced BIM adoption) and the lack of resources (lack of BIM model) (see Figure 7.4). In agreement, Kushwaha (2016) mentioned that the effective adoption of BIM requires collaborative adoption by all stakeholders, such as architects, engineers, QS, sub-contractors, contractors and pre-fabricators; if that does not occur, conflict may arise. Even though, Kumara et al. (2017) suggested that architects should be the BIM initiators in Sri Lanka, Siriwardhana et al. (2018) indicated that only 5% use Revit to deliver BIM models, which indicates fewer opportunities to produce BIM models for QS's. Therefore, Epasinghe et al. (2018) suggested that the government should issue a mandate to demand that major construction companies practice BIM throughout the construction stages. Moreover, according to Kumara et al. (2017), encouragement by clients is also essential for the execution and integration of BIM by architectural firms within their organisations' business models.

A lack of BIM was training found to represent another resource issue, which hinders BIM adoption. Findings in the qualitative analysis section 6.5.5.4, indicates that organisations resist providing BIM training, whilst the absence of BIM training providers mean a lack of appropriate training. Respondents also believed that labour turnover and the high cost of training have resulted in organisations not providing training for their employees. Moreover, no organisation currently offers exclusive BIM training in Sri Lanka, which indicates a lack of BIM education. Therefore, the lack of resources (lack of training) has a strong relationship with both unawareness (lack of BIM education providers) and organisational barriers (high cost of training) (see Figure 7.4). Suggestions indicated that, construction organisations could organise a place to study and train in BIM, which would be cost-effective and beneficial for all AEC stakeholders. Besides, it was also suggested that the organisational motivation encourages employees to engage in self-study on BIM. Suggestions also indicated that, training should also focus on ideas and conversation. Furthermore, the quantitative findings (section 5.11.2, Table 5.22) confirmed that the lack of BIM training results in a lack of adoption among QS's. According to Kushwaha (2016), considerable funds are required to provide training to existing staff. However, as mentioned in section 6.4.1, organisations can minimise training costs by requesting that software vendors fulfil the need for training. Besides, according to Epasinghe et al. (2018), training can also be gained free of charge via the Internet and through online forums. Nevertheless, Suranga et al. (2018) indicated that no organisations test, demonstrate and train new technologies in the Sri Lankan context. Therefore, Siriwardena et al. (2018) suggested that the government must perform this role within an overall BIM adoption strategy.

Unlike traditional cost estimation, in BIM cost estimation requires a strong internet connection at all times due to the use of a model. However, findings from the qualitative section (6.5.5.5) indicated that many organisations provide limited Internet facilities for employees due to the high cost. This indicates a strong relationship between the lack of resource (lack of internet) and financial barrier (high cost). Besides, some respondents believed that the lack of government intervention has also increased the cost of the Internet, which indicates a relationship between the lack of market demand (government intervention) and lack of resources (lack of Internet) (see Figure 7.4). Moreover, employees face many difficulties when working as the Internet speed is poor. Interviewees believed that government involvement is essential to provide high-speed Internet facilities at a lower cost for organisations. Furthermore, this finding is similar to the quantitative results (section 5.11.6, Table 5.26), where the majority of respondents agreed that the lack of Internet facilities has resulted in poor BIM adoption among QS's. Abanda et al. (2018) identified that high-speed Internet facilities and unlimited data offer key strategies in the adoption of BIM by enabling the use of interoperable files. Ahmed (2018) further supported this view by indicating that the majority of BIM tools are Internet based, while effective BIM adoption requires proper Internet facilitates. However, Epasinghe et al. (2018) mentioned that, due to government taxes, organisations struggle to provide sufficient network facilities to support BIM-based software. Thus, the government could help to increase network facilities through reduced taxes. Therefore, it can be concluded that, due to low speed and high cost, limited Internet facilities represent another resource issue for BIM adoption.

As noted in section 6.5.5.6, the qualitative findings revealed that the cost of SW and a lack of BIM demand have resulted in a limited number of SW licences, which means another resource issue. Due to its high cost, many organisations have only obtained the maximum six licences although they employ more than 30 employees. This reveals a strong relationship between the lack of resources (number of

SW licences) and the financial barrier (high cost of SW) (Figure 7.4). Nevertheless, pre-defined goals and processes would minimise the financial difficulties, as discussed in section 7.4.2. Besides, even if organisations want to increase the number of licences, low demand for BIM hinders any investment in SW. Therefore, only a few employees are able to work in BIM-based SW, while others have to wait their turn. This reveals that a limited number of SW licences have been issued due to the lack of client demand; in other words, there is a strong relationship between the lack of resources and the lack of market demand (Figure 7.4). Hence, many Sri Lankan software development companies are capable of developing and providing BIM-based software for local clients at a lower price (Epasingha et al., 2018). Therefore, this would offer a solution for organisations to increase their number of licences. Moreover, Wedikkara (2018) suggested that negotiating the monopoly market for software programs by organisations and institutions would allow business to get more licences. Thus, these resources issues have resulted in the low adoption of BIM amongst QS organizations.

7.4.6 Lack of Market Demand for BIM

The lack of demand for BIM was found to be another barrier to BIM adoption among Sri Lankan QS organisations. The demand for BIM within the Sri Lankan construction industry is at a far lower level than many other countries. As illustrated in Table 5.27, the lack of demand factor (external pressure) was ranked fourth among the six main barriers. Findings from the case study analysis (section 6.5.6) endorsed this position, as many respondents find the lack of client demand, lack of government intervention, unbalanced BIM adoption and scalability represent the main reasons for low BIM market demand in Sri Lanka. The findings in qualitative section 6.5.6.1 revealed that unawareness, the lack of government intervention and few professionals using BIM are the main reason for the low adoption of BIM. BIM is not just a SW; rather, it is a combination of people, process and technology. However, the majority of Sri Lankan QS organisations who have started to use BIM focus on its function as SW but have not yet considered the people (trained and BIM specialists) and processes (strategies, policies or mandates) involved. Although QS organisations have started to use BIM, many professionals - such as architects - still do not produce BIM drawings due to unawareness, the lack of training and the lack of client demand. Moreover, respondents indicated that low BIM adoption is also impacted by the lack of government intervention. Therefore, respondents believe that a nationally developed BIM mandate would accelerate the use of BIM in the Sri Lankan construction industry. Thus, results also indicated that the government should issue a mandate that considers capacity, such as the financial status and resources of local contractors. Hence, they also suggested that, by mandating BIM for all, foreign contractors would bring greater benefits to the Sri Lankan construction industry.

These findings were further supported by the quantitative analysis (5.11.5, Table 5.25) in which respondents have confirmed that the perceived lack of industry adoption has resulted in unbalanced BIM adoption. Moreover, the findings from section 5.11.5 (Table 5.25), also confirmed that the absence of a BIM mandate is a major barrier to the adoption of BIM, as it increases the unbalanced uptake. Moreover, the lack of government direction was found to be another issue to hinder BIM adoption by Sri Lankan QS organisations (Table 5.25).

Epasinghe et al. (2018), further supported this view by indicating that BIM adoption would only be successful if all stakeholders - namely civil engineers, quantity surveyors, project managers, clients, and architects - adopt BIM at the same time. BIM adoption by only one profession does not make a big different and it would be difficult to achieve the expected BIM benefits. It is clear that BIM adoption among QS's solely depend upon the architect's involvement in BIM. BIM adoption among architects is be a key driver for the adoption by QS's. Kumara et al. (2017) similarly identified that architects should be early BIM adopters, prior to any other profession. Weddikkara (2019) also stated that the adoption of BIM is still impossible since the Sri Lankan government is not ready to support BIM.

Hence, NBS (2019) reported that the decision taken by the UK government to mandate BIM, meant that both private and public sector construction organisations had to fully embed BIM. This indicates that government intervention is a key driver for BIM adoption. According to Siriwardene et al. (2018), some Sri Lankan construction organisations have followed the same scenario by mandating BIM within their organisations. By initiating BIM in a greater number of projects, the government could motivate others to use BIM, especially private sector clients (Kushwaha, 2016). Therefore, Epasinghe et al. (2018) suggested that the Sri Lankan government must mandate the use of BIM models and practice for large-scale projects, which would help to increase the demand for BIM.

The case study findings (in section 6.5.6.2) revealed that the lack of client demand has also resulted in low demand for BIM. Many QS organisations started using BIM as a result of demand from foreign clients. However, the results of this study indicate that the demand for BIM from local clients is almost zero. The majority of local clients are not aware of BIM or its benefits, which indicated a relationship between the lack of market demand and unawareness (Figure 7.4). Therefore, respondents believed that raising clients' awareness of BIM and its benefits would be one of the most significant steps for its adoption. As such, knowledge has to be provided through CPD, seminars, conferences, etc., by encouraging clients to start thinking about BIM. Respondents also believed that increased awareness would result in high client demand for BIM. This finding is further supported by the respondents whose data were considered in the quantitative section (5.11.5, Table 5.25) in which they confirmed the lack of client awareness results in low demand for BIM. Besides, they also believed that clients' financial capabilities also affected client demand. According to NBS (2019), the lack of client demand has been identified as a main barrier to BIM adoption, as they are concerned with capital investment. This indicates the client's gap in BIM knowledge and the benefits it offers long term. Nevertheless, the clients do not always demand BIM; hence, they could also be the reason why an organisation avoids its adoption (Somani, 2019).

The qualitative results in section 6.5.6.3 indicated that a lack of government intervention also results in a lack of demand for BIM. Many countries have adopted BIM as a result of BIM mandates, which were introduced by their governments. However, results indicate that government intervention to encourage BIM adoption is almost non-existent in the Sri Lankan construction industry. Findings from the qualitative case study analysis (see section 6.5.6.3) endorse this position, as many respondents find that political corruption, a lack of professional involvement, and economic crisis result in the lack of government intervention. In many industries, there is no any transparency due to pollical corruption; as a result, most government officers refuse to use modern technology for construction, as it means they cannot cheat (especially during the bidding process). In fact, respondents suggested that, instead of the government, the involvement of government agencies would offer another way to overcome the lack of government intervention. Moreover, Weddikkara (2018) indicated that professional bodies should organise symposiums for the government to draw attention to the importance of BIM and its applications.

Findings from the case studies (see section 6.5.6.4) indicated that scalability was another reason for the lack of BIM demand. Many interviewees were unsure whether BIM would fit with the size of the Sri Lankan construction industry. However, respondents believed that shared adoption would offer a solution to increase the scale; alternatively, they stated that adoption could be achieved through a comparative model, by comparing BIM adoption with a similar characteristic of the construction industry. Therefore, it can be concluded that the lack of demand for BIM is another barrier to BIM adoption within Sri Lankan QS organisations.

The above discussion summarises the barriers to BIM adoption for Sri Lankan QS firms, while Figure 7.4 indicates the significant relationships among the barriers. Moreover, it was also possible to identify the mitigating actions to overcome the impact of these barriers through cases studies and literature publications based in Sri Lanka. Accordingly, Table 7.2 lists barriers and sub barriers identified through the analysis. Moreover, Table 7.3 lists the mitigating actions identified within the above analysis.

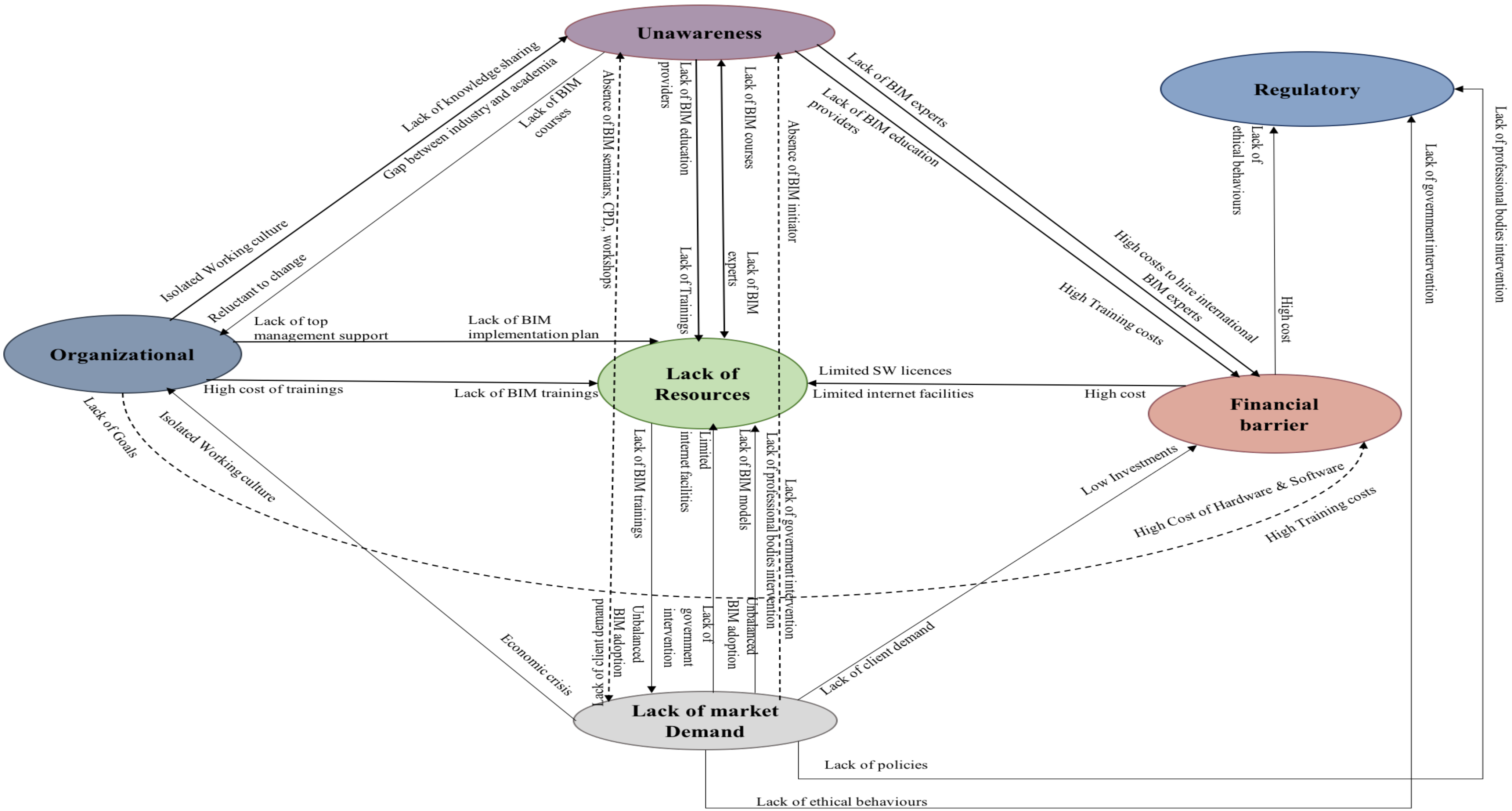


Figure 7.4: Schematic diagram of the significant relationships between the barriers to BIM adoption.

Table 7.2: Barriers and sub-barriers to BIM adoption

Barrier	Sub barriers	Cases Studies	Questionnaire survey	Literature review
Financial	Cost of hardware and software	✓	✓	✓
	Upgrading costs	✓	✗	✓
	Training costs	✓	✓	✓
	Lack of goals	✓	✗	✓
Organizational	Isolated working culture	✓	✓	✓
	People mindset	✓	✓	✓
	Fear of sharing responsibilities	✓	✓	✓
	Reluctant to change	✓	✗	✓
	Lack of goals and processes	✓	✗	✓
Regulatory	Lack of policies	✓	✗	✗
	Contractual issues	✓	✓	✓
	Legal issues	✓	✓	✓
	Lack of ethical behaviours	✓	✗	✗
Unawareness	Lack of knowledge sharing	✓	✗	✓
	Absence of BIM initiator	✓	✓	✓
	Lack of BIM education	✓	✓	✓
	The gap between industry and the academia	✓	✗	✓
Lack of Resources	Lack of BIM experts	✓	✓	✓
	Absence of BIM implementation plan	✓	✓	✓
	Lack of BIM models	✓	✗	✗
	Limited number of SW licenses	✓	✓	✓
	Limited internet facilities	✓	✗	✓
	Lack of training	✓	✓	✓
Lack of Market Demand for BIM	Lack of client demand	✓	✓	✓
	Lack of government intervention	✓	✗	✗
	Unbalance BIM adoption	✓	✓	✓
	Scalability	✓	✗	✗

Table 7.3: Mitigating actions to overcome the barriers

Sub-barriers	Mitigating actions	Cases studies	Literature Review
Cost of hardware and software	1. Define end goal to achieve through BIM adoption, ex: Improve the accuracy of pre-tender cost estimates.	✓	
	2. Identify appropriate processes to achieve pre-defined goals as a part of BIM adoption organizational wise.	✓	
	3. Seek support from technological companies in Sri Lanka to minimize the initial investment for fancy hardware and software.		✓
	4. Get support from FOSS (Free and Open Source software).		✓
	5. Collaboration with funding agencies such as government, private and leading construction organizations.		✓
Upgrading costs	1.Collaboration with funding agencies such as government, private and leading construction organizations.		✓
	2.Negotiate upgrading costs with software service providers.		✓
Training costs	1.Request software vendor to provide training for existing staff, as a part of their service.		✓
Lack of goals	1.Define expecting end goal\goals (e.g. Improve the accuracy of cost estimates) to achieve through BIM adoption.	✓	
	2.Identify processes look-alike	✓	
Isolated working culture	1.Implant a positive collaborative culture within the industry philosophy/ organizational philosophy.	✓	✓
	2.Consider the use of structured processes, techniques and advanced digital technologies aid in collaboration issues.		✓
	3.Develop organizational strategies to improve employee's phycology and mentality.	✓	
	4.Carry out training programs for professionals in ad-hoc basis.	✓	
People mindset	1.Build an organizational culture to make employees think they are working as a team.	✓	
Fear of sharing responsibilities	1.Build an organizational culture to make employees think they are working as a team.	✓	
Reluctant to change	1.Introduce and maintain an innovative culture within the organization where anyone can share anything which motivates them to learn about BIM.	✓	
Lack of goals and processes	1.Define expecting end goal\goals (e.g. Improve the accuracy of cost estimates) to achieve through BIM adoption.	✓	
	2.Identify processes look-alike	✓	
	3.Encourage organizations to understanding of BIM and trying to improvise some of the identified processes to achieve end goal.	✓	
Lack of policies	1.Develop policies considering threshold, issues, and repercussions.	✓	
	2.Execute developed policies through enforcement.	✓	
Contractual issues	1.Consider the use of internationally develop BIM standards such as construction measurement standards (ICMS).		✓
	2.Develop BIM friendly contractual standards considering the nature of the Sri Lankan construction industry.	✓	
Legal issues	1.Establish ground rules in terms of using models and data.		✓
	2.Frozen BIM model in lumpsum contracts.	✓	
	3.Update construction contracts with a new clause for intellectual property rights (such as model ownership, copyrights, legal and illegal use of models, and up to what extent trade information should be disclosed) in contracts.		✓
Lack of ethical behaviours	1. Define certain standards and guidelines to improve the ethical behaviours of the organizations.	✓	
	2. Define certain standards for technology usage.		✓
Lack of knowledge sharing	1. Integrate teaching and learning mechanisms into the organizational culture.	✓	
Absence of BIM initiator	1. Encourage architects to use BIM.	✓	
	2. Establish training programs, lecture sessions along with piloting Revit on selected small projects such as houses to convince architects to use BIM.		✓
	3. Universities, professional bodies, and the government commence island-wide BIM workshops, CPD's and conferences.	✓	
Lack of BIM education	1. Consider the government to take the role of BIM educator.		✓
	2. Incorporate BIM into the existing education curriculum.		✓
	3. Professional bodies (IQSSL, SLIA, RICS, etc) to conduct continuous BIM promoting programs with aid from foreign institutions and the university grant commission (UGC).		✓
	4. Introduce master and PhD level BIM-based programs to the government universities in collaboration with foreign universities.		✓
	5. Encourage large scale construction companies to apply BIM for large scale construction projects to provide live BIM-based experiences for the students and the industry practitioners.		✓
The gap between industry and the academia	1. Establish an organization to test and demonstrate new technologies with the aid of government.		✓
	2. Provide continuous BIM promoting practices for both academics and industry practitioners.		✓
Lack of BIM experts	1. Formulate the role of BIM manager within the Sri Lankan construction industry.	✓	
	2. Provide continuous BIM promoting practices for both academics and industry practitioners.		✓
	3. Establish reliable BIM education programs which fulfil the need of BIM experts.	✓	
	4. Ensure BIM experts are not limited to academia, but also in the industry.	✓	
Absence of BIM implementation plan	1. Develop a local framework to adopt BIM, reflected BIM drivers and barriers.	✓	✓
	2. Get a consultation from early BIM adopters prior to developing a framework.		✓
	3. Develop BIM adoption strategies organizational wise by identifying goals and processes.	✓	
Lack of BIM models	1. Introduce a BIM mandate for major construction companies to practice BIM during construction stages.		✓
	2. Encourage architectural firms to execute and integrate BIM into the organization's business models.		✓
	3. Request architects to provide drawings in the BIM version.	✓	
Limited number of SW licenses	1. Encourage local software development companies to develop BIM-based software at a lower price for local clients.		✓
	2. Develop an agreement between QS organizations and software developers for software price negotiations to increase the inhouse number of licenses.		✓
Limited internet facilities	1. Allow government intervention in providing high-speed internet facilities at a lower cost for QS organizations.	✓	
	2. Encourage the government to reduce taxes for network facilities.	✓	✓
Lack of training	1. Request software vendor to provide training for existing staff, as a part of their service.		✓
	2. Establish an organization to test, train and demonstrate new technologies with the aid of government.		✓
	3. Establish an industry-recognized place to study and train BIM for all the construction industry stakeholders.	✓	
	4. Execute training programs with a focus on ideas and conversation.	✓	
	5. Establish an organizational mechanism to motivate employees to self-study and self-training with the use of internet and online forums on BIM.	✓	
Lack of client demand	1. Carry out awareness programs to increase client's awareness of BIM and its benefits.	✓	
	2. Conduct/ organize CPD, seminars, conferences, and workshops for clients.	✓	
Lack of government intervention	1. Professional bodies organize symposiums to the government to bring attention to the importance of BIM and its applications.		✓
	2. Incorporate government agencies on behalf of the government.	✓	
Unbalance BIM adoption	1. Define architects as the early BIM adopters prior to any other profession.		✓
	2. Professional bodies to organize public symposiums to make the government, the politicians as well as the private sector the importance of BIM and its applications.		✓
	3. Develop a BIM mandate for the Sri Lankan construction industry considering the capacity such as the financial and resources of local contractors.	✓	
	4. Mandate the use of BIM for all foreign contractors.	✓	
	5. Initiate BIM in a greater number of local projects		✓
	6. Encourage private sector clients to use BIM within their projects.		✓
	7. Mandate the use of the BIM model and BIM practice for large scale construction projects.		✓
Scalability	1. Increase the scale through shared BIM adoption.	✓	
	2. Consider the use of a comparative model managed by comparing BIM adoption with a similar characteristic of construction industry.	✓	

Figure 7.5 illustrates the updated version of the conceptual framework for objective 3 (BIM barriers) based on the discussion in section 7.4.

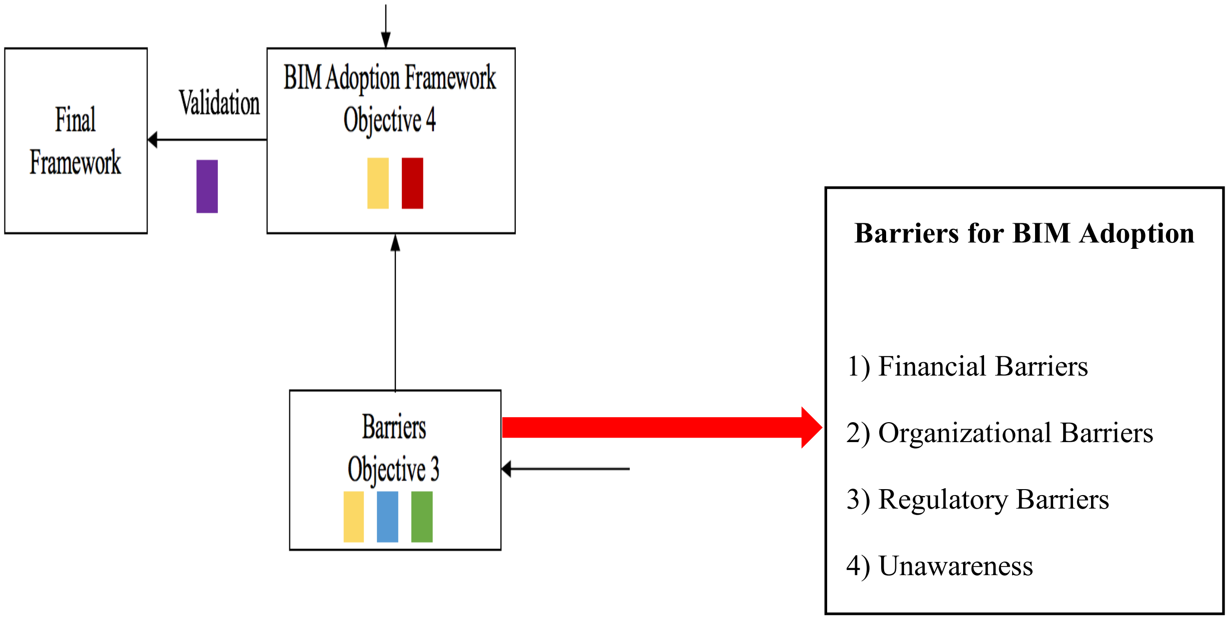


Figure 7.5 Updated conceptual framework for objective 3 - BIM barriers

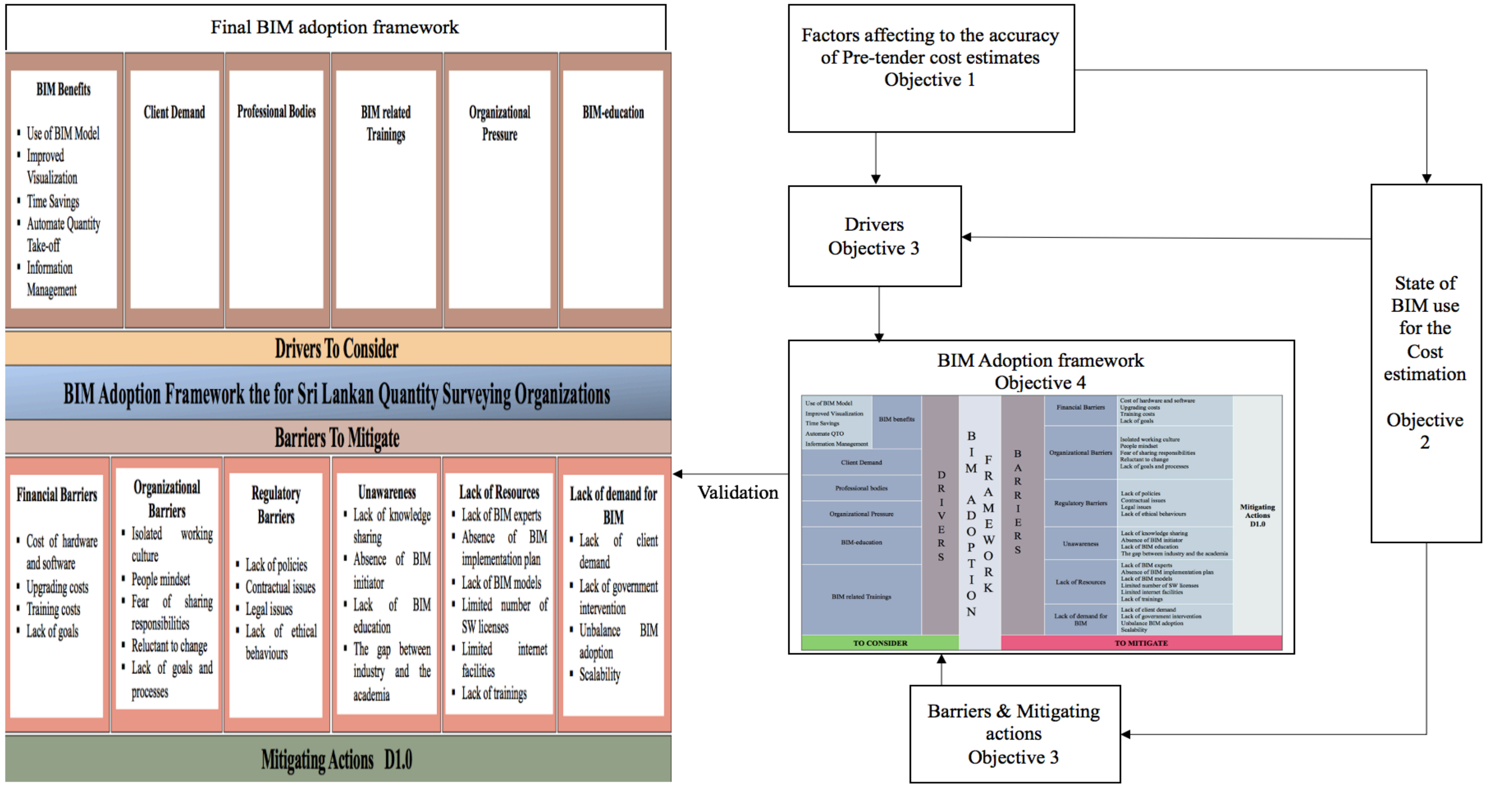


Figure 7.6 Updated framework

8 FRAMEWORK DEVELOPMENT AND VALIDATION

8.1 Framework Development

The previous chapter interpreted the results from both the survey data and the semi-structured interviews. The chapter illustrates a consecutive data gathering process on the fundamental output of the framework. The development of a framework is core to this research. Within social science research, scholars have defined frameworks in many ways. Ngulube et al. (2015) identified a research framework as an instrument for the researchers to interpret their findings in an understandable way. According to Patrick (2018), a framework is a logically structured representation of perceptions, variables or relationships based on the findings of a scientific study. Consequently, the outcome of this study is logically structured to support the interpretation and understanding of the problem through the development of a framework.

Predominantly, the findings are arranged under two research gaps shown in the conceptual framework (see Figure 7.6). The frameworks identify gaps in BIM adoption and provide mitigating actions that would enhance BIM adoption. F.W was developed based on the data derived from questionnaire survey, cases studies (semi-structured interviews) and literature review. Systematically, F.W was developed considering two main aspects. The left-hand column represents the factors for consideration, or the drivers for BIM adoption. Organisations can conduct a self-assessment prior to adopting BIM to check whether they have these driving factors within their working environment. The right-hand column represents the factors to be mitigate, also known as the barriers. These main barriers and root causes for each barrier prevent the adoption of BIM. Thereby, organisations need to undertake appropriate mitigating actions to minimise the negative impact of these barriers for a successful BIM adoption.

Mainly, the framework supports Sri Lankan quantity surveying organisations to adopt BIM within their existing practice in order to improve the accuracy of pre-tender cost estimates. A successful adoption of BIM eliminates majority of weaknesses discussed in section 7.2. Nevertheless, the framework also helps in other sectors, such as education, the government etc., by identifying their roles and responsibilities within the process of BIM adoption. Proposed mitigating actions for each sub-barrier (root cause) are based on a literature review and data collected through cases studies (semi-structured interviews). Figure 8.1 illustrates the entire findings derived from the analysis, which thereby generates the final framework for the research and its validation, which is explained in section 8.2.

Figure 8.1: The BIM adoption framework for Sri Lankan quantity surveying organisations

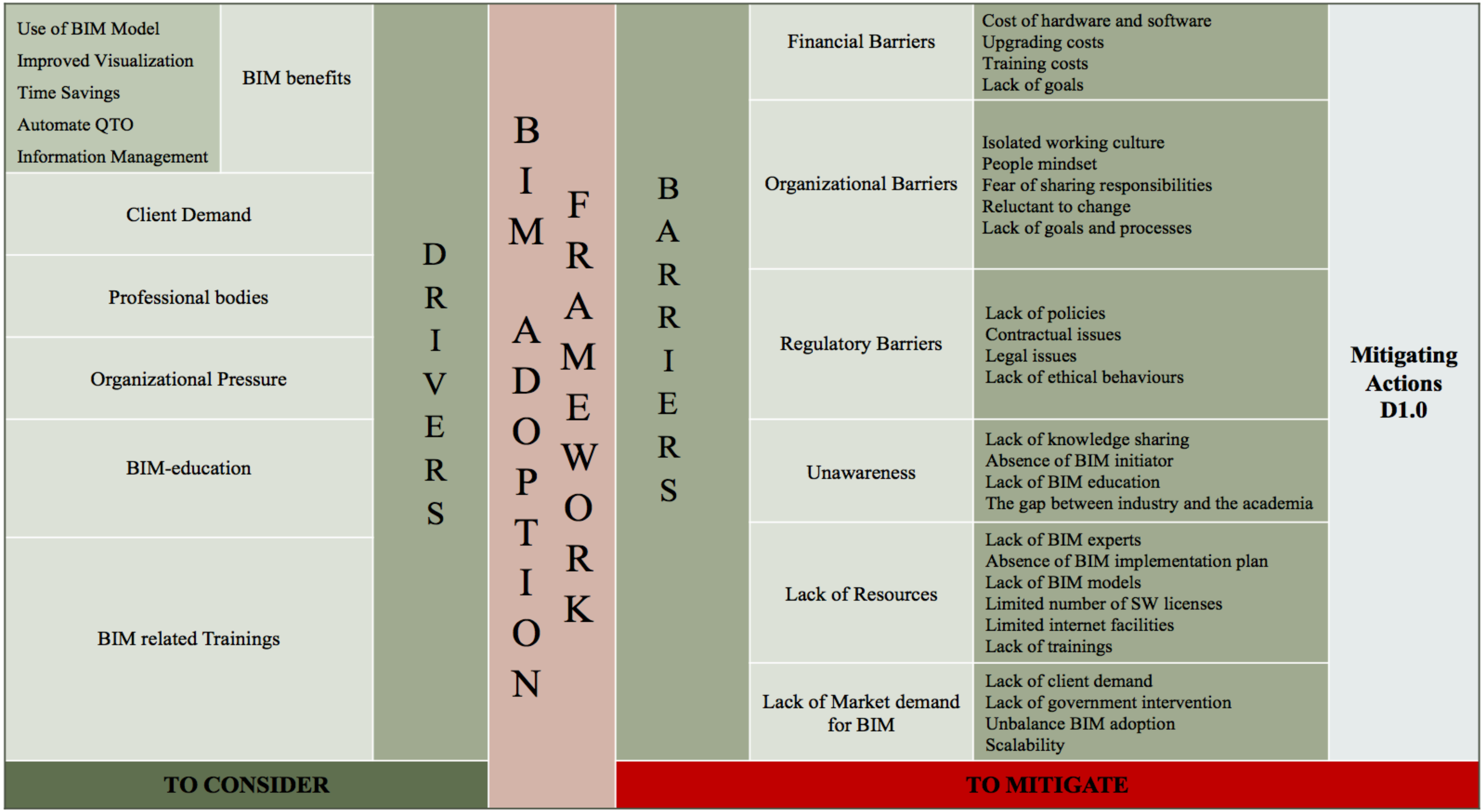


Table 8.1: Barrier, sub-barriers and mitigating actions

Barrier	Sub-barriers	Mitigating Actions (D1.0)
Financial Barriers	Cost of hardware and software	1. Define end goal to achieve through BIM adoption, ex: Improve the accuracy of pre-tender cost estimates. 2. Identify appropriate processes to achieve pre-defined goals as a part of BIM adoption organizational wise. 3. Seek support from technological companies in Sri Lanka to minimize the initial investment for fancy hardware and software. 4. Get support from FOSS (Free and Open Source software). 5. Collaboration with funding agencies such as government, private and leading construction organizations.
	Upgrading costs	1.Collaboration with funding agencies such as government, private and leading construction organizations. 2.Negotiate upgrading costs with software service providers.
	Training costs	1.Request software vendor to provide training for existing staff, as a part of their service.
	Lack of goals	1.Define expecting end goal\goals (e.g. Improve the accuracy of cost estimates) to achieve through BIM adoption. 2.Identify processes look-alike
Organizational Barriers	Isolated working culture	1.Implant a positive collaborative culture within the industry philosophy/ organizational philosophy. 2.Consider the use of structured processes, techniques and advanced digital technologies aid in collaboration issues. 3.Develop organizational strategies to improve employee's phycology and mentality. 4.Carry out training programs for professionals in ad-hoc basis.
	People mindset	1.Build an organizational culture to make employees think they are working as a team.
	Fear of sharing responsibilities	1.Build an organizational culture to make employees think they are working as a team.
	Reluctant to change	1.Introduce and maintain an innovative culture within the organization where anyone can share anything which motivates them to learn about BIM.
	Lack of goals and processes	1.Define expecting end goal\goals (e.g. Improve the accuracy of cost estimates) to achieve through BIM adoption. 2.Identify processes look-alike 3.Encourage organizations to understanding of BIM and trying to improvise some of the identified processes to achieve end goal.

Regulatory Barriers	Lack of policies	1.Develop policies considering threshold, issues, and repercussions. 2.Execute developed policies through enforcement.
	Contractual issues	1.Consider the use of internationally develop BIM standards such as construction measurement standards (ICMS). 2.Develop BIM friendly contractual standards considering the nature of the Sri Lankan construction industry.
	Legal issues	1.Establish ground rules in terms of using models and data. 2.Frozen BIM model in lumpsum contracts. 3.Update construction contracts with a new clause for intellectual property rights (such as model ownership, copyrights, legal and illegal use of models, and up to what extent trade information should be disclosed) in contracts.
	Lack of ethical behaviours	1. Define certain standards and guidelines to improve the ethical behaviours of the organizations. 2. Define certain standards for technology usage.
Unawareness	Lack of knowledge sharing	1. Integrate teaching and learning mechanisms into the organizational culture.
	Absence of BIM initiator	1. Encourage architects to use BIM. 2. Establish training programs, lecture sessions along with piloting Revit on selected small projects such as houses to convince architects to use BIM. 3. Universities, professional bodies, and the government commence island-wide BIM workshops, CPD's and conferences.
	Lack of BIM education	1. Consider the government to take the role of BIM educator. 2. Incorporate BIM into the existing education curriculum. 3. Professional bodies (IQSSL, SLIA, RICS, etc) to conduct continuous BIM promoting programs with aid from foreign institutions and the university grant commission (UGC). 4. Introduce master and PhD level BIM-based programs to the government universities in collaboration with foreign universities. 5. Encourage large scale construction companies to apply BIM for large scale construction projects to provide live BIM-based experiences for the students and the industry practitioners.
	The gap between industry and the academia	1. Establish an organization to test and demonstrate new technologies with the aid of government. 2. Provide continuous BIM promoting practices for both academics and industry practitioners.

Lack of Resources	Lack of BIM experts	1. Formulate the role of BIM manager within the Sri Lankan construction industry. 2. Provide continuous BIM promoting practices for both academics and industry practitioners. 3. Establish reliable BIM education programs which fulfil the need of BIM experts. 4. Ensure BIM experts are not limited to academia, but also in the industry.
	Absence of BIM implementation plan	1. Develop a local framework to adopt BIM, reflected BIM drivers and barriers. 2. Get a consultation from early BIM adopters prior to developing a framework. 3. Develop BIM adoption strategies organizational wise by identifying goals and processes.
	Lack of BIM models	1. Introduce a BIM mandate for major construction companies to practice BIM during construction stages. 2. Encourage architectural firms to execute and integrate BIM into the organization's business models. 3. Request architects to provide drawings in the BIM version.
	A limited number of SW licenses	1. Encourage local software development companies to develop BIM-based software at a lower price for local clients. 2. Develop an agreement between QS organizations and software developers for software price negotiations to increase the inhouse number of licenses.
	Limited internet facilities	1. Allow government intervention in providing high-speed internet facilities at a lower cost for QS organizations. 2. Encourage the government to reduce taxes for network facilities.
	Lack of training	1. Request software vendor to provide training for existing staff, as a part of their service. 2. Establish an organization to test, train and demonstrate new technologies with the aid of government. 3. Establish an industry-recognized place to study and train BIM for all the construction industry stakeholders. 4. Execute training programs with a focus on ideas and conversation. 5. Establish an organizational mechanism to motivate employees to self-study and self-training with the use of internet and online forums on BIM.
Lack of Market demand for BIM	Lack of client demand	1. Carry out awareness programs to increase client's awareness of BIM and its benefits. 2. Conduct/ organize CPD, seminars, conferences, and workshops for clients.
	Lack of government intervention	1. Professional bodies organize symposiums to the government to bring attention to the importance of BIM and its applications. 2. Incorporate government agencies on behalf of the government.
	Unbalance BIM adoption	1. Define architects as the early BIM adopters prior to any other profession. 2. Professional bodies to organize public symposiums to make the government, the politicians as well as the private sector the importance of BIM and its applications. 3. Develop a BIM mandate for the Sri Lankan construction industry considering the capacity such as the financial and resources of local contractors. 4. Mandate the use of BIM for all foreign contractors. 5. Initiate BIM in a greater number of local projects 6. Encourage private sector clients to use BIM within their projects. 7. Mandate the use of the BIM model and BIM practice for large scale construction projects.
	Scalability	1. Increase the scale through shared BIM adoption. 2. Consider the use of a comparative model managed by comparing BIM adoption with a similar characteristic of construction industry.

8.2 Validation and Refinement of the Findings

The researcher was able to develop a BIM adoption framework for Sri Lankan QS organisations based on the findings obtained from the questionnaires and semi-structured interviews, and by comparing the findings with the literature. The developed BIM adoption framework consists of factors to consider (driving factors) and factors to mitigate (barriers). Accordingly, mitigating actions are suggested for each barrier and its sub-factors to minimise their impact.

The framework has been externally validated by testing the framework findings against their applicability to the wider context within Sri Lanka. Professionals were selected from the specific firms and invited to participate in semi-structured telephone interviews. The professionals were invited via an email, and once they agreed to participate, the framework was sent to them. Six professionals, including previous participants, were invited to participate in the validation interviews. Four professionals agreed to participate, and Table 8.2 illustrates their profiles.

Table 8.2: Expert profiles

Expert No.	Description
E1	General Manager, XX Pvt Ltd, Charted QS, Member of RICS, and visiting lecturer for QS and Project Management.
E2	CEO, Charted QS and construction manager YY Pvt Ltd
E3	Senior QS, private QS consultancy Firm in Sri Lanka
E4	Charted QS and senior lecturer in quantity surveying and BIM

All arrangements to conduct the semi-structured interviews were made via email and phone. The interviews took place at a convenient time for each participant. Notes were taken during the interviews, the conversations were recorded, and the duration varied from 25 to 30 minutes dependant on the participant. The following questions were asked during the interviews:

1. What is your opinion about the clarity of the framework (FW); is it clear enough to support BIM adoption? (Title, general outlook, language)
2. What do you think about the structure of the FW? Why? (Understandable)
3. Do you believe that the FW has addressed all the factors faced during the adoption of BIM? (Completeness)
4. What do you think about the applicability of the framework components and their suggested actions? Why? (Applicability)
5. Do you believe the current framework design will help BIM adoption in your firms? Why? (Adaptability)
6. Based on what we have discussed today, in your opinion, what is the most important issue that you would like to highlight about the FW? Do you have any suggestions?

Using content analysis, the collected data were manually analysed. The following sub-section presents the responses to each question.

8.2.1 Validation of the BIM Adoption Framework

The first question, 'What is your opinion about the clarity of the framework; is it clear enough to support BIM adoption' was designed to identify the extent to which the framework is clear in terms of the title, general outlook, and language used. All agreed that the FW is clear and easy to understand as it not complicated. One participant stated, "*it's very clear to me as you have divided it into different areas, and those areas have further divided into subsections makes very sensible to me*". Another participant added, "*I will rate it 8 out of 10 in terms of clarity. I think you have done a good job*". In terms of language three participants agreed it is clear. However, one of them stated, "*some of the phrases you've used more into BIM, I understand that there's a specific BIM language, but at the same time you need to consider the users of this FW, as not many can understand BIM language*". Moreover, another respondent pointed out that the vertical letters used are not that clear and they suggested the use of non-vertical letters would be clearer to users. In terms of title, one participant suggested including 'Sri Lanka'. The researcher considered these suggestions for the final FW.

The aim of the second question, which was 'What do you think about the structure of the FW?" Why?' aimed to identify the responses to the FW design (including the colours used). All four participants agreed that the FW design was very clear and easy to understand. One of them stated, "*it's better to develop an FW in an expandable way in [the] near future; maybe you can reference in your report how to do it, and at some point, there should be a link to international standards*". This is a good point; however, this could be undertaken as further research, and as such, this was added under the further research section. Another respondent stated "*as I'm aware of BIM, [the] FW is clearer to me. But how about people who are not familiar with BIM will they understand this design?*" This FW was mainly developed for QS organisations; therefore, the first users of this FW would be top management prior to any engagement with the sub-sections. As this was very clear to them, they could develop the format in a more readable way for their employees or use their own strategy to implement these actions. In terms of the colours, all were considered acceptable.

The third question, 'Do you believe that the FW has addressed all the factors faced during the BIM adoption?' intended to examine the extent to which the FW addressed the factors affecting BIM adoption. All respondents confirmed that, for the time being, the FW has addressed the majority of factors and covered a wide area concerning Sri Lankan BIM adoption. One respondent stated, "*I understand your study focused on [the] macro-level; therefore, in terms of preliminary adoption yeah it consists of pretty much all the factors*". However, respondents further added that there would be more factors to consider in the future.

The fourth question, "What do you think about the applicability of framework components and suggested actions? Why?', aimed to examine the participants' thoughts about the suggested actions and their applicability to real cases or scenarios. All respondents agreed with the drivers and barriers given in the framework along with mitigating actions given for the barriers. They were fairly confident that the suggested actions were applicable in real practice. One respondent stated, "*you have done a deep analysis of the factors and its mitigation actions; overall, well-suggested actions*". Another respondent stated, "*it'll be easy to adopt BIM within organisations with the use of this FW, if relevant parties who have addressed … this FW can address these actions*". Thus, the interviews were carried out on a factor basis, and interesting conversations and suggestions emerged for most of the actions.

Under the financial barrier, respondents agreed that the cost of hardware and software, upgrade costs, training costs and the lack of goals result in the financial barrier. Moreover, all respondents accepted the given mitigating actions for the cost of hardware and software. However, respondent 1 stated "*some countries' governments have agreements with SW companies to provide SW licenses at a concessional rate, to minimise the use of crack versions. Thereby the government has agreed not to let them use trial versions or crack versions*". Thus, they suggested considering this point as a mitigating action for the cost of hardware and SW. A further respondent was keen on the second mitigating action; they suggested that, along with the defined end goal, there should be a strategy to assess the success or failure of a defined goal. The above two suggestions are extremely useful points; therefore, the researcher will consider altering the final FW to reflect the experts' points of view.

All respondents agreed on the given mitigation actions under upgrading costs. However, the fourth respondent mentioned changing the term from upgrading costs to upgrading costs for software licenses, which they felt made more sense. The second respondent stated that, "*when you are considering SW & HW cost, you always have the option to outsource it. Some people take too much stress, because they don't see that as an option. As it is very expensive to upgrade, companies better outsource that activity to different third-party agencies. As there are specific companies that only deal with those activities, so, four or five companies can have one company to do these upgrades at a lower cost*". Therefore, this point should be added to the final FW. Moreover, the third respondent suggested adding a yearly plan to the second action, as they indicated that it would be good to have long-term agreement that benefited both parties. This point was also altered in the final FW. The mitigating action for training costs was accepted by respondents 2, 3 and 4 without further comment. Although respondent 1 also agreed, they stated: "*the use of cost-effective training sessions within the organisations, such as online training, will be another mitigating action*". Accordingly, for the final FW, the researcher will consider adding this adding this point. The final sub-factor under the financial barrier was the lack of goals. All respondents agreed with the first mitigating action, without any further comment. Respondents 1 and 4 agreed with the second mitigating action without any comment. Respondents 2 and 3 also agreed, but stated: "*processes look-alike isn't clear, and needs more clarity; instead of processes look-alike I would call it workflow design, you need to define it a little bit*". Both respondents believe it is important to consider language to ensure understanding by users.

As illustrated in Table 8.3, the suggestions made by the respondents were included for the financial barriers. Altered suggestions are indicated in bold sentences.

Table 8.3: Final BIM adoption framework - financial barriers

Barrier	Sub Barriers	Mitigating Actions (D1.0)
Financial Barriers	Cost of hardware and software	1. Define end goal to achieve through BIM adoption, ex: Improve the accuracy of pre-tender cost estimates. 2. Identify appropriate routes to achieve pre-defined goals as a part of BIM adoption organizational wise. **3. Develop a strategy to asses success or failure of the defined goal.** 4. Seek support from technological companies in Sri Lanka to minimize the initial investment for fancy hardware and software. 5. Get support from FOSS (Free and Open Source software). 6. Collaboration with funding agencies such as government, private and leading construction organizations. **7. Encourage the government to sign agreement among SW vendors to provide BIM supported SW at a concessional rate for particular organizations.**
	Upgrading costs of software licenses	1.Collaboration with funding agencies such as government, private and leading construction organizations. **2. Outsource all the upgrading work for a specialized company at a lower cost in agreement with few QS organizations.** **3. Negotiate costs of upgrades with a software service provider for a yearly plan (ex; for five years).**
	Training costs	1.Request software vendor to provide training for existing staff, as a part of their service. **2. Introduce/ implement cost-effective training such as web-based, within the organization.**
	Lack of goals	1. Define expecting end goal\goals (e.g. Improve the accuracy of cost estimates) to achieve through BIM adoption. **2. Identify processes to achieve defined goals.**

The next section of the FW validation considered the organisational barriers. All respondents agreed that the given sub factors created barriers within the organisation; however mitigating actions for the sub factors were accepted by all respondents with further comments. In terms of the first action, respondent 2 stated, "*[the] word implant will be an issue; I would put' create a positive collaborative working culture, within the existing culture'*". Respondents 1, 3 and 4 accepted the second action without further comment. However, respondent 2 stated, "*its [a] little length;, you can break [it] into two points, for [the] digitization of workflow*". However, the use of the phrase 'digitization workflow' will be confusing for most users. Therefore, the sentence was divided into two actions, as illustrated in Table 8.3. All respondents without any further comment accepted the third action. The final action was also accepted by all respondents, hence, respondent 2 stated: "*I agree with you, but rephrase 'ad-hoc', I would say strategic professionals*". However, the researcher used the word ad-hoc to denote carrying out training programs whenever necessary. Therefore, the word ad-hoc was replaced with 'whenever necessary' in the final framework.

Apart from above suggestions, respondent 1 stated "*I think what should happen is, it's true at some point of peoples working career they have to start working collaboratively, but can't we introduce those skills at university stage, so then it easier for everyone, even to adopt for existing organizational culture. It may be too late when they join the company to cultivate those skills especially for fresh graduates".* This is a very helpful point; however, as this FW has a separate section to address BIM education, the researcher will consider adding this point under BIM education in the final FW.

Respondents 1, 3 and 4 accepted the action for people's mindsets without any further comment. Respondent 2 accepted it, but also stated: "*I would suggest rephrasing it to create a culture for teamwork or promote teamwork within the organisation*". Therefore, this action will be modified accordingly in the final FW (see Table 8.3). All respondents accepted the action against 'fear of sharing responsibilities', although respondent 2 suggested creating a culture for teamwork. Thus, the action was modified in the final FW. All respondents accepted the action against 'reluctant to change'; however, respondent 1 stated "*first we need to increase awareness of people in terms of BIM and what benefits they can have; we need to convince them the use of BIM will raise your job at a decision-making level rather being [at the] counting of things. So, I believe our education syllabus need[s] to realign to train fresh graduates to make decisions, rather than taking training to take-off. If we could give this understanding, no one will be reluctant to change*". This is an extremely valid point made by the respondents, namely, to increase BIM awareness and the benefits they could gain thereof. In considering the reflections from this respondent, the final FW was altered by adding this point as another mitigating action against reluctant to change (see Table 6.4). Respondents then validated the actions given to mitigate the lack of goals and processes. All respondents agreed on the given actions; however, respondent 2 suggested the use of 'workflow' instead of processes against the fourth action. Therefore, the respondent's suggestion was considered in the final FW. As illustrated in Table 8.4, suggestions made by respondents were considered when altering the organizational barriers. Altered suggestions are indicated in bold sentences.

Thereafter, respondents validated the next section of the FW, namely the regulatory barriers. All respondents accepted the sub factors along with the mitigating actions given. Accordingly, the respondents accepted the actions against the lack of policies but offered further comments. Respondent 1 stated, "*whatever the policies not only on BIM, everything has to be aligned with countries/organisations vision, let's say for 20 years; because usually any country/organisation would have 2, 3 year, 5 year plan. So the polices have to be aligned with countries'/organszations' visions as well*". Therefore, he suggested developing policies concerning the vision of the country/organisation. Respondent 2 added that the words 'threshold' and 'repercussions' needed to be replaced words with similar meanings to make it more understandable. Respondent 3 questioned "*develop policies either organisation wise or, generally*?" This a valid point, as this FW has been developed for QS organisations, which have their own policies. However, national policies will also drive BIM adoption. Respondent 4, suggested the consideration of worldwide policies, which can benefit the development of a new policy. The second action was also accepted by respondents; however, respondent 2, stated "*I agree, hence, there needs to be measurable way of assessing these policies, whether they are working or not".* All above points made by respondents are valid and useful; therefore, the researcher will accommodate these within the final FW.

Table 8.4: Final BIM adoption framework – organisational barriers

Organizational Barriers	Isolated working culture	1. **Create a positive collaborative working culture, within the existing culture** **2. Identify applicable processes to overcome collaboration issues.** **3. Get support from advanced digital technologies to overcome collaboration issues** 3. Develop organizational strategies to improve employee's phycology and mentality. 4. Carry out training programs for professionals **whenever necessary.**
	People mindset	**1. Promote teamwork within the organization.**
	Fear of sharing responsibilities	1. **Create teamwork working culture.**
	Reluctant to change	1.Introduce and maintain an innovative culture within the organization where anyone can share anything which motivates them to learn about BIM. **2. Conduct awareness programs to convince people how BIM going to make their life easier.**
	Lack of goals and processes	1. Define expecting end goal\goals (e.g. Improve the accuracy of cost estimates) to achieve through BIM adoption. 2. Identify processes to achieve defined goals.

Actions under contractual issues were completely accepted by all the respondents; however, respondent 2 stated "*Just by having standards you can't solve issues; you have to have other sets of documents, ex; PAS1192, BIM protocol, specification[s] along with contractual standards to … consider… the nature of SL construction industry as we cannot use international ones straight away".* This is a valid point, as standards alone cannot mitigate contractual issues; instead, there is a need to developing supporting documents alongside the standards. Therefore, the final FW was altered to consider this point of view. Nevertheless, respondent 3 stated "*I 100% agree, but before starting the project, can't we come to a conclusion for a standard ... particular to the project?"* However, as this FW aims to support BIM adoption organisationally, but not on a project basis, there is no any need to change the action.

All respondents accepted the actions under 'legal issues'. Apart from the actions given in the FW, respondent 1 stated, "*all project participant[s] can sign informed consent in terms of confidentiality and as we use models, it's more applicable to current situation*". As it might take a while to establish rules when using model, this will offer a short-term solution for the people who are using models at the moment. Respondent 3 also suggested locking the model on a structural basis when it is completed, which would offer another solution to mitigate legal issues. Therefore, in considering respondents' points of view, 'legal issues' were altered in the final FW. In terms of lack of ethical behaviours, all respondents accepted the mitigating actions without further comment. Therefore, the following table illustrates the updated section of the FW for the regulatory barriers, based on the suggestions made by respondents. Altered suggestions are indicated in bold sentences.

Table 8.5: Final BIM adoption framework – regulatory barriers

Regulatory Barriers	Lack of policies	**1. Develop organizational policies considering inception, issues, consequences, vision and worldwide policies.** **2. Develop national policies considering inception, issues, consequences, vision and worldwide policies.** 3. Execute developed policies through enforcement. 4. **Develop a strategy to asses success or failure of the defined policies.**
	Contractual issues	1. Consider the use of internationally develop BIM standards such as construction measurement standards (ICMS). 2. Develop BIM friendly **contractual standards along with supporting documents** considering the nature of the Sri Lankan construction industry.
	Legal issues	1. Establish ground rules in terms of using models and data. 2. **Sign informed consent form, prior to use of BIM model, in terms of its data and confidentiality.** 3. Freeze BIM model in lumpsum contracts. 4. **Freeze the model structure wise.** 5. Update construction contracts with a new clause for intellectual property rights (such as model ownership, copyrights, legal and illegal use of models, and up to what extent trade information should be disclosed) in contracts.
	Lack of ethical behaviours	1. Define certain standards and guidelines to improve the ethical behaviours of the organizations. 2. Government /organizations to define certain standards for technology usage.

The next section of the FW addresses 'unawareness', and was also validated by respondents. Respondents accepted all the sub factors under 'unawareness'. Respondents 1, 2 and 4 accepted the action under 'lack of knowledge sharing' without any further comment. However, respondent 3 suggested the conduct of weekly knowledge sharing programs by using PowerPoint presentations. The researcher will consider adding this point to the final FW as a mitigating action to the lack of knowledge sharing.

Respondent 1 accepted all actions to mitigate the absence of a BIM initiator and did not offer any further comments. Respondents 2, 3 and 4 accepted action 1, but respondent 3 stated "*I agree and but also trade contractors, this goes hand in hand. As architects only care about visualization, it shouldn't only be architects but also trade contractors should take the lead. It shouldn't stop with architects".* Therefore, they pointed out that it should not just consider architects, but also other professions in the construction industry. In terms of this research, the FW was developed for QS organisations and data was also collected from QS's. In other words, this FW was developed from a QS perspective. For QS's, architects are important, because sequentially in a construction process the QS's starts their work after the architects have undertaken theirs. Nevertheless, as BIM involves collaboration, it is important that all professionals work on the same platform. Therefore, the final FW will be altered based on the respondents' points of view. The remaining actions under the absence of BIM initiator was accepted by all respondents; however, respondent 2 commented on second action stating, "*you should not directly say Revit, you should say model authoring tool, because Revit may not the best tool for architects".* Therefore, in considering this valid point, the final FW will be altered.

Table 8.6 Final BIM adoption framework – unawareness

Unawareness	Lack of knowledge sharing	1.Integrate teaching and learning mechanisms into the organizational culture. **2. Conduct weekly knowledge sharing programs using PowerPoint presentations for employees.**
	Absence of BIM initiator	**1. Consider professional bodies such as CIDA, IQSSL, SLIA, etc to take the role of BIM initiator.** 2. Through professional bodies architects should encouraged to use BIM. 3. Establish training programs, lecture sessions along with piloting **BIM authorizing tools** on selected small projects such as houses to convince architects to use BIM. 4. Universities, professional bodies, and the government commence island-wide BIM workshops, CPD's and conferences.
	Lack of BIM education	1.Consider the government to take the role of BIM educator. 2.Incorporate BIM into the existing education curriculum. 3. **Introduce practice-based BIM courses along with students to get real life BIM experience through pilot BIM projects.** **4. Incorporate collaborative working culture within the BIM curriculum.** 4.Professional bodies (IQSSL, SLIA, RICS, etc) to conduct continuous BIM promoting programs with aid from foreign institutions and the university grant commission (UGC). 5.**Introduce degree level,** master level and PhD level BIM-based programs to the government universities in collaboration with foreign universities. 6.Encourage large scale construction companies to apply BIM for large scale construction projects to provide live BIM-based experiences for the students and the industry practitioners.
	The gap between industry and the academia	1.Establish an organization to test and demonstrate new technologies with the aid of government. 2.Provide continuous BIM promoting practices for both academics and industry practitioners. **3. Use pilot BIM projects to give real-life BIM experience for practitioners.** **4. Compulsory to get at least 6 months BIM experience as a requirement to complete BIM-based courses.**

The lack of BIM education and its mitigating actions comprised the next section that respondents validated. All the respondents fully accepted all mitigating actions. Nevertheless, respondents 2 and 3 commented on second action, by stating "*I agree [with] university level, but I honestly think there has to be [a] BIM introduction degree level as well, as many students don't know what the BIM opportunities are*". Therefore, the final FW was altered by adding this point as another mitigating action to minimise the lack of BIM education. Moreover, respondent 2 suggested incorporating practice-based BIM courses within the curriculum. Similarly, respondent 1 commented on the importance of having pilot BIM projects to give real life examples for graduates. This is a valid point by the respondents; therefore, the researcher will alter the final FW by addressing these comments.

Respondents then validated the next section under unawareness, namely the gap between industry and academia and its mitigating actions. All four respondents accepted the given actions. However, respondent 1, believed that the use of pilot projects also helped to reduce this gap. Respondent 3 suggested a "*mandate to get at least 6 months BIM experience for final year graduates as a part [of] degree requirements will be another mitigating action*". These two points are applicable to mitigating the gap between industry and academia. Therefore, the researcher will alter the final FW by addressing these comments. Table 8.6 illustrates the updated section of the FW for unawareness based on the suggestions made by the respondents. Altered suggestions are indicated in bold sentences.

Respondents then validated the next section of the FW, namely the lack of resources, its sub-factors and mitigating actions. All respondents accepted all sub-factors represent the lack of resources for BIM adoption within the Sri Lankan construction industry. Mitigating actions for the lack of BIM experts were accepted by all respondents and they were really pleased with the suggested actions. However, respondent 1 suggested the use of pilot projects as a mitigating action. The use of pilot projects will give real life BIM experience to all practitioners, and as a result, more BIM experts will emerge. Therefore, the final FW will be altered based on the respondent's point of view. Respondent 4 stated "*hiring foreign BIM specialists, through Board of Investment* (*BOI) approved projects, to get free BIM specialists*". This is a valid point, as BOI approved projects taxes are free; thus, BIM experts could be hired at a lower cost. The researcher will alter the final FW by adding this point as another mitigating action to address the lack of BIM experts.

The next section addressed the 'absence of a BIM implementation plan' and respondents accepted all actions without any further comments. Respondents also accepted all actions under the lack of BIM models. However, respondent 3 suggested "*outsource [the] BIM model, would be another solution for [he] lack of BIM models*". As many countries experience, building a BIM model is very expensive; as a result, they have tended to outsource the BIM model to countries such as India in order to achieve the same result at a lower cost. This would be also work for Sri Lankan QS's as well. Therefore, this is a valid point made by the respondents that will be added to the final FW.

Respondents also accepted the actions to mitigate a limited number of SW licences. However, respondent 1 commented that the cost of hardware and software licences was also valid for this section. Accordingly, 'government intervention with SW agents to get a concessional rate' will be added to final FW as another mitigating action. In terms of the first mitigating action, respondent 2 stated "*Sri Lankan SW companies can build BIM based SW, but if it not interoperable with other SW, we may miss the bus*". Therefore, actions will be altered in the final FW based on the respondent's point of view. Respondent 3 added to the second action, that the agreement should consider a yearly plan, which makes more sense. Respondent 4 mentioned government taxes, which is another issue that limits the number of inhouse SW licences, as it increases the price of certain SW. From the researcher's point of view, taxes could be minimised if the government implements the suggestion by respondent 1.

All respondents accepted the actions for limited Internet facilities without any further comment. However, respondent 1 stated "*the new government has already implemented [the] second action. Now, actually the internet cost has come down, so they've already considered your suggestion".* The final factor under 'lack of resources' was the lack of training, for which all respondents accepted the mitigating actions. However, respondent 4, stated that the use of user-friendly demos within training, such as training materials in Sri Lankan for trainers, would boost the interest in BIM training. This is a valid point, as there are professionals and trainees who are not comfortable with the use of English. Therefore, the final FW will be altered based on this respondent's point of view. Table 8.7 illustrates the updated FW section for the lack of resources based on the suggestions made by respondents. Altered suggestions are indicated in bold sentences

Table 8.7: Final BIM adoption framework – lack of resources

Lack of Resources	Lack of BIM experts	1.Formulate the role of BIM manager within the Sri Lankan construction industry. 2.Provide continuous BIM promoting practices for both academics and industry practitioners **with the use of pilot BIM projects**. 3.Establish reliable BIM education programs which fulfil the need of BIM experts. 4.Ensure BIM experts are not limited to academia, but also in the industry. **5. Hire BIM specialists for BOI approved projects.**
	Absence of BIM implementation plan	1.Develop a local framework to adopt BIM, reflected BIM drivers and barriers. 2.Get a consultation from early BIM adopters prior to developing a framework. 3.Develop BIM adoption strategies organizational wise by identifying goals and processes.
	Lack of BIM models	1.Introduce a BIM mandate for major construction companies to practice BIM during construction stages. 2.Encourage architectural firms to execute and integrate BIM into the organization's business models. 3.Request architects to provide drawings in the BIM version. **4. Outsource to build BIM model for lower cost.**
	A limited number of SW licenses	1.Encourage local software development companies to develop **interoperable** BIM-based software at a lower price for local clients. 2. **Discuss for a yearly agreement (ex; 2years, 3 years and 5 years)** between QS organizations and software developers for software price negotiations to increase the inhouse number of licenses. **3. Encourage the government to sign agreement among SW vendors to provide BIM supported SW at a concessional rate for particular organizations.**
	Limited internet facilities	1.Allow government intervention in providing high-speed internet facilities at a lower cost for QS organizations. 2.Encourage the government to reduce taxes for network facilities.
	Lack of training	1.Request software vendor to provide training for existing staff, as a part of their service. 2.Establish an organization to test, train and demonstrate new technologies with the aid of government. 3.Establish an industry-recognized place to study and train BIM for all the construction industry stakeholders. 4.Execute training programs with a focus on ideas and conversation. 5.Establish an organizational mechanism to motivate employees to self-study and self-training with the use of internet and online forums on BIM. **6. Incorporate user-friendly demos and training materials in Sri Lankan language for training sessions.**

The last section to be validated was the lack of demand for BIM. The lack of client demand, lack of government intervention, unbalanced BIM adoption and scalability were named as sub-factors to the lack of demand for BIM. All the respondents accepted these factors and mitigating actions without any further comment. Respondents also accepted all actions for the lack of government intervention without any further comment. Respondents then validated 'unbalanced BIM adoption'. For many respondents, the phrase "unbalanced BIM adoption" was not clear. Once the researcher explained this to them, they were confident with it. Respondent 1 stated "*Unbalanced BIM adoption among professionals would be more appropriate instead just unbalance BIM adoption*". Therefore, the term will be altered in the final FW in consideration of the feedback.

However, respondents accepted all mitigating actions without any further comment. Hence, respondent 3 added a mandate to employ local professionals in foreign BIM based projects, which would also offer a mitigating action for unbalanced adoption. Therefore, the final FW will be altered based on this comment. Finally, respondents also accepted all actions to mitigate scalability without any further comment. Table 8.8 illustrates the updated FW section for the lack of demand for BIM based on the suggestions made by the respondents. Altered suggestions are indicated in bold sentences.

Table 8.8: Final BIM adoption framework – lack of demand for BIM

Lack of demand for BIM	Lack of client demand	1.Carry out awareness programs to increase client's awareness of BIM and its benefits. 2.Conduct/ organize CPD, seminars, conferences, and workshops for clients.
	Lack of government intervention	1.Professional bodies organize symposiums to the government to bring attention to the importance of BIM and its applications. 2.Incorporate government agencies on behalf of the government.
	Unbalance BIM adoption among professionals	1.Define architects as the early BIM adopters prior to any other profession. 2.Professional bodies to organize public symposiums to make the government, the politicians as well as the private sector the importance of BIM and its applications. 3. Government to develop a BIM mandate for the Sri Lankan construction industry stakeholders considering their capacity such as the financial and available resources. 4. Government to mandate the use of BIM for all foreign contractors. **5. Government to mandate to employ local construction professionals for BIM-based foreign contracts.** 6. Government/ professional bodies to initiate BIM in a greater number of local projects. 7. Government/ professional bodies to encourage private sector clients to use BIM within their projects. 8. Mandate the use of the BIM model and BIM practice for large scale construction projects.
	Scalability	1.Increase the scale through shared BIM adoption. 2.Consider the use of a comparative model managed by comparing BIM adoption with a similar characteristic of construction industry/ BIM adopted organizations.

The fifth question, "*Do you believe the current framework design will help BIM adoption in your firms*? Why?", aimed to examine the adaptability of the FW for current QS firms. All respondents appreciated the development of this FW. Based on respondents' points of view, they think this FW represents a fundamental need, which is lacking in Sri Lankan QS organisations, in terms of BIM adoption. Therefore, all respondents agreed that this FW would help them to adopt BIM within their organisations. Respondent 1 stated, "*because we have international exposure, our company motive is to be dynamic. So, we need to adopt modern technology as soon as possible. So certainly, this FW help us to do so*". Respondent 2 believes this FW would not only help in the adoption of BIM for QS firms, but also across most construction related parties. They stated "*since there aren't any developed FW in Sri Lanka for BIM adoption (QS) I think this FW will be a preliminary foundation for, not only QS organisations, but also for other construction related organisations; [they] will also benefit from this*". Another, respondent indicated, as it consists of many aspects, it will help in the adoption of BIM.

The sixth question was "*Based on what we have discussed today, in your opinion, what is the most important issue that you would like to highlight about the FW?" Have you got any suggestions for them?*" This was designed to examine the respondent's thoughts about further improvements that could be made to the FW. Respondents 1, 3 and 4 suggested altering the aforementioned suggestions. However, respondent 2 stated "*the biggest issue for me is sometimes companies struggle to address all the actions at once, because it seems like lots of work to do, so we need a strategic plan*". This point is true, however, although this FW is developed for QS organisations, several other responsible parties have also been addressed in the FW (for example, the government, architects, education department, professional bodies, etc). For the successful adoption of BIM all parties should implement the suggested actions. Therefore, there is no need for QS organisations to address all given mitigating actions, as some are out of their control.

Figure 8.2: Final BIM Adoption Framework

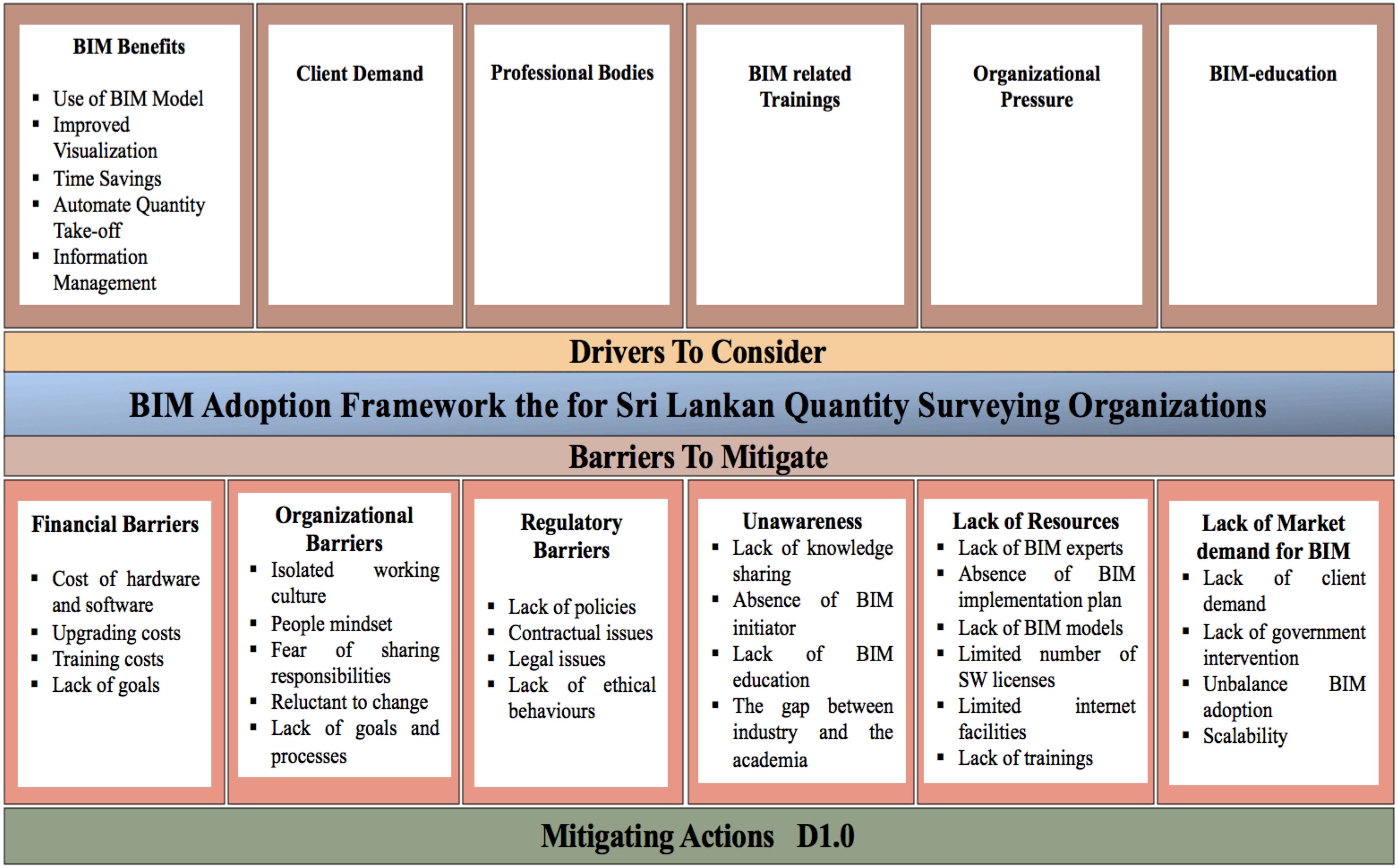


Table 8.9: Barriers, sub-barriers and mitigating actions

Barrier	Sub-barriers	Mitigating Actions (D1.0)
Financial Barriers	Cost of hardware and software	1. Define end goal to achieve through BIM adoption, ex: Improve the accuracy of pre-tender cost estimates. 2. Identify appropriate routes to achieve pre-defined goals as a part of BIM adoption organizational wise. 3. Develop a strategy to assess success or failure of the executed goal/ goals. 4. Seek support from technological companies in Sri Lanka to minimize the initial investment for fancy hardware and software. 5. Get support from FOSS (Free and Open-Source software). 6. Collaboration with funding agencies such as government, private and leading construction organizations. 7. Encourage the government to sign agreement among software vendors to provide BIM supported software at a concessional rate for particular construction related organizations.
	Upgrading costs of software licenses	1.Collaboration with funding agencies such as government, private and leading construction organizations. 2. Selective outsourcing all the upgrading work for a specialized company at a lower cost in agreement with few QS organizations. 3. Negotiate costs of upgrades with a software service provider for a yearly plan (ex; for five years).
	Training costs	1.Request software vendor to provide training for existing staff, as a part of their service. 2. Introduce/ implement cost-effective training such as web-based, within the organization.
	Lack of goals	1. Define expecting end goal\goals (e.g. Improve the accuracy of cost estimates) to achieve through BIM adoption. 2. Identify processes to achieve defined goals.
Organizational Barriers	Isolated working culture	1. Create a positive collaborative working culture, within the existing culture 2. Identify applicable processes to overcome collaboration issues. 3. Get support from advanced digital technologies to overcome collaboration issues 4. Develop organizational strategies to improve employee's phycology and mentality. 5. Carry out training programs for professionals whenever necessary.
	People mindset	1. Promote teamwork within the organization.
	Fear of sharing responsibilities	1. Create teamwork working culture.
	Reluctant to change	1. Introduce and maintain an innovative culture within the organization where anyone can share anything which motivates them to learn about BIM. 2. Conduct awareness programs to convince people how BIM going to make their life easier.
	Lack of goals and processes	1. Define expecting end goal\goals (e.g., Improve the accuracy of cost estimates) to achieve through BIM adoption. 2. Identify processes to achieve defined goals.

Regulatory Barriers	Lack of policies	1.Develop organizational policies considering inception, issues, consequences, vision and worldwide policies. 2. Develop national policies considering inception, issues, consequences, vision and worldwide policies. 3.Execute developed policies through enforcement. 4. Develop a strategy to asses success or failure of the executed policies.
	Contractual issues	1.Consider the use of internationally develop BIM standards such as construction measurement standards (ICMS). 2.Develop BIM friendly contractual standards along with BIM supporting documents considering the nature of the Sri Lankan construction industry.
	Legal issues	1.Establish ground rules in terms of using models and data. 2. Sign inform consent form prior to use of the model in terms of its data and confidentiality. 3.Freeze BIM model in lumpsum contracts. 4. Freeze the BIM model structure wise when it's completed. 5.Update construction contracts with a new clause for intellectual property rights (such as model ownership, copyrights, legal and illegal use of models, and up to what extent trade information should be disclosed) in contracts.
	Lack of ethical behaviours	1. Define certain standards and guidelines to improve the ethical behaviours of the organizations. 2. Government/ organizations to define certain standards for technology usage.
Unawareness	Lack of knowledge sharing	1. Integrate teaching and learning mechanisms into the organizational culture. 2. Conduct knowledge sharing programs weekly using PowerPoint presentations for employees.
	Absence of BIM initiator	1. Consider professional bodies such as CIDA, IQSSL, SLIA, etc to take the role of BIM initiator. 2. Through professional bodies encourage architects to use BIM. 3. Establish training programs, lecture sessions along with BIM authorizing tools on selected piloting projects such as houses to convince architects to use BIM. 4. Universities, professional bodies, and the government commence island-wide BIM workshops, CPD's and conferences.
	Lack of BIM education	1. Consider the government to take the role of BIM educator. 2. Incorporate BIM into the existing education curriculum. 3. Introduce practice-based BIM courses along with students to get real-life BIM experience through pilot BIM projects. 4. Incorporate collaborative working culture practices within the BIM curriculum. 5. Professional bodies (CIDA, IQSSL, SLIA, RICS, etc) to conduct continuous BIM promoting programs with aid from foreign institutions and the university grant commission (UGC). 6. Introduce degree level, master and PhD level BIM-based programs to the government universities in collaboration with foreign universities. 7. Encourage large scale construction companies to apply BIM for large scale construction projects to provide live BIM-based experiences for the students and the industry practitioners.
	The gap between industry and the academia	1.Establish an organization to test and demonstrate new technologies with the aid of government. 2. Provide continuous BIM promoting practices for both academics and industry practitioners. 3. Use pilot BIM projects to give real-life BIM experience for practitioners. 4. Compulsory for BIM students to get at least 6 months BIM experience as a requirement to complete their BIM courses.

Lack of Resources	Lack of BIM experts	1. Formulate the role of BIM manager within the Sri Lankan construction industry. 2. Provide continuous BIM promoting practices for both academics and industry practitioners with the use of pilot BIM projects. 3. Establish reliable BIM education programs which fulfil the need of BIM experts. 4. Ensure BIM experts are not limited to academia, but also in the industry. 5. Hire foreign BIM specialist through BOI approved projects.
	Absence of BIM implementation plan	1. Develop a local framework to adopt BIM, reflected BIM drivers and barriers. 2. Get a consultation from early BIM adopters prior to developing a framework. 3. Develop BIM adoption strategies organizational wise by identifying goals and processes.
	Lack of BIM models	1. Government to introduce a BIM mandate for major construction companies to practice BIM during construction stages. 2. Encourage architectural firms to execute and integrate BIM into the organization's business models. 3. Request architects to provide drawings in the BIM version. 4. Outsource to develop BIM model for lower cost.
	A limited number of SW licenses	1. Encourage local software development companies to develop interoperable BIM-based software at a lower price for local clients. 2. discuss for a yearly agreement (ex: 2 years ,3 years and 5 years, etc) between QS organizations and software developers for software price negotiations to increase the inhouse number of licenses. 3. Encourage the government to sign agreement among SW vendors to provide BIM supported SW at a concessional rate for particular organizations.
	Limited internet facilities	1. Allow government intervention in providing high-speed internet facilities at a lower cost for QS organizations. 2. Encourage the government to reduce taxes for network facilities.
	Lack of training	1. Request software vendor to provide training for existing staff, as a part of their service. 2. Establish an organization to test, train and demonstrate new technologies with the aid of government. 3. Establish an industry-recognized place to study and train BIM for all the construction industry stakeholders. 4. Execute training programs with a focus on ideas and conversation. 5. Establish an organizational mechanism to motivate employees to self-study and self-training with the use of internet and online forums on BIM. 6. Incorporate user-friendly demos and learning materials in Sri Lankan language during training sessions.
Lack of Market Demand	Lack of client demand	1. Professional bodies Carry out awareness programs to increase client's awareness of BIM and its benefits. 2. Conduct/ organize CPD, seminars, conferences, and workshops for clients.
	Lack of government intervention	1. Professional bodies to organize BIM awareness meetings for government and politicians to discuss importance of BIM and its applications. 2. Incorporate government agencies on behalf of the government.
	Unbalance BIM adoption	1. Define architects as the early BIM adopters prior to any other profession. 2. Professional bodies to organize public symposiums to make the government, the politicians as well as the private sector the importance of BIM and its applications. 3. Government to develop a BIM mandate for the Sri Lankan construction industry stakeholders considering their capacity such as the financial and available resources. 4. Government to Mandate the use of BIM for all foreign contractors. 5. Government to mandate to employ and train local construction practitioners in BIM-based foreign construction projects. 5. Government/ professional bodies to initiate BIM in a greater number of local projects 6. Government/ professional bodies to encourage private sector clients to use BIM within their projects. 7. Government to mandate the use of the BIM model and BIM practice for large scale construction projects.
	Scalability	1. Increase the scale through shared BIM adoption. 2. Consider the use of comparative model to compare BIM adoption with a similar characteristic of construction industry/ BIM adopted organization.

8.3 Links Among the Conceptual Framework and the Developed BIM Adoption Framework

The conceptual framework (Figure 3.20) illustrates are barriers that need to be minimised, alongside the driving factors that need to be considered for the successful adoption BIM by Sri Lankan QS organisations. This study was conducted to identify these drivers and barriers along with relevant mitigating actions to overcome the barriers. Accordingly, six drivers and barriers were recognised, and the reasons for these barriers were expanded along with the mitigating actions. These were logically presented in the final framework (see Figure 8.2). The framework identifies the main drivers and barriers, while explaining the mitigating actions for each barrier. The main target audience of this framework is QS organisations; however, professional construction bodies, the government, the education sector, and architects can also be identified as target audiences of this framework. The framework answers the research questions, 'What are the driving factors for BIM adoption into Sri Lankan quantity surveying firms?' and 'Why have many Sri Lankan quantity surveying firms not yet adopted BIM?'

8.4 Summary and Link

This chapter summarises the findings of the research, as linked with the research problem and conceptual framework. The findings were logically structured in the format of a framework that enables BIM adoption among Sri Lankan quantity surveying organisations. The chapter further explains the validation process executed to ensure the reliability of the findings. Therefore, the next chapter concludes the study and offers recommendations for further areas of investigation.

9 CONCLUSIONS

9.1 Introduction

The previous three chapters presented the research findings from the analysis of the questionnaire survey and semi-structured interviews. This chapter attempts to draw conclusions and recommendations based on the findings and outcomes of the research.

- Firstly, the research problem and research objectives for the study are revisited;
- Secondly, a summary of the key findings is given;
- Thirdly, the contributions of this research to theory and practice are articulated;
- Finally, the limitations of the research and further research areas emerging from this study are noted.

9.2 Summary of the Research Problem and Research Objectives

The background of this research considers the weaknesses in conventional pre-tender cost estimate practices when producing accurate cost estimates in Sri Lanka. It was noted that, with the use of Building Information Modelling (BIM), many countries have improved the accuracy of pre-tender cost estimates, as BIM has capability to minimise or eliminate the majority of weaknesses in conventional cost estimate practices. Therefore, a need to replace the existing practice with BIM-based cost estimate practice was initially identified in order to improve the accuracy of pre-tender cost estimates. Moreover, it was also discovered that the absence of a nationally developed BIM framework prevents the adoption of BIM within Sri Lankan quantity surveying practice; indeed, many other countries have adopted BIM through such a framework. Therefore, it is necessary to develop a BIM adoption framework for Sri Lankan quantity surveying organisations to improve the accuracy of pre-tender cost estimates. Accordingly, the researcher established the following research aim and objectives for the study. The aim of the research was:

To develop a BIM adoption framework for Sri Lankan quantity surveying organisations to increase the accuracy of pre-tender cost estimates.

Based on the research aim, the following research objectives were developed:

1. To identify the current status of pre-tender cost estimates and the factors affecting the accuracy of pre-tender cost estimates in Sri Lanka.
2. To evaluate the development of, and the use of, BIM to improve the accuracy of pre-tender cost estimates.
3. To identify the BIM adoption drivers and barriers along with the mitigating actions to overcome the impact of the barriers identified.
4. To develop and validate a BIM adoption framework for Sri Lankan Quantity Surveying firms to improve the accuracy of pre-tender cost estimates.

Based on the research objectives and research problem highlighted above, the next section summarises the key results of this research.

9.3 Summary of the Key Results

9.3.1 Objective 1

Evaluating the current status of cost overruns and identifying the factors affecting the accuracy of pre-tender cost estimates was the first objective of this study. Using a literature review, questionnaire survey and case studies (semi-structured interviews) as techniques, this objective was framed to identify the current status of pre-tender cost estimates and the factors affecting its accuracy. The findings related to this objective discussed in chapter 2, 5 and 6, are summarised below:

In order to identify the current status of pre-tender cost estimates, the researcher wanted to explore two key issues, which were the status of cost overruns and the importance of accurate pre-tender cost estimates. The researcher achieved this through conducting a literature review and found that construction cost overruns represent a global issue; however, cost overruns are pre-dominant in the Sri Lankan construction industry. Furthermore, the researcher was able to identify inaccurate initial cost estimates as the main cause of cost overruns. Therefore, the accuracy of pre-tender cost estimates is important for the client, contractor and the entire project team the various reasons summarised in Table 2.4. The findings related to the accomplishment of this objective were stated in section 2.2 and 2.3.

The second purpose of the objective 1 was to identify factors affecting the accuracy of pre-tender cost estimates. This is one of the key aspects of this study as it is important to evaluate how BIM supports ways to address these factors under objective 2. Thereby, factors were identified through the literature review, questionnaire survey and semi-structured interviews, whilst results revealed seven key factors and their sub-factors, which are summarised below.

9.3.1.1 The Use of 2D drawings

The findings identified the use of 2D drawings as a key reason behind for pre-tender cost estimates. The use of 2D drawings is problematic due to a lack of visualisation, the inconsistent adjustment of changes, and revisions to the drawings. Moreover, results also revealed that the lack of visualisation mainly occurs due to incomplete drawings and project complexity, whereas changes and revisions are consequences of an architect's last-minute submissions, client alterations, isolated working culture, and insufficient information (see sections 5.5 and 6.3.1 for detail). Also, the findings from the literature review showed similar factors, as stated in section 2.4.1.

9.3.1.2 Lack of Information

The lack of information was the next key factor derived from the data. It was further revealed that poor information flow, unusable data, the absence of a proper database and paper-based information sharing are the sub-factors behind a lack of information. Findings further revealed the reasons for each subfactor. Accordingly, restricted access to information, the absence of a proper database and paper-based information sharing were among the reasons for poor information flow. Moreover, the use of paper-based information sharing was attributed to isolated working culture and a fear of new technologies. Results also offered reasons to generate unusable data as paper-based information sharing, a lack of communication and a lack of coordination. Moreover, it was revealed that there is no common database for the Sri Lankan construction industry, and among the reasons for this is poor information flow; the private and government sectors use their own developed databases; thus, none of the relevant authorities have taken action to develop a common database, which has resulted in the absence of a common database (see sections 6.3.2 and 5.5 for detail). Findings from the literature review also revealed similar factors, as stated in section 2.4.3.

9.3.1.3 Inefficiencies in Existing Software (SW)

The next key factor derived from the findings was inefficiencies in current SW, as it contains inaccurate mathematical formulas due to wrong assumptions, a lack of SW knowledge amongst QSs, and difficulties in tracing changes. Moreover, it was also found that inaccurate calculations are another reason for inefficiencies in current SW due to missing elements or quantities (see sections 6.3.3 and 5.5 for detail). Besides, findings from the literature review revealed similar factors, as stated in section 2.4.9.

9.3.1.4 Inadequate Knowledge and Skills of an Estimator

According to the findings, inadequate estimator knowledge and skills were also found to be another key factor affecting the accuracy. This is due to wrong assumptions and a lack of SW operational skills amongst QS's. It was also revealed that wrong assumptions occur as a result of the QS's lack of updates, unawareness of current rates, and difficulties in reading 2D drawings. Moreover, it was also revealed that an inadequate understanding of risk allocation and the inability to develop appropriate formulas amongst QS's have also resulted in a lack of SW operational skills (see section 6.3.4 and 5.5 for detail). The literature review findings also revealed similar factors, as stated in section 2.4.5.

9.3.1.5 Isolated Working Culture

The next key factor was isolated working culture, which was derived from both questionnaire survey and semi-structured interviews. Findings indicated that a lack of coordination, lack of communication and the economic crisis have resulted in the isolation of people's work. Findings further elaborate that a lack of trust, poor links among professionals and a lack of communication have resulted in a lack of coordination. Besides, the lack of communication results from the lack of response to emails, paper-based information sharing, poor links among professionals, freelance working consultants, and a lack of coordination. Moreover, developing countries, political instability, and freelance working consultants were found to be the reasons for the economic crisis (see sections 6.3.5 and 5.5 for detail). Also, the findings from the literature review showed similar factors, as stated in section 2.4.2 and 2.4.4.

9.3.1.6 Manual Quantity Take-Off (MQTO)

It was also recognised that MQTO is another key factor that affects the accuracy of cost estimates. Moreover, time-consuming tasks and inaccurate quantities were identified as the sub-factors behind MQTO. The lack of information, time constraints, missing elements, double counting, inaccurate assumptions, manual deductions, project complexity and discrepancies in AutoCAD were among the reasons for inaccurate quantities. Besides, a lack of information, poor visualisation in 2D drawings, the need to update information, and the detection of changes seemed to be time-consuming tasks within the MQTO (see section 6.3.6 and 5.5 for detail). Findings from the literature review also revealed similar factors, as stated in section 2.4.7.

9.3.1.7 Time Constraints

Time constraints represent the last key factor derived from the findings. It was revealed that pressure on quantity surveyors and the lack of site visits occur as a result of time constraints. Moreover, it was also found that the QS is under more pressure due to MQTO, client pressure, and the use of 2D drawings (see sections 6.3.7 and 5.5 for detail). The literature review findings also revealed similar factors, as stated in sections 2.4.5 and 2.4.8.

9.3.2 Objective 2

The second objective of this study evaluated the development, and use, of BIM to improve the accuracy of pre-tender cost estimates. The motive was to evaluate how BIM and its use have developed in order to either eliminate or minimise the impact of the factors (identified in objective 1) affecting the accuracy of cost estimates. The researcher mainly achieved this objective from the literature review (detailed in section 3.1 to 3.4), and the results are summarised below.

In order to identify the development of BIM, the researcher developed two key issues, namely how BIM originated and developed throughout time. Through the literature, the researcher found that BIM evolved as result of the experimental war undertaken by many countries, such as USA, Japan, etc. Moreover, it was revealed that BIM officially evolved in 1982 through the development of ArchiCAD. Since then, BIM has been adopted within many countries' construction industries due to its tremendous benefits. BIM dimensions 3D, 4D and 5D further illuminate its capacity to improve the accuracy of pre-tender cost estimates. The findings related to the accomplishment of this objective are stated in sections 3.1, 3.2, 3.3 and 3.4.

The second phase of this objective was to evaluate how BIM helps to address the key factors identified in objective 1 in order to improve the accuracy of pre-tender cost estimates. This is one of the key aspects of this study as it confirms that the use of BIM helps to improve the accuracy of pre-tender cost estimates thereby its worth to develop a BIM adoption framework to support BIM adoption. Accordingly, the researcher critically evaluated the literature and the findings revealed that the use of BIM 3D models, better information management, Automate Quantity Take-Off (AQTO), time savings, improved collaboration and communication were key benefits offered by BIM to improve the accuracy of pre-tender cost estimates. The following subsections briefly describe how these key benefits are addressed by the key factors identified in objective 1.

9.3.2.1 The Use of BIM 3D Models

The use of BIM models is considered a key benefit of its use, as they help to overcome the issues encountered when using 2D drawings; therefore, models eliminate the issues associated with the lack of visualisation, changes, and revision to the drawings. As the model is capable of automatically identifying changes, the QS does not need to spend spare time identifying the changes. Moreover, improved visualisation reduces the manual revisions through early clash detections. In addition, the case studies (semi-structured interviews) revealed that most respondents find that BIM models are a key driver for the adoption of BIM (see sections 3.3.1 and 7.3.1 for detail).

9.3.2.2 Better Information Management

It was also revealed that the rich information contained in a BIM model results in the rich flow of information while also creating a reliable cost database. As the model allows for the upload and download of any project element information it avoids unusable data and can reduce the number of requests for paper-based information. Thereby, BIM has the capability to successfully address the issues related to the lack of information, as identified under objective 1. Moreover, the semi-structured interview findings also revealed better information management is a driving factor for the adoption of BIM by QS's into their existing practices (see sections 3.3.2 and 7.3.1 for detail).

9.3.2.3 Automated Quantity Take-Off (AQTO)

Literature reveals that this is one of the key benefits that can help to improve the accuracy of cost estimates. AQTO addresses more than one affecting factor, namely MQTO, software issues and inadequate estimator knowledge and skills. AQTO allows for the direct extraction of quantities from the BIM model, the elimination of time-consuming tasks and the reduction to the inaccurate calculations that regularly occurs in MQTO. Moreover, as there are unique BIM SW specially designed for AQTO (such as CostX), issues such as inaccurate mathematical formulas and inaccurate calculations are reduced. Therefore, the impact of 'inefficiencies in existing software' could be minimised with the use of BIM, as it eliminates or minimises such problems. Besides, AQTO also helps to address the issues related to inadequate estimator knowledge and skills, as it eliminates inaccurate assumptions. Furthermore, as such SW contains the required formulas to take-off the quantities, the QS is not required to develop formulas and therefore does not require excessive knowledge of SW operational skills. Apart from the literature findings, the QS's further identified that AQTO is a major driving factor for their adoption of BIM during the semi-structured interviews (see sections 3.3.3 and 7.3.1 for detail).

9.3.2.4 Time Savings

The use of BIM also helps to reduce the time spent by QS's on time consuming tasks, such as MQTO (section 9.3.2.3), the use of 2D drawings through AQTO, and the development of BIM models. Thereby, the QS can save a considerable amount of time which could be used on other tasks, such as conducting site visits. Moreover, it also helps to reduce the client pressure, as it allows the QS time to prepare accurate cost estimates over a shorter period (see section 3.3.6).

9.3.2.5 Improved Collaboration and Communication

The literature revealed that the use of a centralised BIM model also helps to overcome the barriers associated with an isolated working culture. Accordingly, collaboration and communication among project stakeholders could be improved with the use of a BIM model. It encourages team work rather isolated working (see section 3.3.4 for detail).

9.3.3 Objective 3

The third objective of this study was to identify the BIM adoption drivers and barriers along with mitigating actions to overcome the impact of these identified barriers. This objective was formulated to identify, verify and validate the drivers and barriers faced by quantity surveying organisations during BIM adoption and to identify the mitigating actions they have taken, or want to take, to overcome the identified barriers. The drivers and barriers were identified using a questionnaire survey and semi-structured interviews within a case study approach. Moreover, the mitigating actions were identified through semi-structured interviews (case studies) and the literature review. Accordingly, the researcher discovered six key drivers with related sub factors, and six barriers with subfactors and mitigating actions, which were further analysed and discussed in Chapters 5, 6 and 7. The development of the key factors and mitigating actions was the major outcome of this objective and are summarised below.

9.3.3.1 Drivers

Drivers were identified as the key factors for consideration when adopting BIM; identifying and ensuring access to these factors would better support BIM adoption within organisations.

9.3.3.1.1 BIM benefits

The findings from questionnaire survey and semi-structured interviews identified the use of a BIM model, automated quantity take-off, improved visualisation, improved information management, and timesaving as the leading BIM adoption benefits for quantity surveying organisations. Moreover, it was further revealed that the use of a BIM model can result in improved visualisation, automated quantity take-off and improved information management; this indicates a strong relationship between the use of BIM model and visualisation, automated quantity take-off and information management. Therefore, quantity surveyors consider these benefits as key BIM drivers for the adoption of BIM (sections 5.9, 6.4.1 and 7.3.1).

9.3.3.1.2 Client Demand

The findings of questionnaire survey and semi-structured interviews identified that client demand is a key BIM driver. The result demonstrated that many organisations have adopted BIM due to foreign client requests, by further identifying a strong relationship between client demand and organisational pressure. Therefore, client demand acts as another driver for Sri Lankan quantity surveying organisations to adopt BIM (see sections 5.9, 6.4.3 and 7.3.2 for detail).

9.3.3.1.3 Professional Bodies

Professional bodies were the next key driver derived from the findings. This further emphasised that workshops and conferences organised by professional bodies helped to increase BIM knowledge amongst construction stakeholders, especially clients. Increased knowledge was found to be beneficial for them in adopting BIM into their organisations. Therefore, the professional bodies driver revealed a strong relationship between BIM education, organisational pressure and client demand (see sections 5.9, 6.4.5 and 7.3.4 for detail).

9.3.3.1.4 BIM Related Training

The next key driver derived from the semi-structured interviews was BIM related training. This indicates that training provided by organisations prior to BIM adoption and post BIM adoption helped both employees and organisations to make the transition to BIM both easier and more successful. Moreover, training and workshop organised by professional bodies and some educational providers were identified as a strong BIM driver for organisations to adopt BIM. Therefore, the driver 'BIM training' further indicated a strong relationship between organisational pressure, BIM education and professional bodies (see sections 6.4.2 and 7.3.3 for details).

9.3.3.1.5 Organisational Pressure

Organisational pressure is another key BIM driver derived from this study. Apart from client demand (discussed in 9.2.3.1.2), the intervention of professional bodies (discussed in 9.2.3.1.3), BIM education (discussed in 9.2.3.1.6), top organisational management was also identified as a strong influence on BIM adoption. Accordingly, top management have developed their own strategies to aid BIM adoption. Besides, it was further identified that the 'organisational pressure' driver has a strong relationship with the client demand driver, BIM benefit driver, BIM education driver and professional bodies driver (see sections 5.9, 6.4.6 and 7.3.6 for detail).

9.3.3.1.6 BIM Education

Findings from both the questionnaire survey and semi-structured interviews identified that BIM-based education is another key driver for BIM adoption. Accordingly, workshops, seminars, BIM-related courses, etc have helped to increase the awareness of most organisational employees Moreover, it was further revealed that BIM education has accelerated due to client and organisational requests for BIM courses, and through the intervention of professional bodies through annual BIM events. This indicates that the 'BIM education' driver has a strong relationship with the client demand, organisational pressure and professional bodies drivers (see sections 5.9, 6.4.4 and 7.3.5 for detail).

9.3.3.2 Barriers

Barriers are the obstacles to BIM adoption faced by quantity surveying; these need mitigation to enable successful BIM adoption.

9.3.3.2.1 Financial Barriers

The findings from both the questionnaire survey and the semi-structured interviews identified financial barriers as a key deterrent to BIM adoption. The analysis further emphasised that hardware and software costs, upgrading costs, training costs and the lack of goals are the main reasons for this financial barrier. Moreover, the findings further revealed that a lack of market demand for BIM has hindered organisational interest to invest in BIM, by indicating a strong relationship between market demand and the financial barrier. Besides, the lack of BIM expertise and the lack of BIM education providers have resulted in high training costs for organisations. This further revealed a relationship between the financial barrier and unawareness barrier. Moreover, according to the study results, the lack of goals and processes were also found to represent a major reason for the high training costs, which further revealed a relationship between the organisational and financial barriers. However, the results also suggested mitigating actions to help overcome or minimise these costs under the financial barrier (see sections 5.11.1, 6.5.1 and 7.4.1 for detail).

9.3.3.2.2 Organisational Barriers

The next key barrier derived from the findings was organisational. It was revealed that an isolated working culture, people's mindsets, a fear of sharing responsibilities, reluctance to change, and a lack of goals and processes are the main issues that need to be addressed for this barrier. Moreover, the sub-factors related to these issues were also identified. Accordingly, isolated working culture occurs as a result of the plethora of freelance working professionals and the economic crisis. Moreover, it was further revealed that the economic crisis influenced the relationship between the organisational and lack of market demand barriers. Traditional practices and a fear of sharing responsibilities have resulted in people's fixed mindsets. The main explanation for the fear of sharing responsibilities is people's mind-sets. Moreover, key reasons behind the factor were found to include: language difficulties, traditional practices, and the existing government sector mean that change is not welcomed, whilst there is also a fear of losing one's job, a lack of trust, selfishness, and the perpetuation of a myth that BIM is hard to learn. Findings further revealed that 'unawareness' is a major reason why people fear of losing their job; this also influences the myth that BIM is hard to learn, the lack of trust, and thereby indicates a strong relationship between the organisational and unawareness barriers. Moreover, failures to identify an end goal through BIM, have resulted in a lack of end goals. Nevertheless, the findings also indicated some mitigating actions to overcome each sub-factor, which helps to minimise the overall impact of the organisational barriers towards BIM adoption (see sections 5.11.4, 6.5.2 and 7.4.2 for detail).

9.3.3.2.3 Regulatory Barriers

Regulatory barriers represent another key barrier derived within this study. Accordingly, it was identified that the lack of policies, contractual issues, legal issues and a lack of ethical behaviour are the main issues for the regulatory barriers. Moreover, it was also revealed that a failure to define ownership of the model and undefined model responsibilities are key reasons for legal issues. The absence of a BIM-based contract and the failure of existing contracts to facilitate proper BIM-based practice have resulted in contractual issues. Moreover, it was further revealed that the lack of support by professional bodies has also resulted in the absence of proper BIM contracts. This further identifies a relationship between the regulatory and lack of market demand barrier. According to the findings, the lack of professional and government involvement are the main reasons for this lack of policy. Accordingly, the study identified a relationship between 'regulatory' and a lack of market demand through the lack of government policy. A lack of ethical behaviour has occurred as a result of this absence alongside the use of trial versions. Moreover, it was further revealed that the relationship between the financial and regulatory barriers was attributed to the high cost of hardware and SW. As a result, many organisations have (unethically) tended to use trial versions. Furthermore, the mitigating actions to overcome these issues are derived from the findings (see sections 5.11.3, 6.5.3 and 7.4.3 for detail).

9.3.3.2.4 Unawareness

The next key barrier was unawareness, as derived from the questionnaire survey and semi-structured interview findings. The lack of knowledge sharing, the absence of a BIM initiator, a lack of BIM education and the gap between industry and academia were found prominent issues underpinning the unawareness barrier. Furthermore, reasons for the lack of knowledge sharing among employees were noted as: selfishness, a lack of communication, an isolated working culture and the egos of senior professionals. This revealed a relationship between the unawareness and organisational barriers. Another important issue derived from this study was absence of a BIM initiator, which was attributed to the lack of government and professional involvement. This indicates a strong relationship between the lack of market demand and unawareness. Moreover, the lack of industry demand for BIM, the lack of BIM experts, the lack of BIM courses, the absence of BIM within the education curriculum, the lack of BIM education providers and the lack of BIM seminars, workshops and conferences were found to be the main reasons for the lack of BIM education. The study further indicated that a lack of market demand has resulted in a limited number of BIM seminars and workshops by revealing a relationship between the lack of market demand and unawareness as a result of lack of client demand. According to the study results, the gap between industry and academia result from a lack of communication and isolated working cultures. Moreover, it was further indicated that the relationship between the organisational barrier and unawareness is influenced by an isolated working culture that has created a gap between industry and academia. Hence, this study also derived mitigating actions to overcome or minimise the impact of the aforementioned issues (see sections 5.11.5, 5.11.2, 6.5.4 and 7.4.4 for detail).

9.3.3.2.5 Lack of Resources

The lack of resources was found to be another key barrier in terms of BIM adoption for QS organisations. Accordingly, the lack of BIM experts, the absence of a BIM implementation plan, the lack of BIM models, the limited number of SW licenses, limited internet facilities and a lack of training are the main resources issues identified within the study results. Moreover, the findings also revealed the main reasons for each lack of resource. Subsequently, the lack of BIM education, and limited industrial BIM experts were identified as the main reasons for the lack of BIM experts. This further reveals a strong relationship between unawareness and the lack of resources. A lack of involvement by top management was found to influence the absence of a BIM implementation plan. Therefore, the study identified a relationship between the organisational barrier and the lack of resources. Architects not producing BIM models and unbalance BIM adoption among construction industry professionals were found to be the main reason for the lack of BIM models. Accordingly, this study further identified a relationship between the lack of resources and the lack of market demand. Moreover, this study also revealed that the cost of SW and a lack of BIM demand have resulted in a limited number of organisational SW licences. In addition, limited Internet facilities have occurred as a result of low-speed Internet connections and high cost of Internet access. Therefore, it was further revealed that the lack of resources has a relationship on both the financial and lack of market demand barriers. Moreover, the unwillingness to invest in BIM training and the absence of proper BIM training providers have created a lack of BIM training within the industry. This further reveals a relationship between unawareness and the organisational barriers. Nevertheless, mitigating actions to overcome these issues were also derived from the findings (see sections 5.11.6, 5.11.2, 6.5.5 and 7.4.5 for detail).

9.3.3.2.6 Lack of Market Demand for BIM

The next key barrier derived from the findings was the lack of demand for BIM. Moreover, it was revealed that a lack of client demand, lack of government intervention, unbalanced BIM adoption and scalability issues were key reasons for its low demand in Sri Lanka. Furthermore, the findings further revealed that unawareness was also critical as many professionals are still not using BIM and the lack of government intervention was cited as the main reason for the unbalanced adoption of BIM among industry professionals. Unawareness of BIM and its benefits, unbalanced BIM adoption among construction industry professionals, and the client's limited financial capabilities have resulted low demand for BIM amongst clients. Furthermore, a relationship between the lack of market demand and unawareness was noted, while political corruption, a lack of professional involvement and the economic crisis have prevented government involvement its adoption. Results further revealed that the failure to define a scale for the adoption of BIM is a key reason for its scalability issues. However, mitigating actions to overcome these issues were also derived from the findings (see sections 5.11.5, 6.5.6 and 7.4.6 for detail).

9.3.4 Objective 4

The fourth objective of this study was to develop and validate a BIM adoption framework to enhance BIM adoption among Sri Lankan Quantity Surveying firms and thereby improve the accuracy of pre-tender cost estimates. This objective was designed to identify the possible driving factors and explore ways to overcome the barriers to BIM adoption. The objective was achieved by arranging the key findings in objective 3 in a structured format that is easily usable by quantity surveying organisations, construction industry practitioners and relevant authorities. The findings related to this objective are discussed in chapter 8 and summarised below.

The first phase of this objective was to develop a framework. A framework was developed based on the established research gaps, drivers, barriers and mitigating actions to overcome or minimise the impact of the barriers identified. The framework content was based on the well-researched outcomes from industry and academic experts. The format of the framework consists of two main sections, namely factors to consider and factors to mitigate. Factors to consider reflect on the driving factors for BIM adoption, while factors to mitigate reflect on the barriers and mitigating actions for each identified barrier (see section 8.1 for detail).

The second phase of this objective was to validate the developed framework. The main reason for this validation was to certify that the users are satisfied that the developed framework is a usable product; furthermore, if the users are not satisfied with the framework it will not be workable in a BIM adoption context. At the validation stage, the researcher received many positive comments from the interviewees, and they recommended alterations or changes to specific sections in order to increase the validity and robustness of the study. Consequently, by critically reviewing the interviewees' views the researcher modified some features of the developed framework, which helped to finalise the new BIM adoption framework, which aimed to improve the accuracy of pre-tender cost estimates. With the accomplishment of this objective, the overall research aim has also been accomplished (see section 8.2 for detail).

9.4 Contribution of the Research to Theory and Practice

This study contributes to the existing body of knowledge by developing a framework to enhance BIM adoption in Sri Lankan quantity surveying organisations. The theoretical and practical contributions to the knowledge of this study are stated as follows.

9.4.1 Contribution to Theory

The adoption of Building Information Modelling (BIM) is beneficial to improve the accuracy of cost estimates in quantity surveying practices. Hence, BIM adoption can improve the accuracy of cost estimates but is limited to a limited number of quantity surveying organisations in the Sri Lankan construction industry. The most frequently cited reason for this limitation is the absence of a BIM framework to support its adoption. Even though many countries have already adopted BIM through a developed supported framework, many authors argued that internationally developed BIM frameworks are not readily adaptable for a Sri Lankan context. In this context, the study provides a new perspective on BIM adoption studies by exploring the BIM driving factors and barriers in a Sri Lankan context in order to accelerate BIM adoption among Sri Lankan QS organisations.

Academic research into BIM and its adoption is a relatively recent phenomenon, whilst at this time, many Sri Lankans consider BIM a buzzword. Therefore, this research contributes to a less researched area of academic study by identifying the factors to positively or negatively affects BIM adoption with specific consideration of the Sri Lankan context.

The study presents a framework that identifies the drivers and barriers to BIM adoption. Furthermore, it also identifies the sub barriers for each main barrier in order to consider what QS's have to address when adopting BIM in Sri Lanka. This is a significant contribution to theory as this study is among the first to identify these BIM barriers and associated sub-factors from a QS perspective within the Sri Lankan context. Furthermore, the framework identifies mitigating actions either to overcome or minimise the impact of each barrier with reference to responsible sectors; thus, it is beneficial to identify their role and responsibilities in order to support BIM adoption.

9.4.2 Contribution to Practice

This study identifies the barriers and drivers faced during the adoption of BIM from a quantity surveyor's perspective. Based on the empirical findings, the study offers a framework to support BIM adoption. The proposed framework will benefit quantity surveying organisations, architects, construction related professional bodies, the government, academics and other construction industry related professionals. It will also benefit other construction industry stakeholders or organisations in order to determine the best practice for BIM adoption within their organisations.

This study identifies six main barriers, namely financial, organisational, regulatory, unawareness, lack of resources and a lack of demand for BIM. The study concludes by identifying the mitigating actions to minimise or overcome the impact of each barrier. This is a significant contribution to practice, which can be adapted to ensure the successful adoption of BIM among quantity surveying organisations. Moreover, as this research prioritised an understanding of BIM adoption, it could offer a valuable contribution to the practice of BIM adoption.

As the framework is validated by experts, there is opportunity to apply it in support of BIM adoption in the Sri Lankan construction industry. It may also be adopted by as a guide by other developing countries, which have similar characteristics to the Sri Lankan construction industry.

9.5 Limitations of the Study

Apart from above highlighted contributions, this study also has some limitations, as follows;

1. The focus of this study was only concerned with quantity surveying practice. The participants of this study were from quantity surveying backgrounds and no other disciplines related to the construction industry were consulted. As this research does not claim the viewpoints of all construction players in Sri Lanka, the results and findings of the study indicate a limited perspective on the overall adoption of BIM in Sri Lanka. Nevertheless, study results indicate the role of few other disciplines, such as architects, in the adoption of BIM from a quantity surveyor's perspective. Therefore, by using the same research approach this study could offer a benchmark for the appraisal of BIM adoption towards other construction industry disciplines.
2. Data was collected via a questionnaire survey and semi-structured interviews. Interviews were conducted in selected large-scale QS organisations located in the capital Colombo. Therefore, the findings are more applicable to large-scale QS organisations. However, some factors are common to any sized organisation, such as education. Therefore, medium and small-scale QS organisations also benefit from this study when considering related areas of BIM adoption. However, the medium and small-scale organisations also need further study to appraise BIM adoption.
3. The final framework of this study was validated using series of expert interviews; hence, it did not test its applicability and practicality, which were beyond the scope of this research.

9.6 Further Research

Recommendations for further research are presented below.

One of the limitations of this study is that the final framework has not been tested for applicability and practical allegations, as that is beyond the scope of this study. Consequently, it is recommended that the final framework is applied in selected quantity surveying organisations to test its validity in practice.

This study focused on quantity surveying organisations, so most of solutions offered in the final framework enhance the BIM adoption process in QS organisations. Therefore, it is recommended to conduct a similar study from different perspective, such as architects, to appreciate a wider range of factors related to BIM adoption.

The main consideration of this study was large-scale QS organisations and it is recommended that a study is conducted to appreciate the factors related to BIM adoption for medium and small-scale construction organisations.

The final framework of this study lists the barriers and suggested mitigating actions for each barrier, which were mostly identified from the literature and case studies, followed by the validation by experts in the field. Thus, another study could explore how these suggested actions could be implemented.

Although the findings directly address the Sri Lankan construction industry, this framework could be further developed to consider the standards of other developing countries and supported by empirical evidence to confirm this. Therefore, another study could be conducted in other developing countries, based on similar case selection criteria.

9.7 Concluding Note

This chapter highlighted the main conclusion of the study and demonstrated that the aim and objectives have been fulfilled. The primary outcome of the study is a framework to identify the factors affecting BIM adoption, such as the drivers, barriers and mitigating actions to minimise or overcome the impact of the barriers identified. Thus, the outcome of the research contributes to both theory and practice in BIM adoption. Nevertheless, the researcher has taken steps to manage the consequences of the limitations inherent to the study. Finally, the outcomes of this study noted further research areas in terms of application, focus and background.

10 References

Ariff Putra Ansaruddin Agus, Muhammad, Noraini Hamzah, and Muhamad Azry Khoiry. 2019. “BIM Implementation in Asia Towards Functionalities: A Systematic Review.” *International Journal of Engineering & Technology; Vol 8, No 1.2 (2019): Special Issue 2DO - 10.14419/Ijet.V8i1.2.24873* 8:60–65.

ABAB. (2020, 01 20). Australasian BIM Advisory Board. Retrieved from abab.net: http://www.abab.net.au

ABAB. 2018. “BIM Process Consistency: Digital Design , Construction and Operation.”

ABAB. 2019. “Australian BIM Strategic Framework.”

Abanda, F. H., B. Kamsu-Foguem, and J. H. M. Tah. 2017. “BIM – New Rules of Measurement Ontology for Construction Cost Estimation.” *Engineering Science and Technology, an International Journal* 20(2):443–59.

Abanda, F. H., Mzyece, D., Oti, A. H., & Manjia, M. B. (2018). A Study of the Potential of Cloud/Mobile BIM for the Management of Construction Projects. MDPI.

Abdulfattah, Noor M., Ahmed M. Khalafallah, and Nabil A. Kartam. 2017. “Lack of BIM Training: Investigating Practical Solutions for the State of Kuwait.” *World Academy of Science, Engineering and Technology, International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering* 11(8):1050–56.

Aboagye, Anthony Q. Q. 2019. “Principal Components of Variables Hypothesised to Cause Project Delays and Cost Overruns in Ghana.” 2(1).

Abubakar, M., Y. Ibrahim, D. Kado, and K. Bala. 2014. “Contractors Perception of the Factors Affecting Building Information Modelling (BIM).” *Computing in Civil and Building Engineering* 167–78.

Adhikari, Aravinda, and Chung Wai Keung. 2018. “The Impact of BIM on Quantity Surveyor’s Role- the Contractor Perspective.” *ICEC-PAQS Conference 2018* (November):1–17.

Ahady, S., Gupta, S., & Malik, R. K. (2017). A critical review of the causes of cost overrun in construction industries in developing countries. International Research Journal of Engineering and Technology.

Ahady, Shambalid, Sakshi Gupta, and R. K. Malik. 2017. “A Critical Review of the Causes of Cost Overrun in Construction Industries in Developing Countries.” *International Research Journal of Engineering and Technology (IRJET)* 04(03):2550–58.

Ahmad, N. A. 2019. “Cost Overruns on Federal Capital Territory Authority Road Construction Projects.” *Cost Overruns on Federal Capital Territory Authority Road Construction Projects* 13(1):1–14.

Ahmed, Ayman, Hisham Gabr, Tamer Abdel Aziz, and Mahmoud Ahmed Hussien. 2018. “Causes and Impacts of Poor Communication.” *2nd International Conference on Sustainable Construction and Project Management* (February 2019):0–11.

Ahmed, Shakil. 2018. “Analysis of the Causes of Accident in Construction Project.” (November).

Ahuja, R., Sawhney, A., Jain, M., Arif, M., & Rakshit, S. (2018). Factors influencing BIM adoption in emerging markets—the case of India. International Journal of Construction Management.

Aibinu , A. A., & Pasco , T. (2008). The accuracy of pre-tender building cost estimates in Australia. Construction Management and Economics, (pp. 1257-1269).

Aibinu, A. A. 2012. “The Rocky Road to BIM Adoption: Quantity Surveyors Perspectives.” *CIB Joint International Symposium on Management of Construction: Research to Practice* 539–54.

Aibinu, Ajibade, and Sudha Venkatesh. 2014. “Status of BIM Adoption and the BIM Experience of Cost Consultants in Australia.” *Journal of Professional Issues in Engineering Education and Practice* 140(3):1–10.

AIQS, and NZIQS. 2018. “Australia and New Zealand BIM Best Practice Guidelines.” (September).

Akram, Muhammad, Tauha Hussain Ali, Nafees Ahmed Memon, and Shabir Hussain Khahro. 2017. “Causal Attributes of Cost Overrun in Construction Projects of Pakistan.” *International Journal of Civil Engineering and Technology* 8(6):477–83.

Alaloul, Wesam Salah, Mohd Shahir Liew, and Noor Amila Wan Abdullah Zawawi. 2016. “Identification of Coordination Factors Affecting Building Projects Performance.” *Alexandria Engineering Journal* 55(3):2689–98.

Alhasan, Soleen, Bimal Kumar, and Joseph V. Thanikal. 2017. “Effectiveness of Implementing 5D Functions of Building Information Modeling on Professions of Quantity Surveying - A Review.” *International Journal of Civil Engineering and Technology* 8(5):783–800.

Alhumayn, Saud, Ezekiel Chinyio, and Issaka Ndekugri. 2017. “The Barriers and Strategies of Implementing BIM in Saudi Arabia.” *WIT Transactions on the Built Environment* 169:55–67.

Ali Bhatti, Imtiaz, Abd Halid Abdullah, Sasitharan Nagapan, Nabi Bux Bhatti, Samiullah Sohu, and Ashfaque Ahmed Jhatial. 2018. “Implementation of Building Information Modeling (BIM) in Pakistan Construction Industry.” *Technology & Applied Science Research* 8(4):3199–3202.

Ali, Babar, Hafiz Zahoor, Khwaja M. Mazher, and Ahsen Maqsoom. 2018. "BIM Implementation in Public Sector of Pakistan Construction Industry." *ICCREM 2018: Innovative Technology and Intelligent Construction - Proceedings of the International Conference on Construction and Real Estate Management 2018* (August):42–51.

Ali, M. T. (2019). Study on the Development of BIM/DPD Around the World and Relevant Application in Western Canada. Canada: Edmonton Construction Association.

Ali, Mohammed Tareq. 2019. "Study on the Development of BIM / DPD Around the World and Relevant Application in Western."

Aljohani, Abdulelah. 2017. "Construction Projects Cost Overrun: What Does the Literature Tell Us?" *International Journal of Innovation, Management and Technology* 8(2):137–43.

Allahaim, Fahad Saud A., and Li Liu. n.d. "An Empirical Classification of Cost Overrun in Infrastructure Projects by Using Cluster Analysis."

Allahaim, Fahad, and Li Liu. 2012. "Understanding Major Causes Cost Overrun for Infratsrtucture Projects; a Typology Approach." *37th Annual Conference of the Australasian Universities Building Educators Association (AUBEA)* (July):424–37.

Alomari, Kasim, John Gambatese, and Jason Anderson. 2017. "Opportunities for Using Building Information Modeling to Improve Worker Safety Performance." *Safety* 3(1):1–11.

AlTabbaa, Omar, and Samuel Ankrah. 2016. *University of Huddersfield Repository*. Vol. 104.

Ameh, Oko John, Aliu Adebayo Soyingbe, and Koleola Tunwase Odusami. 2010. "Significant Factors Causing Cost Overruns in Telecommunication Projects in Nigeria." *Journal of Construction in Developing Countries* 15(2):49–67.

Amoateng, Augustine, and Kwaku Osei. 2017. "External Market Conditions That Affect Cost of Tendering in Public Institutions: Evidence from Ghana." *British Journal of Economics, Management & Trade* 17(3):1–12.

Anant Narayan Shete, and Vaibhav Durwas Kothawade. 2016. "An Analysis of Cost Overruns and Time Overruns of Construction Projects in India." *International Journal of Engineering Trends and Technology* 41(1):33–36.

Andrić, Jelena M., Abdul Majeed Mahamadu, Jiayuan Wang, Patrick X. W. Zou, and Ruoyu Zhong. 2019. "The Cost Performance and Causes of Overruns in Infrastructure Development Projects in Asia." *Journal of Civil Engineering and Management* 25(3):203–14.

Andrić, Jelena M., Abdul Majeed Mahamadu, Jiayuan Wang, Patrick X. W. Zou, and Ruoyu Zhong. 2019. "The Cost Performance and Causes of Overruns in Infrastructure Development Projects in Asia." *Journal of Civil Engineering and Management* 25(3):203–14.

Anigbogu, N. A., Ahmad , Z. B., & Molwus, J. J. (2019). Cost Overruns on Federal Capital Territory Authority Road Construction Projects. ournal of the Environment V.

Anigbogu, Natalia. 2019. "Cost Overruns on Federal Capital Territory Authority Road Construction Projects." *Cost Overruns on Federal Capital Territory Authority Road Construction Projects* 13(1):1–14.

Anon. 2007. "Comments Comments 1 Comments on technical measures centered on the role of public research institutes Comments コメント 2 From the standpoint of product developers of branded foods Comments 3 Comments on four reports from the viewpoint of agricultural economics." *Journal of Food System Research* 14(2):70–75.

Anon. 2013. "Causes and Effects of Delays in Capital Construction Projects at the State Universities in Sri Lanka Causes and Effects of Delays in Capital Construction Projects at the State Universities in Sri Lanka." 4(02).

Anon. 2017. "Thimphu Bhutan Report on Report Hydropower Project Cost Overrun." (December).

Anon. n.d "ExploringAccuracyFactorsinCostEstimatingPracticetowardsImplementingBuildingInformationModellingBIM.Pdf."

Anon. n.d. "Implementation of BIM in India I Engineers&Architects Blog."

Anon. n.d. "Redefining the Dimensions of BIM."

Anon. n.d. "What_are_the_facilitating_factors_to_the."

Arayici, Yusuf, John Counsell, Lamine Mahdjoubi, Gehan Nagy, Soheir Hawas, and Khaled Dewidar. 2017. *Heritage Building Information Modelling*.

Arditi, David, Guzin Tarim Akan, and San Gurdamar. 1985. "Cost Overruns in Public Projects." *International Journal of Project Management* 3(4):218–24.

Aryani, Ahmad Latiffi, Juliana Brahim, and Mohamad Syazli Fathi. 2014. "The Development of Building Information Modeling (BIM) Definition." *Applied Mechanics and Materials* 567(June):625–30.

Ashworth , A., & Hogg , K. (2007). Willis Practices and Procedure for Quantity Surveyor. Oxford; Malden, Mass: Blackwell publishing.

Ashworth, A., Hogg, K., Higgs, C., & Willis, C. J. (2013). Willis's practice and procedure for the quantity surveyor. Oxford: Wiley-Blackwell.

Asiedu, Richard O., and Hans W. Alfen. 2014. "Factors Engendering Cost Misrepresentation of Public Sector Projects in Ghana." *International Journal of Sustainable Construction Engineering & Technology* 5(2):2180–3242.

Associates, New, and Liquidated Damages. 2017. "KALANA ' 16 Get-Together - College of Quantity Surveying." (275).

Attanayake, Chulanee. 2018. "Mattala : Attracting Business into a Lonely Airport." (December 2018).

Äüôú, Ö. 2003. "No Title." (1):6–8.

Autodesk. (2007). BIM and Cost Estimating . Autodesk.

Avsatthi, B. (2016). cost estimation in cosntruction using BIM. Ahmedabad: Hi-Tech CADD services.

Azhar, Salman, Malik Khalfan, and Tayyab Maqsood. 2012. "Building Information Modeling (BIM): Now and Beyond." *Australasian Journal of Construction Economics and Building* 12(4):15–28.

Babatunde, S., Ekundayo, D., Adekunle, A., & Bello, W. (2020). Comparative analysis of drivers to BIM adoption among AEC firms in developing countries : a case of Nigeria. Journal of Engineering, Design and Technology, 29.

Babič, Nenad Čuš, and Danijel Rebolj. 2016. "Culture Change in Construction Industry: From 2d toward Bim Based Construction." *Journal of Information Technology in Construction* 21(March):86–99.

Balachandra, H. K. (2014). Sri Lanka Country report. Colombo: nstitute for Construction Training and Development (ICTAD).

Bank, Inter-american Development. 2018. *Better Spending for Better Lives: How Latin America and the Caribbean Can Do More with Less*.

Barzandeh, Mohammad, and Unitec New Zealand. n.d. "Accuracy of Estimating Techniques for Predicting Residential Construction Costs – a Case Study of an Auckland Residential Construction Company."

Bečvarovská, Radka, and Petr Matějka. 2014. "Comparative Analysis of Creating Traditional Quantity Takeoff Method and Using a BIM Tool." *Construction Maeconomics Conference 2014*.

Bettemir, Ö. H. 2018. "Development of Spreadsheet Based Quantity Take-off and Cost Estimation Application." *Journal of Construction Engineering, Management & Innovation* 1(3):108–17.

Bjornen, K. H., and J. R. Stacy. 2009. “Developing a 2 Year Oil and Gas Education Program.” *SPE Production and Operations Symposium, Proceedings* 295–304.

Board, Editorial. 2014. “IQSSL ’ s Annual General Meeting - 2014 (Cont ’ d).” 03(275).

Board, Editorial. 2016. “The Institute of Quantity Surveyors , Sri Lanka IQSSL ’ s Annual General Meeting - 2016 (Cont ’ d).” 05(275).

Board, Editorial. 2016. “The Institute of Quantity Surveyors , Sri Lanka IQSSL Annual Forum 2015 IQSSL Annual Forum 2015 (Cont).” 05(275).

Boon, J. (2009). Preparing for the BIM revolution. In Pacific Association of Quantity Surveyors Conference. PAQS.

Boon, J., & Prigg, C. (2012). Evolution of quantity surveying practice in the use of BIM–the New Zealand experience. In Joint CIB International Symposium of W055, W065, W089, W118. Montreal: CIB International Symposium.

Bosch-Sijtsema, Petra, Anders Isaksson, Martin Lennartsson, and Henrik C. J. Linderoth. 2017. “Barriers and Facilitators for BIM Use among Swedish Medium-Sized Contractors - ‘We Wait until Someone Tells Us to Use It.’” *Visualization in Engineering* 5(1).

Britto, A. .., B. .. Perera, and I. .. Illankoon. 2013. “Factors Affecting the Accuracy of Pre-Tender Estimation of Road Construction in Sri Lanka.” (December):243–54.

Bui, N. (2019). Implementation of Building Information modelingin Vietnamese infrastructure construction: A case studyof institution al influences on a bridge project. Wiley.

Bui, Nam. 2020. “Implementation of Building Information Modeling in Vietnamese Infrastructure Construction: A Case Study of Institutional Influences on a Bridge Project.” *Electronic Journal of Information Systems in Developing Countries* 86(4):1–13.

Buiab, N., Merschbrockb, C., & Mun, E. (2016). A review of Building Information Modelling for construction in developing countries. Creative Construction Conference 2016 (pp. 487 – 494). ScienceDirect.

Building, Green, and Awards Ceremony. 2017. “S y m p o s i u m 30.” (July).

Building, The, Information Foundation, and Senate Properties. 2018. “Observatory Finland.”

Burgess, Gemma, Michael Jones, and Kathryn Muir. 2018. “BIM in the UK House Building Industry: Opportunities and Barriers to Adoption.” *Cambridge: University of Cambridge* (March).

Burrell, G., & Morgan, G. (1979). Sociological paradigms and organisational analysis. London: Heinemann.

Byland, C., & Magnusson, A. (2011). Model Based Cost Estimations- an international comparison. Retrieved from Thesis [online], available:http://www.bekon.lth.se/fileadmin/byggnadsekonomi/CarlBylund_A Magnusson_Model_Based_Cost_Estimations_- _An_International_Comparison__2_.pdf

Calabresi, Stephen. 1973. "H Ow To R Everse G Overnment I Mposition of I Mmorality : A S Trategy For." *Harvard Journal of Law & Public Policy* 113(July):1–6.

Cantarelli, Chantal C. 2011. "Cost Overruns in Large-Scale Transport Infrastructure Projects." (November):1–19.

Cartlidge, D. P. (2009). Quantity Surveyor's Pocket Book. Oxford: Butterworth- Heinemann.

CCI. (2007). Chamber of Construction Industry Sri Lanka . Colombo: CCI Publication.

Central Bank of Sri Lanka. (2015). Annual Report. Colombo: Central Bank;Sri Lanka.

Central-Bank. (2019). Annual Report. Colombo: Central Bank of Sri Lanka.

Cheng, Min Yuan, Hsing Chih Tsai, and Wen Shan Hsieh. 2009. "Web-Based Conceptual Cost Estimates for Construction Projects Using Evolutionary Fuzzy Neural Inference Model." *Automation in Construction* 18(2):164–72.

Choi, Jungsik, Hansaem Kim, and Inhan Kim. 2015. "Open BIM-Based Quantity Take-off System for Schematic Estimation of Building Frame in Early Design Stage." *Journal of Computational Design and Engineering* 2(1):16–25.

CIC. (2019). BIM Adoption Survey 2019. Hong Kong: Construction Indsutry Council. Retrieved from https://www.bim.cic.hk/en/resources/publications_detail/73

Cicco, R. D. (2018, 02 28). BIM, the Chinese way. Retrieved from AEC Magazine: https://www.aecmag.com/comment-mainmenu-36/1577-bim-the-chinese-way-bim-aec

CIDB Malaysia. 2017. "Annual Report CIDB 2017." 125.

CIDB. 2015. *BIM Execution Plan (BEP)*.

CIDB. 2016. "BIM Guide 1 : Awareness." *Construction Industry Development Board Malaysia* 1–20.

CIDB. 2016. "BIM Guide 3: Adoption." *Construction Industry Development Board Malaysia*.

Clarizen. (2017, September 22). Why is Cost Estimation So Important (& How Can I Get Better at It?). Retrieved from https://www.clarizen.com/cost-estimation-important-can-get-better-2/

constrack360. (2019). Sri Lanka Building Construction Industry Databook Series: Market Size & Forecast 2019 - 2023. Retrieved from Constrack360: https://www.constrack360.com

Cooray, N. H. K., H. M. D. N. Somathilake, Mihiri Wickramasinghe, T. D. S. H. Dissanayke, and D. M. M. I. Dissanayake. 2019. "Analysis of Cost Control Techniques Used on Building Construction Projects in Sri Lanka." *SSRN Electronic Journal* 05(23):909–23.

Creswell, J., and V. Pioano Clark. 2007. "Introducing a Mixed Method Design." *Designing and Conducting Mixed Methods Research* 58–89.

Crowley, Claire. 2013. "Identifying Opportunities for Quantity Surveyors to Enhance and Expand the Traditional Quantity Modelling." *CITA BIM Gathering* 1–7.

Cunningham, Tony. 2017. "What Causes Cost Overruns on Building Projects? -An Overview." *Review* 0–29.

Dalkey, N. C., & Helmer, O. (1963). An experimantal application of the Delphi method to use of experts. Management science, 458-467.

Dandan, Tala Hassan, Ghaleb Sweis, Lilana Salem Sukkari, and Rateb J. Sweis. 2019. "Factors Affecting the Accuracy of Cost Estimate during Various Design Stages." *Journal of Engineering, Design and Technology* 18(4):787–819.

Davies, Kathryn, Suzanne Wilkinson, and Dermott McMeel. 2017. "A Review of Specialist Role Definitions in Bim Guides and Standards." *Journal of Information Technology in Construction* 22(June):185–203.

Debons, A. 1961. "The Current and Future Position of Psychology in Antarctica." *Acta Psychologica* 19(C):887.

Diana, Licia, and Pietrosemoli De Dikdan. 2018. "Sustainable Construction As a Mean for Competitiveness . the Venezuelan Opportunities 1." (March).

Dietz, D. M. (2018, 06 28). What is the difference between pre-construction and post-construction? Retrieved from quora.com: http://www.quora.com

Dixon, Torn. 1988. "Realizing the Benefits of SMT." *The Electronics Assembly Handbook* 129–37.

Documents, Boq, and Quantity Takeoff. 2017. “BIM기반 물량 및 내역정보 생성을 위한 내역서 개선방안 Improvement of BoQ Documents for the BIM Based Quantity Takeoff.” 7(2):16–24.

Dolage, D. A. R., and D. L. G. Rathnamali. 2013. “Causes of Time Overrun in Construction Phase of Building Projects : A Case Study on Department of Engineering Services of Sabaragamuwa Provincial Council.” *Engineer: Journal of the Institution of Engineers, Sri Lanka* 46(3):9.

Dubas, Sebastian, and Jerzy Pasławski. 2017. “The Concept of Improving Communication in BIM during Transfer to Operation Phase on the Polish Market.” *Procedia Engineering* 208:14–19.

Durdyev, Serdar, Maksat Omarov, Syuhaida Ismail, and Mengheng Lim. 2017. “Significant Contributors to Cost Overruns in Construction Projects of Cambodia.” *Cogent Engineering* 4(1).

Eadie, Robert, Henry Odeyinka, Mike Browne, Clare McKeown, and Michael Yohanis. 2013. “An Analysis of the Drivers for Adopting Building Information Modelling.” *Journal of Information Technology in Construction* 18(April 2015):338–52.

Eastman, C., Eastman, C. M., Teicholz, P., & Sacks, R. (2011). BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors. John Wiley & Sons.

EDB. (2015). Construction services sector of Sri Lanka. Sri Lanka export development board.

Elbeltagi, Emad, Ossama Hosny, Mahmoud Dawood, and Ahmed Elhakeem. 2014. “BIM-Based Cost Construction Estimation / Monitoring For Building.” *Emad Elbeltagi Int. Journal of Engineering Research and Applications* 4(7):56–66.

EOS Group. n.d. “Building Information Modeling : A Cost Estimating Perspective.” *EOS Group*.

Epasinghe, E. A. K., H. S. Jayasena, L. M. B. N. Kolugala, and M. K. C. S. Wijewickrama. 2018. “Open BIM Adoption in Sri Lankan Construction Industry.” (December):1–13.

Epasinghe, E. A., Jayasena , H. S., Kolugala, L. M., & Wijewickrama, M. K. (2018). Open BIM Adoption in Sri Lankan Construction Industry. FOSS4G Asia 2018 Conference. Colombo: University of Moratuwa.

EUBIM Task Group. 2016. “Handbook for the Introduction of Building Information Modelling by the European Public Sector.” *EUBIM Task Group* 84.

Executive, Acting, The Airport, and Authority Hong. n.d. “BIM Initiatives by Construction Industry Council.”

Fernando, P. D. (2018). BUILDING INFORMATION MODELING ADAPTATION FOR CONSTRUCTION PROFESSIONALS IN SRI LANKA. Birmingham: Birmingham School of the Built Environment.

FERREIRA, Rita Cristina. 2008. "CIB W78 2008 International Conference on Information Technology in Construction Santiago, Chile." *Construction* (Itgi 2006):1–16.

Finco Enginnering. (2017, Aug 21). THE SRI LANKAN CONSTRUCTION SECTOR'S INCREASED INVESTMENT AND DEVELOPMENT. Colombo, Sri La.

Forgues, Daniel, Ivanka Iordanova, Fernando Valdivesio, and Sheryl Staub-French. 2012. "Rethinking the Cost Estimating Process through 5D BIM: A Case Study." *Construction Research Congress 2012: Construction Challenges in a Flat World, Proceedings of the 2012 Construction Research Congress* (May 2015):778–86.

França, Alda, and Assed Haddad. 2018. "Causes of Construction Projects Cost Overrun in Brazil." *International Journal of Sustainable Construction Engineering and Technology* 9(1):69–83.

Franco, Juan, Faiza Mahdi, and Hussein Abaza. 2015. "Using Building Information Modeling (BIM) for Estimating and Scheduling, Adoption Barriers." *Universal Journal of Management* 3(9):376–84.

Froehlich, James B. 2014. "Message from the President." *Vascular Medicine (United Kingdom)* 19(6):518.

Gaidytė, Rita. 2010. "2D and 3D Modeling Comparison." 1–38.

Galagoda, A. (2017). Construction industry's challenges and the future. Colombo: Ceylon Today.

Gamil, Yaser, and Ismail Abdul Rahman. 2017. "Identification of Causes and Effects of Poor Communication in Construction Industry: A Theoretical Review." *Emerging Science Journal* 1(4):239–47.

Gb, Paul Terna, and Oluseye Samuel Ajuwon. 2017. "Effects of Project Cost Overruns and Schedule Delays in Sub-Saharan Africa." *European Journal of Interdisciplinary Studies* 7(2):46.

Gebrehiwet, Tsegay, and Hanbin Luo. 2019. "Risk Level Evaluation on Construction Project Lifecycle Using Fuzzy Comprehensive Evaluation and TOPSIS." *Symmetry* 11(1).

Gerges, M., Austin, S., Mayouf, M., Ahiakwo , O., Jaeger, M., Saad, A., & Gohary, T. (2017). Aninvestigation into the implementation of building information modelling in the Middle East. Journal of Information Technology in Construction, 1-15.

Ghorbani, S. (2019). projectcontrolacademy.com. Retrieved from projectcontrolacademy.com: https://www.projectcontrolacademy.com/cost-overrun/

Gill, J., & Johnson, P. (2010). Research Methods for Managers. Sheffield: SAGE Publications Ltd.

Girginkaya Akdag, Suzan, and Uzair Maqsood. 2019. "A Roadmap for BIM Adoption and Implementation in Developing Countries: The Pakistan Case." *Archnet-IJAR* 14(1):112–32.

Goh, K. C., H. H. Goh, S. H. Toh, and S. E. Peniel Ang. 2014. "Enhancing Communication in Construction Industry through BIM." *11th International Cnnference on Innovation & Management* 313–24.

Gołaszewska, Małgorzata, and Marek Salamak. 2017. "Wyzwania w Przedmiarowaniu i Kosztorysowaniu w Technologii Bim Na Przykładzie Modelu Wiaduktu Drogowego." *Czasopismo Techniczne* 4/2017:71–80.

Government Contracts Committee for Construction (GCCC). 2017. "BIM-Adoption-Strategy-Statement-of-Intent." *A Public Sector BIM Adoption Strategy* 10.

Grant, Maria J., and Andrew Booth. 2009. "A Typology of Reviews: An Analysis of 14 Review Types and Associated Methodologies." *Health Information and Libraries Journal* 26(2):91–108.

Gu, Ning, and Kerry London. 2010. "Understanding and Facilitating BIM Adoption in the AEC Industry." *Automation in Construction* 19(8):988–99.

Gulati, P. (2009). Research Management: Fundamental and Applied Research. India: Global India Publications.

Gunasekara, K., & Jayasena, H. S. (2013). Identification of a Technological framework for Implementing Building Information Modelling in Sri Lanka. The Second World Construction Symposium (pp. 244-252). Colombo: Socio-Economic Sustainability in Construction.

Haider, Usman, Usama Khan, Asif Nazir, and Muhammad Humayon. 2020. "Cost Comparison of a Building Project by Manual and BIM." *Civil Engineering Journal* 6(1):34–49.

Haider, Usman, Usama Khan, Asif Nazir, and Muhammad Humayon. 2020. "Cost Comparison of a Building Project by Manual and BIM." *Civil Engineering Journal* 6(1):34–49.

Halwatura, R. U., and N. P. N. P. Ranasinghe. 2013. "Causes of Variation Orders in Road Construction Projects in Sri Lanka." *ISRN Construction Engineering* 2013(January 2013):1–7.

Hamada, Hussein M., Ahmad Haron, Zahrizan Zakiria, and Ali M. Humada. 2016. "Benefits and Barriers of BIM Adoption in the Iraqi Construction Firms." *International Journal of Innovative Research in Advanced Engineering (IJIRAE)* 3(08):76–84.

Hamma-adama , & Kouider, T. (2019). omparative Analysis of BIM Adoption Efforts by Developed Countries as Precedent for New Adopter Countries. Current Journal of Applied Science and Technology , 1-15.

Hamma-adama, Mansur, and Tahar Kouider. 2019. "Comparative Analysis of BIM Adoption Efforts by Developed Countries as Precedent for New Adopter Countries." *Current Journal of Applied Science and Technology* (June):1–15.

Hamma-adama, Mansur, and Tahar Kouider. 2019. "What Are the Barriers and Drivers Toward BIM Adoption in Nigeria?" (July):529–38.

Hamma-Adama, Mansur, Tahar Kouider, and Huda Salman. 2018. "State of Building Information Modelling (Bim) Adoption in Nigeria." *Association of Researchers in Construction Management (ARCOM)* 34(September):334–43.

Hamsah, Syahril Ali Ibrahim. 2016. "No Title 23(45):5–24.

Hannon, J. J. (2007). Estimators' Functional Role Change with BIM. AACE International Transactions.

Harrison, Curtis, and Derek Thurnell. 2015. "BIM Implementation in a New Zealand Consulting Quantity Surveying Practice." *International Journal of Construction Supply Chain Management* 5(1):1–15.

Harun, Aizul Nahar, Suzana Abd Samad, Mohd Nasrun Mohd Nawi, and Nuzul Azam Haron. 2016. "Existing Practices of Building Information Modeling (BIM) Implementation in the Public Sector." *International Journal of Supply Chain Management* 5(4):166–77.

Hassan, S. (2017, 2 22). Estimation and the Tendering process in Construction Industry. Retrieved from www.linkedin.com: https://www.linkedin.com/pulse/estimation-tendering-process-construction-industry-ul-hassan-1?trk=portfolio_article-card_title

Hatem, Wadhah A., Abbas M. Abd, and Nagham N. Abbas. 2018. "Barriers of Adoption Building Information Modeling (BIM) in Construction Projects of Iraq." *Engineering Journal* 22(2):59–81.

Hatmoko, J. U., Fundra, Y., Wibowo , M. A., & Zhabrinna. (2019). Investigating Building Information Modelling (BIM) Adoption in Indonesia Construction Industry. MATEC Web of Conferences. Researchgate.

Hendrickson, C. (2000). Project Management for Construction. Pittsburgh: Carnegie Mellon University.

Herr, Christiane M., and Thomas Fischer. 2019. “BIM Adoption across the Chinese AEC Industries: An Extended BIM Adoption Model.” *Journal of Computational Design and Engineering* 6(2):173–78.

Hitchcock, Marion. 2020. “Take-Off.” (December 2017):1–2.

Honda, Masataka. 2016. ?.” *Kazoku Syakaigaku Kenkyu* 28(2):250–250.

HOOK, J. (2019, 11 7). buildsoft.com. Retrieved from buildsoft.com: https://www.buildsoft.com.au/blog/10-statistics-defining-the-australian-construction-industry-in-2019

Hosseini, M. R., M. O. Namzadi, R. Rameezdeen, S. Banihashemi, and N. Chileshe. 2016. “Barriers To Bim Adoption: Perceptions From Australian Small and Medium-Sized Enterprises (Smes).” (July).

Hosseini, M. Reza, Saeed Banihashemi, Nicholas Chileshe, Mehran Oraee Namzadi, Chika Udaeja, Raufdeen Rameezdeen, and Tammy McCuen. 2016. “BIM Adoption within Australian Small and Medium-Sized Enterprises (SMEs): An Innovation Diffusion Model.” *Construction Economics and Building* 16(3):71–86.

Hutton, J. (2019). Cost overruns in major government projects. London: Taxpayersalliance.

ICE. (2020, 02 18). Pre-tender estimate for contracts. Retrieved from designingbuildings: https://www.designingbuildings.co.uk/wiki/Pre-tender_estimate_for_contracts

IMF. (2012). World economic outlook. . washington, DC:: International menetary fund.

Initiative, Infrastructure Transparency. n.d. “The CoST Afghanistan - Infrastructure Transparency Initiative.”

Institute of Civil Engineers. 2019. “Reducing the Gap between Cost Estimates and Outturns for Major Infrastructure Projects and Programmes.” *Ice* (210252):1–16.

IQSSL. (2017). BIM Symposium 2017. Colombo: Focus.

Islam, Muhammad Saiful, and Bambang Trigunarsyah. 2017. “Construction Delays in Developing Countries: A Review.” *Journal of Construction Engineering and Project Management* 7(1):1–12.

Ismail, N. A., Adnan, H., & Bakhary, N. A. (2019). Building Information Modelling (BIM) Adoption by Quantity Surveyors: A Preliminary Survey from Malaysia. Conf. Series: Earth and Environmental Science. Malaysia: IOP Publishing.

Ismail, Noor Akmal Adillah, Maria Chiozzi, and Robin Drogemuller. 2017. “An Overview of BIM Uptake in Asian Developing Countries.” *AIP Conference Proceedings* 1903.

Ismail, Noor Akmal Adillah, Robin Drogemuller, Scott Beazley, and Robert Owen. 2016. "A Review of BIM Capabilities for Quantity Surveying Practice." *MATEC Web of Conferences* 66:1–7.

Jagadeesh, G. M., Final Year, and B. Arch Student. 2019. "Investigation of BIM Adoption in India." *International Journal of Engineering Research and Technology (IJERT)* 8(11):252–58.

Jasanth, R. (2016). Future Impediments in Implementation of Building Information Modeling (BIM) and Quantity Surveyor's strategies in Northern Province, Sri Lanka. Colombo: Sheffield Hallam University.

Jayadi, Almadani, and Leni Sagita Riantini. 2016. "The Development of 4D Bim Based Infrastructure Construction Time Planning Standard Operating Procedure To Enhance Communication Quality From Infrastructure." 1–10.

Jayalath, Ayesha, and Terans Gunawardhana. 2017. "Towards Sustainable Constructions: Trends in Sri Lankan Construction Industry." *International Conference on Real Estate Management and Valuation 2017* (October):137–43.

JAYASENA , H. S., NAGALINGAM, & RANADEWA. (2013). Building Information Modelling and future Quantity Surveyor"s Practice in Sri Lankan Construction Industry. . The Second World Construction Symposium (pp. 81- 92). Colombo: Socio-Economic Sustainability in Construction.

Jayasena, H. S., & Weddikkara, C. (2013). Assessing the BIM Maturity in a BIM Infant Industry. The Second World Construction Symposium 2013: Socio-Economic Sustainability in Construction (pp. 62-69). Colombo: Ceylon Institute of Builders.

Jiang, Xinan (Northeaster University). 2011. "Developments in Cost Estimating and Scheduling in BIM Technology Author:" 88.

John, D. D. (2016). Building Information Modeling (BIM) technology Adoption and Implementation in the Sri Lankan Construction Industry. Georgia: Georgia Southern University.

Jongo, Jaffari S., Dennis N. G. A. K. Tesha, Raymond Kasonga, Justine J. Teyanga, and Kenan S. Lyimo. 2019. "Mitigation Measures in Dealing with Delays and Cost Overrun in Public Building Projects in Dar-Es-Salaam, Tanzania." *International Journal of Construction Engineering and Management* 8(3):81–96.

Jung, Wooyoung, and Ghang Lee. 2015. "The Status of BIM Adoption on Six Continents." *International Journal of Civil, Structural, Construction and Architectural Engineering* 9(5):406–10.

K. A. D. S. M. Chandraratne, K. A. K. Devapriya, and T. P. W. S. I. Pandithawatta. 2019. "Development of a Computer Model for Cost Estimation in Educational Buildings." (November):266–75.

Kalinichuk, Sergey. 2015. “Building Information Modeling Comprehensive Overview.” *Journal of Systems Integration* (2009):25–34.

Karunakaran, P., A. H. Abdullah, S. Nagapan, S. Sohu, and K. K. Kasvar. 2018. “Categorization of Potential Project Cost Overrun Factors in Construction Industry.” *IOP Conference Series: Earth and Environmental Science* 140(1).

Kassem, M.; Succar, B.; Dawood, N. 2013. “TeesRep - Teesside ’ s Research Repository A Proposed Approach To Comparing the BIM Maturity of Countries.” *Proceedings of the CIB W78 2013: 30th International Conference* (October):9–12.

Kassem, Mohamad, Trevor Brogden, and Nashwan Dawood. 2012. “BIM and 4D Planning: A Holistic Study of the Barriers and Drivers to Widespread Adoption.” *Journal of Construction Engineering and Project Management* 2(4):1–10.

Kavuma, Andrew, Jongho Ock, and Hyounseung Jang. 2019. “Factors Influencing Time and Cost Overruns on Freeform Construction Projects.” *KSCE Journal of Civil Engineering* 23(4):1442–50.

Kehily, Dermot, and Jason Underwood. 2017. “Embedding Life Cycle Costing in 5D BIM.” *Journal of Information Technology in Construction* 22:145–67.

Khabisi, Lisebo Jereminah. 2012. “Causes and Effects of Cost Overruns in Public Sector Construction Projects In.” 1–169.

Khosakitchalert, Chavanont, Nobuyoshi Yabuki, and Tomohiro Fukuda. 2019. “Improving the Accuracy of BIM-Based Quantity Takeoff for Compound Elements.” *Automation in Construction* 106(November 2018):102891.

Khosakitchalert, Chavanont, Nobuyoshi Yabuki, and Tomohiro Fukuda. 2020. “Automated Modification of Compound Elements for Accurate BIM-Based Quantity Takeoff.” *Automation in Construction* 113(January):103142.

Koria, Mikko. 2009. “Managing for Innovation in Large and Complex Recovery Programmes: Tsunami Lessons from Sri Lanka.” *International Journal of Project Management* 27(2):123–30.

Kostka, Genia, and Jobst Fiedler. 2016. *Large Infrastructure Projects in Germany: Between Ambition and Realities*.

Kotb , M. H., Aly, A. S., & Muhammad, K. M. (2019). Risk Assessment of Time and Cost Overrun Factors throughout Construction Project Lifecycle. Life science, 78-91.

Krzysztof Zima, and Agnieszka Leśniak. 2013. "Limitations of Cost Estimation Using Building Information Modeling in Poland." *Journal of Civil Engineering and Architecture* 7(5):545–54.

Kulasekara, G., Jayasena, H. S., & Ranadewa, K. T. (2013). Comparative effectiveness of quantity surveying in a building information modelling implementation. The Second World Construction Symposium (pp. 101-107). Colombo: Ceylon Institute of Builders.

KUMAR , G. R. (n.d). ESTIMATION AND QUANTITY SURVEYING. NPR COLLEGE OF ENGINEERING & TECHNOLOGY.

Kumara, E. K., Jayasena , H. S., & Ariyachandra, M. R. (2017). SOFTWARE CAPABILITIES OF SRI LANKAN ARCHITECTURAL PROFESSIONALS FOR BIM ADOPTION. What's New and What's Next in the Built Environment Sustainability Agenda? Colombo: The 6th World Construction Symposium 2017.

Lam, K. C., Qaung, T., Long, N. D., & Ogunlana, S. (2004). Large construction projects in developing countires. International journal of project management, 553-561.

Langford , D., Rowlinson , S., & Sawacha, E. (2008, 06 28). Safety behaviour and safety management: its influence on the attitudes of workers in the UK construction industry. Retrieved from wiley.com: https://onlinelibrary.wiley.com/doi/abs/10.1046/j.1365-232x.2000.00137.x

Lanka, Sri. 2019. "Quarterly E-Journal Of." 09(02).

Lara Nieto, Carmen. 1990. "The Problem of Communication in Merleau-Ponty." *Man's Self-Interpretation-in-Existence* (August 2014):263–74.

Larasati, Dewi, Furry Andini Willis, Yulita Hanifah, Fauzan Alfi Agirachman, and Suhendri Suhendri. 2018. "Factors That Affects Maturity Level of BIM Implementation in Indonesia; Case Studies of 5 Construction Key Actors." *Engaging Architectural Science: Meeting the Challenges of Higher Density: 52nd International Conference of the Architectural Science Association, RMIT University, Australia* 673–81.

Laures Solutions . (2010, September 24). Importance of cost estimation. Retrieved from https://lauressolutions.wordpress.com/2010/09/24/importance-of-cost-estimation/

Lee, Dong Gun, Ji Young Park, and Sang Hoon Song. 2018. "BIM-Based Construction Information Management Framework for Site Information Management." *Advances in Civil Engineering* 2018.

Lee, s., Trench, W., & Wills, A. (2011). Willie's Elements of Quantity Surveying. Oxford: Wiley-Blackwell.

Lee, Xia Sheng, Cheah Wei Tsong, and Mohd Faris Khamidi. 2016. "5D Building Information Modelling-A Practicability Review." *MATEC Web of Conferences* 66.

Lester, Eur Ing Albert. 2017. "Building Information Modelling (BIM)." *Project Management, Planning and Control* (May):509–27.

Level, B. I. M., and Capability Statement. n.d. "BIM Level 2 Capability Statement."

Li, Jinmin. 2016. "Integrating Building Information Modelling (BIM), Cost Estimating and Scheduling for Buildings Construction at the Conceptual Design Stage." 158.

Liao, Longhui, and Evelyn Ai Lin Teo. 2017. "Critical Success Factors for Enhancing the Building Information Modelling Implementation in Building Projects in Singapore." *Journal of Civil Engineering and Management* 23(8):1029–44.

Lim, Yaik Wah. 2016. "Building Information Modelling for Building Energy Efficiency Evaluation." *6th Annual International Conference on Architecture and Civil Engineering (ACE 2018)* (Ace):423–26.

Lindblad, Hannes, and Jacob Rudolphsson Guerrero. 2020. "Client's Role in Promoting BIM Implementation and Innovation in Construction." *Construction Management and Economics* 38(5):468–82.

Lindblad, Hannes, and Susanna Vass. 2015. "BIM Implementation and Organisational Change: A Case Study of a Large Swedish Public Client." *Procedia Economics and Finance* 21(15):178–84.

Lindner, U. K. 1991. "Khk - Moderne Konzepte Der 90Er Jahre." *Internist* 32(8):500–501.

Liu, Bingsheng, Min Wang, Yutao Zhang, Rui Liu, and Anmin Wang. 2017. "Review and Prospect of BIM Policy in China." *IOP Conference Series: Materials Science and Engineering* 245(2).

Liu, Hexu, Ming Lu, and Mohamed Al-Hussein. 2014. "BIM-Based Integrated Framework for Detailed Cost Estimation and Schedule Planning of Construction Projects." *31st International Symposium on Automation and Robotics in Construction and Mining, ISARC 2014 - Proceedings* (Isarc):286–94.

Liu, Shijing, Benzheng Xie, Linda Tivendal, and Chunlu Liu. 2015. "The Driving Force of Government in Promoting BIM Implementation." *Journal of Management and Sustainability* 5(4):157.

Liu, Shijing, Benzheng Xie, Linda Tivendal, and Chunlu Liu. 2015. "Critical Barriers to BIM Implementation in the AEC Industry." *International Journal of Marketing Studies* 7(6):162.

Liu, Ziwen, Yujie Lu, and Lu Chang Peh. 2019. "A Review and Scientometric Analysis of Global Building Information Modeling (BIM) Research in the Architecture, Engineering and Construction (AEC) Industry." *Buildings* 9(10).

Long, N. D., Ogunlana, S., Quang, T., & Lam, K. C. (2004). Large construction projects in developing countries: a case study from Vietnam. International Journal of project management, 553-561.

Lu, Weisheng. 2018. *BIM and Big Data for Construction Cost Management*.

M. M. G. D. Abeykoon, N. Zainudeen, C. S. R. Perera, and H. A. S. Madhuwanthi. 2019. “Client’s Impact to the Schedule Delays in Road Projects: Contractor’s Perspective.” (November):179–88.

Mahamid, Ibrahim, and Nabil Dmaidi. 2013. “Risks Leading to Cost Overrun in Building Construction from Consultants’ Perspective.” *Organization, Technology & Management in Construction: An International Journal* 5(2):860–73.

Mahamid, Ibrahim. 2018. “Critical Determinants of Public Construction Tendering Costs.” *International Journal of Architecture, Engineering and Construction* 7(1).

Malkanthi, S. N., A. G. D. Premalal, and R. K. P. C. B. Mudalige. 2017. “Impact of Cost Control Techniques on Cost Overruns in Construction Projects.” *Engineer: Journal of the Institution of Engineers, Sri Lanka* 50(4):53.

Malleson, A. (2018). The National BIM Report 2018. NBS.

Mamphey, S. (2016, September 5). BIM Rise of Machines. Retrieved from Faithful Gould: https://www.fgould.com/uk-europe/articles/bim-rise-machines

Management, Development. 2018. “Determinants of Infrastructure Project Delays and Cost Escalations . The Case of Road and Rail Construction Projects in Ethiopia Determinants of Infrastructure Project Delays and Cost Escalations : The Cases of Road and Railway Construction Projects in Et.” 102–36.

Management, Financial. 2019. “Of i Na Nc Ial Em En t o f P Pe Ro Rty d an Co Tr Ns u l o f F MANAGING FINANCIAL AND ECONOMIC n t o f P a Rty Pe Nd Ns Co Tru.”

Manfredonia, B. (2016). COST ESTIMATING . WBDG.

Mansfield, NR, OO Ugwu, and T. Doran. 1994. “Causes of Delay and Cost Overruns in Nigerian Construction Projects.” *International Journal of Project Management* 12(4):254–60.

Matarneh, Rana T., and Sadeq A. Hamed. 2017. “Exploring the Adoption of Building Information Modeling (BIM) in the Jordanian Construction Industry.” *Journal of Architectural Engineering Technology* 06(01):1–7.

Matejka, Petr, and Stanislav Vitasek. 2018. “Comparison of Different Cost Estimation Methods with Use of Building Information Modelling (BIM).” *Engineering for Rural Development* 17:843–49.

Matin, Danial Mirzai. 2016. "Identifying The Effective Factors for Cost Overrun and Time Delay in Water Construction Projects." *Technology & Applied Science Research* 6(4):1062–66.

Matipa, W. M., Kelliher, D., & Keane, M. (2008). How a Quantity Surveyor Can Ease Cost Management at the Design Stage Using A Building Product Model. Construction Innovation, (pp. 164-181).

Mattsson, Martin, and Mathias Rodny. 2013. "BIM in Infrastructure. Using BIM to Increase Efficiency through the Elimination of Wasteful Activities." 102.

Mayouf, Mohammad, Michael Gerges, and Sharon Cox. 2019. "5D BIM: An Investigation into the Integration of Quantity Surveyors within the BIM Process." *Journal of Engineering, Design and Technology* 17(3):537–53.

McAuley, B., A. Hore, and R. West. 2016. "BICP Global BIM Study." *BICP BIM Global Study* 61–65.

McGinnis , A. (2016). How far will traditional cost estimating take us? Linkedin. Retrieved from Linkedin: file:///Users/anushkarathnayake/Dropbox/Estimation/How%20far%20will%20traditional%20cost%20estimating%20take%20us%3F%20%7C%20Anthony%20McGinnis%20%7C%20Pulse%20%7C%20LinkedIn.webarchive

Mehran, Donya. 2016. "Exploring the Adoption of BIM in the UAE Construction Industry for AEC Firms." *Procedia Engineering* 145:1110–18.

Memon, Aftab Hameed, Ismail Abdul Rahman, and Nur Melly Edora Harman. 2014. "Implementation of Building Information Modeling in Malaysian Construction Industry." 1621(4):343–49.

Mertens, D. (2008). Mixed method and the politics of human research. Los Angeles: Sage.

MHC. 2014. *The Business Value of BIM for Construction in Major Global Markets*.

Mitchell, D. (2012). 5D BIM: Creating cost certainty and better buildings. RICS Cobra Conference. Las Vegas: RICS.

Mollasalehi, S., A. A. Aboumoemen, A. Rathnayake, A. Fleming, and J. Underwood. 2018. "Development of an Integrated BIM and Lean Maturity Model." in *IGLC 2018 - Proceedings of the 26th Annual Conference of the International Group for Lean Construction: Evolving Lean Construction Towards Mature Production Management Across Cultures and Frontiers*. Vol. 2.

Mollasalehi, S., A. Rathnayake, A. A. Aboumoemen, J. Underwood, A. Heming, U. Kulatunga, and P. Coates. 2017. "How BIM-Lean Integration Enhances the Information Management Process in the

Construction Design." in *IGLC 2017 - Proceedings of the 25th Annual Conference of the International Group for Lean Construction*.

Moreno, Cristina, Svetlana Olbina, and Raja R. Issa. 2019. "BIM Use by Architecture, Engineering, and Construction (AEC) Industry in Educational Facility Projects." *Advances in Civil Engineering* 2019.

Mu, Ari. 2019. "済無No Title No Title." *Journal of Chemical Information and Modeling* 53(9):1689–99.

Muhwezi, L., J. Acai, and G. Otim. 2014. "An Assessment of the Factors Causing Delays on Building Construction Projects in Uganda." *Construction Engineering and Management* 3(1):13–23.

Mukuka, Mulenga, Clinton Aigbavboa, and Wellington Thwala. 2015. "Effects of Construction Projects Schedule Overruns: A Case of the Gauteng Province, South Africa." *Procedia Manufacturing* 3(Ahfe):1690–95.

Murali, Surabattuni, and Sanjeet Kumar. 2019. "Factors Affecting Overruns Construction Time and Cost: A Case Study." *International Journal of Recent Technology and Engineering* 7(6C2):284–88.

Musa, Suria, Amanda Marshall-Ponting, Faizatul Akmar Abdul Nifa, and Syairah Aimi Shahron. 2018. "Building Information Modeling (BIM) in Malaysian Construction Industry: Benefits and Future Challenges." *AIP Conference Proceedings*

Namlı, Ersin, Ümit Işıkdağ, and Mustafa Nabi Kocakaya. 2019. "Building Information Management (BIM), A New Approach to Project Management." *Journal of Sustainable Construction Materials and Technologies* 4(1):323–32.

National Building Specification. 2011. "Building Information Modelling Report 2011." *National BIM Report 2011* (March):1–21.

NATSPEC. 2016. "National BIM Guide v1.0 Sep 2011.Doc." (September 2011).

Navarro, Carlos. 2017. "Construction Delays , Cost Overruns Could Postpone Opening of New Airport in Mexico City."

NBS. (2019). National BIM Report. National BIM Report.

NBS. 2019. "National BIM Report 2019." *National BIM Report 2019 :The Definitive Industry Update* 1–28.

Newton, Sidney, Martin Skitmore, and Peter E. D. Love. 2014. "Managing Uncertainty to Improve the Cost Performance of Complex Infrastructure Projects." *International Conference on Construction in a*

Changing World, CIB - International Council for Research and Innovation in Building and Construction 660–71.

Nichols, M. R. (2019, 11 15). What is the difference between pre-construction and post-construction? Retrieved from quora.com: https://www.quora.com

Nigam, Manish, Abhishek Dixit, and Kshitij Kumar Sachan. 2016. "BIM Vs Traditional Quantity Surveying And Its Future Mapping." *International Journal of Engineering Development and Research* 4(2):1261–65.

Nigussie, Tariku, and M. K. Chandrasekar. 2020. "Influence of Rebar Practice in the Total Cost of Building Construction Projects : The Case of Hawassa City , Ethiopia." 12(1):54–65.

Nkado,, R., & Meyer, T. (2001). Competencies of professional quantity surveyors: South African perspective. Construction Management and Economics, 481-491.

Nutter, Christopher L., and Leed Ap. n.d. "Common Challenges Associated With Design and Construction Delivery Using Building Information Modeling (Bim)."

Nyoni, T. (2019). Cost overrun factors in construction industry: a case of Zimbabwe. Harare: epartment of Economics, Faculty of Social Studies, University of Zimbabwe.

OBG. (2016). Sri Lanka's construction sector sees increased investment and development. Colombo: Oxford Business group.

Odeyinka, Henry, & Doherty. (2008). An evaluation of quantity surveying software using in nothern ireland. London: COBRA.

Odinot, Geralda, Gezinus Wolters, and Anne van Giezen. 2013. "Accuracy, Confidence and Consistency in Repeated Recall of Events." *Psychology, Crime and Law* 19(7):629–42.

Odusami, K. T., & Onukwube, H. N. (2008). Factors Affecting The Accuracy of Pre-Tender Cost Estimate in Nigeria. RICS Construction and Building Research Conference. Dublin: RICS.

Oladokun, Michael G., Adeyinka A. Oladokun, and Isaac A. Odesola. 2013. "Accuracy of Pre-Tender Cost Estimates of Consultant Quantity Surveyors in Nigeria." *A Compendium of International Real Estate and Construction Issues* 1(May):39–52.

Olanrewaju, Abdullateef, Seong Yeow Tan, and Lee Foo Kwan. 2017. "Roles of Communication on Performance of the Construction Sector." *Procedia Engineering* 196(June):763–70.

Olatunji, O. A., Sher, W. D., Gu, N., & Ogunsemi, D. (2010). Building information modelling processes: benefits for construction industry. In W078- Special Track 18th CIB World Building Congress (p. 137). Salford: CIB.

Olawumi, T. O., & Chan, D. W. (2019). Development of benchmarking model for BIM implementation in developing countries. Benchmarking An International Journal.

Olsen, Darren, and J. Mark Taylor. 2017. "Quantity Take-Off Using Building Information Modeling (BIM), and Its Limiting Factors." *Procedia Engineering* 196(June):1098–1105.

Oluyemi-Ayibiowu, B. D*., Aiyewalehinmi, O. E., and Omolayo, O. J. 2019. "Most Critical Factors Responsible For Cost Overruns In Nigeria Building Construction Industry." 5(2):2500–2508.

Ongprasert, Saratchai, and Rapee Parichatrkanont. n.d. "BIM / CIM Implementation in the Thailand Private Sector : Extension to 6D Analysis – Safety Simulation of A Railway Station." 43–54.

Onungwa, N., & Uduma-Olugu. (2017). Building Information Modelling and Collaboration in the Nigerian Construction Industry. Journal of Construction Business and Management, 10.

Oo, Bee Lan. 2017. "Release of Construction Clients' Pre-Tender Cost Estimates: An Experimental Study." *Construction Economics and Building* 17(4):37–47.

Ouellet, Jennifer A., and Lisa M. Walke. 2019. "History and Trends." *Geriatric Practice: A Competency Based Approach to Caring for Older Adults* 3–11.

Page, News. 2015. "The Institute of Quantity Surveyors , Sri Lanka Extra-Ordinary General Meeting IQSSL ' s Board Gathering." 04(02).

Pales, E. (2013). An analysis of BIM adoption holdback, assuming a sharp change in process and culture. Horsens: VIA University College.

Pall, Goutom K., Adrian J. Bridge, Jason Gray, and Martin Skitmore. 2019. "Causes of Delay in Power Transmission Projects: An Empirical Study." *Energies* 13(1).

Papadonikolaki, Eleni. 2017. "Alignin g BIM Adoption Drivers with B IM Implementation i n Loosel y Couple d Constructi On."

Paper, Conference. 2009. "The Accuracy of Pre-Tender Cost Estimates . of Consultant Quantity." (January).

Patuti, Indriati Martha, Ahmad Rifa'i, Kabul Basah Suryolelono, and Suprapto Siswosukarto. 2018. "Model of Timber Crib Walls Using Counterweight in Bone Bolango Regency Gorontalo Province Indonesia." *International Review of Civil Engineering* 9(3):98–104.

Paul, S. (2018, December 15). BIM adoption around the world: how good are we? Retrieved from geospatialworld: https://www.geospatialworld.net/article/bim-adoption-around-the-world-how-good-are-we/

Perera, B. A. K. S., M. K. C. S. Wijewickrama, W. R. S. C. Ranaweera, and I. S. W. Gamage. 2019. "Significant Factors Influencing the Bid Mark-up Decision of Infrastructure Projects in Sri Lanka." *International Journal of Construction Management* 0(0):1–15.

Perera, Kanchana K. S., and Navoda Ranasighe. 2018. "Proceedings of Annual Technical Sessions 2018 Institute of Quantity Surveyors Sri Lanka." (January).

Perera, Kanchana K. S., and Thilini Jayawickrama. 2018. "Adaptability of Shared Work Space Concept in Office Buildings in Sri Lanka." (June).

Perera, Srinath, Sadhana De Sliva, Robert Osei-Kyei, Yilin Yin, Lei Zhou, Xiaohua Jin, Nirodha Fernando, Solomon Babatunde, and Yingbin Feng. 2019. "BIM Execution Framework for Early-Stage Estimating in PPP Projects." (June).

Personal, Munich, and Repec Archive. 2019. "Cost Overrun Factors in Construction Industry : A Case of Zimbabwe." *Munich Personal RePEc Archive* (96788).

Polycarp Olaku Alumbugu, Wasiu Adeniran Ola-awo, SAIDU, Ibrahim, ABDULLAHI, Mustapha Muhammed, and Abdulmumin Abdulazeez. 2014. "Assessment of the Factors Affecting Accuracy of Pre-Tender Cost Estimate in Kaduna State, Nigeria." *IOSR Journal of Environmental Science, Toxicology and Food Technology* 8(5):19–27.

Popov, V., Migilinskas, D., Juocevičius, V., & Mikalauska, S. (2008). Application of building information modelling and construction process simulation ensuring virtual project development concept in 5D environment. Retrieved from http://dspace.vgtu.lt/handle/1/440

Price, D., and K. Andy. 2010. "Causes Leading to Poor Site Coordination in Building Projects." *Organization, Technology & Management in Construction : An International Journal* 2(2):167–72.

Priyantha, THS, Gayani Karunasena, and VAK Rodrigo. 2011. "Causes, Nature and Effects of Variations in Highways." *Built-Environment Sri Lanka* 9(1–2):14.

Proverbs, D., Gd Holt, and H. Cheok. 2000. "Construction Industry Problems: The Views of UK Construction Directors." *Proceedings of the 16th Annual …* 1(September):73–81.

Rahman, I. A., Ismail, I. B., & Jaber, M. M. (2018). Risk Assessment of Time and Cost Overrun Factors throughout Construction Project Lifecycle: Pilot Study. International Journal of Engineering & Technology, 717-723.

Rahman, W. (2019, 10 20). What is the difference between pre-construction and post-construction? Retrieved from quora.com: https://www.quora.com

Raisbeck, P., & Aibinu, A. A. (2010). Early Stage Cost Estimation and The Relationship of Architects to Quantity Surveyors. 26th Annual ARCOM Conference. Leeds: ARCOM.

Rajakumar, AC. 2016. "Analysis of Cost Overrun in Road Construction Activities – A Critical Review." *International Research Journal of Engineering and Technology* 06(04):1433–39.

Ramabhadran, Muralidaran. 2018. "An Investigation into Cost Overrun in Construction Projects in United Arab Emirates." *International Journal of Construction Engineering and Management* 7(1):1–21.

Rathnasiri, Pavithra, and Suranga Jayasena. 2019. "Green Building Information Modelling Technology Adoption for Existing Buildings in Sri Lanka. Facilities Management Perspective." *Intelligent Buildings International* (July):1–22.

Rathnayake, A., & Samir, H. (2019). Current Status of Awareness and Readiness Towards Building Information Modelling (BIM) Among Sri Lankan Quantity Surveyors. CITC. London: Sprigfield.

Rathnayake, A., Mollasalehi,, S., Aboumoemen , A., Kulatunga, U., & Samir , H. H. (2019). Building Information Modelling Adoption for better cost estimation: Sri Lankan perspective. The Tenth International Conference on Construction in the 21st Century (CITC-10) . Colombo: CITC.

Reinholdt, E. (2014, June 17). Design Practice: How to Pick the Right Drawing Software. Retrieved from houzz: https://www.houzz.com

Revit. 2006. "Building Information Modeling and Cost Estimating." *Autodesk* 8.

RICS, Dawn Smith, Simon Lovegrove, Alan Muse, Donald Duo Zhong Pan, Anil Sawhney, Paul Watkins, Gareth Whisson, and Townsend Seah Kwee Yong. 2015. "RICS Professional Guidance, Global: BIM for Cost Managers: Requirements from the BIM Model." *RICS Guidance Note* (August):16.

RICS. (2014). International BIM implemetation guide. RICS.

RICS. (2014). Tendering strategies. London: RICS.

RICS. 2014. "RICS Guidance, UK: Tendering Strategies." 24.

RICS. 2017. "Building Information Modelling for Project Managers." *Bim-Pm* (May):42.

Ridenour, C. S., & Newman, I. (2008). A1ixed Inethods research: Exploring. Carbondale: Southern Illinois University press.

Robinson, H., Symonds, B., Gilbertson, B., & Ilozor, B. (2015). Design Economics for the Built Environment: Impact of Sustainability on project evaluation. Chichester: Wiley Blackwell.

Rogers, J., Chong,, H., Christopher , P., Lim, C. C., & Jayasena, H. S. (2015). BIM Development and Trends in Developing Countries : Case Studies. UAE: Bentham Science Publishers.

Roslan, Ahmad Farhan, Zuhairi Abd Hamid, Maria Zura Mohd Zain, Nurulhuda Mat Kilau, Natasha Dzulkalnine, and Afifuddin Husairi Hussain. 2019. "Building Information Modelling (BIM) Stage 2 Implementation Strategy for the Construction Industry in Malaysia." *Malaysian Construction Research Journal* 6(Special issue 1):153–61.

Rowe, G., & Wright, G. (1999). The delphi technique as a forcasting tool: issues and analysis. International journal of forecasting, 353-375.

Rowe, G., & Wright, G. (2001). Esperts opinois in forecasting: The role of the delphi technique. International Series in Operations Research & Management Science , 125-144.

S. K. G. U. K. Jayawardhana, C. Hadiwattage, and M. M. M. P. Mahinkanda. 2019. "Significance of Construction Technology Knowledge for Quantity Surveyors in Expressway Construction Projects." 524–34.

Sabol, Louise. 2008. "Challenges in Cost Estimating with Building Information Modeling." *BIM-Cost Estimating* 1–16.

Safapour, Elnaz, Sharareh Kermanshachi, Jennifer Shane, and Stuart Anderson. 2017. "Exploring and Assessing the Utilization of Best Practices for Achieving Excellence in Construction Projects." *6th CSCE-CRC International Construction Specialty Conference 2017 - Held as Part of the Canadian Society for Civil Engineering Annual Conference and General Meeting 2017* 1:670–79.

Sahil, A. .. 2016. "Adoption of Building Information Modeling in Developing Countries :" *Degree Of Master Thesis, Colorado State University*.

Saidu, Ibrahim, and Winston Shakantu. 2016. "The Contributions of Construction Material Waste to Project Cost Overruns in Abuja, Nigeria." *Acta Structilia* 23(1).

Saidu, Ibrahim, and Winston Shakantu. 2017. "An Investigation into Cost Overruns for Ongoing Building Projects in Abuja, Nigeria." *Acta Structilia* 24(1):53–72.

Saka, Abdullahi B., and Daniel W. M. Chan. 2019. "A Scientometric Review and Metasynthesis of Building Information Modelling (BIM) Research in Africa." *Buildings* 9(4).

Samiullah Sohu, Abd Halid Abdullah, Sasitharan Nagapan, Nafees Ahmed Memon, Riduan Yunus, and Muhammad Fikri Hasmori. 2018. "Causative Factors of Cost Overrun in Building Projects of Pakistan." *International Journal of Integrated Engineering* 10(9):5–10.

Sarda, Chandan, and N. K. Gupta. 2018. "Avoiding Cost Overruns of Residential Construction Projects in Western Part of Pune City , India." *Avoiding Cost Overruns of Residential Construction Projects in Western Part of Pune City, India* 05(July):1357–61.

Sattineni, Anoop, and R. Harrison Bradford. 2011. "Estimating with BIM: A Survey of US Construction Companies." *Proceedings of the 28th International Symposium on Automation and Robotics in Construction, ISARC 2011* 564–69.

Saunders, M., Lewis, P., & Thornhill, A. (2016). Research methods for business students. Essex: Persons education limited.

Scott, Lloyd. 2018. "ARCOM Doctoral Workshop Research Methodology."

Seed, Lawrence S. 2015. "The Dynamics of BIM Adoption : A Mixed Methods Study of BIM as an Innovation within the United Kingdom Construction Industry." *Thesis* 1(May).

Seeley, I. H. (1996). Building Economics. London: Macmillan.

Senouci, Ahmed, Alaa Ismail, and Neil Eldin. 2016. "Time Delay and Cost Overrun in Qatari Public Construction Projects." *Procedia Engineering* 164(June):368–75.

Shabani, Ms Neema, Justine Mselle, Samwel Alananga Sanga, and Arbogasti Isidori Kanuti. 2018. "Stability of Construction Cost-Variability Factor Rankings from Professionals ' Perspective : Evidence from Dar Es Salaam – Tanzania." 8(2):17–33.

Shah, Raj Kapur. 2016. "An Exploration of Causes for Delay and Cost Overruns In Construction Projects: Case Study of Australia, Malaysia & Ghana." *Journal of Advanced College of Engineering and Management* 2:41.

Shanmugam, M., N. Zainudeen, and R. D. G. Amaratunga. 2006. "Simulation Modelling of Cost Overruns in Building Projects." *6th International Postgraduate Research Conference in the Built and Human Environment* 103–15.

Shashi Kumar Yadav, Dr. Anjay Kumar Mishra. 2019. "Scholars Journal of Engineering and Technology Status of Time and Cost Overrun of Health Building Construction Projects in Nepal." (October).

Shen, Z., & Issa, R. R. (2010). Quantitative evaluation of the BIM-assisted construction detailed cost estimates. DigitalCommons University of Nebraska. Retrieved from http://digitalcommons.unl.edu/constructionmgmt

Shibani, Dr Abdussalam. 2015. "Time and Cost Overrun in Construction Projects in Egypt Time and Cost Overrun in Construction Projects in Egypt." (September):22–29.

Shrestha, Pramen P., Leslie A. Burns, and David R. Shields. 2013. "Magnitude of Construction Cost and Schedule Overruns in Public Work Projects." *Journal of Construction Engineering* 2013(2):1–9.

Siemiatycki, Matti. 2015. "On Infrastructure Projects :" (11).

Siemiatycki, Matti. 2018. "The Making and Impacts of a Classic Text in Megaproject Management: The Case of Cost Overrun Research." *International Journal of Project Management* 36(2):362–71.

Silva, D., Rajakaruna, N., & Bandara, K. T. (2014). Challenges faced by the construction industry in Sri Lanka. Colombo: University of Moratuwa.

Siriwardhana, M. S., Jayasena, H. S., Wijewickrama, M. K., & Kolugala, L. M. (2018). SUITABLE GOVERNMENT INITIATIVE STRATEGY FOR BIM IMPLEMENTATION IN SRI LANKA. The 7th World Construction Symposium 2018. Colombo: Built Asset Sustainability: Rethinking Design, Construction and Operations.

Smith, Peter. 2014. "BIM Implementation - Global Strategies." *Procedia Engineering* 85:482–92.

Smith, Peter. 2014. "Sustainable Development & BIM – The Role of the 5D Quantity Surveyor." *Procedia - Social and Behavioral Sciences* 1–11.

Smithwick, Jake, Joshua Jason Mischung, and Kenneth Timothy Sullivan. 2014. "Impact of Quantity Takeoff Software on Student Performance in a University Construction Estimating Course: A Case Study." *ASEE Annual Conference and Exposition, Conference Proceedings*.

Society, American, and International Law. 2009. "Akinci, B., and Fischer, M,, 1998. Factors Affecting Contractors' Risk of Cost Overburden." (August).

Sohu, Samiullah, Abd Halid Abdullah, Sasitharan Nagapan, Nafees Ahmed Memon, Riduan Yunus, and Muhammad Fikri Hasmori. 2018. "Causative Factors of Cost Overrun in Building Projects of Pakistan." *International Journal of Integrated Engineering* 10(9):122–26.

Song, J., Wang, G., Liu, Z., & Wang, H. (2018). Key Factors Affecting BIM Adoption in China Based on TOE&RC. International Conference on Mechanics, Materials and Structural Engineering. China: nternational Conference on Mechanics, Materials and Structural Engineering.

Southbay Construction. (2015, December 4). COST ESTIMATION: THE CORNERSTONE OF EVERY CONSTRUCTION PROJECT. California, Campbell, USA.

Stanley, R., & Thurnell, D. (2013). Current and anticipated future impacts of BIM on cost modelling in Auckland. 38th AUBEA International Conference. Auckland: AUBEA International Conference.

Stanley, Sarah E., and Aaron S. Benjamin. 2016. "That's Not What You Said the First Time: A Theoretical Account of the Relationship between Consistency and Accuracy of Recall." *Cognitive Research: Principles and Implications* 1(1):1–11.

Suddaby, R. (2006). What grounded theory is not. Academy of management journal, 633-43.

Sun, Chengshuang, Shaohua Jiang, Miroslaw J. Skibniewski, Qingpeng Man, and Liyin Shen. 2017. "A Literature Review of the Factors Limiting the Application of BIM in the Construction Industry." *Technological and Economic Development of Economy* 23(5):764–79.

Sunil, K., Pathirage, C. P., & Underwood, J. (2015). The Importance of Integrating Cost Management with Building Information Modeling (BIM). University of Salford, School of the Built Environment. Salford: University of Salford.

Svalestuen, Fredrik, Vegard Knotten, Ola Lædre, Frode Drevland, and Jardar Lohne. 2017. "Using Building Information Model (Bim) Devices To Improve Information Flow and Collaboration on Construction Sites." *Journal of Information Technology in Construction* 22(February):204–19.

Taboada, José Antonio, and Alessandra Garrido-Lecca. 2014. "Case Study on the Use of Bim at the Bidding Stage of a Building Project." *22nd Annual Conference of the International Group for Lean Construction: Understanding and Improving Project Based Production, IGLC 2014* 1473–82.

Tadewos, Shambel Gebrehiwot, and Dixit Patel. 2018. "Factors Influencing Time and Cost Overruns in Road Construction Projects : Addis Ababa , Ethiopian Scenario : Review Paper." *International Research Journal of Engineering and Technology* 05(2014):177–80.

Tagg, Morgan Christian. 2017. "The State of BIM-Based Quantity Take-Off Implementation Among Commercial General Contractors." 124.

Tahir, M. M., Haron, N. A., Alias, A. H., Harun, A. N., Muhammad, I. B., & Baba, D. L. (2018). Improving Cost and Time Control in Construction Using Building Information Model (BIM): A Review. SCIENCE & TECHNOLOGY , 21 - 36.

Tahir, Muhammad Muhammad, Nuzul Azam Haron, Aidi Hizami Alias, and Ikechukwu A. Diugwu. 2019. "Causes of Delay and Cost Overrun in Malaysian Construction Industry." *Lecture Notes in Civil Engineering* 9(November):47–57.

Taylor, R., & Judd, L. (1989). Delphi method applied to tourism. New York: Prentice Hall.

Telaga, Abdi Suryadinata. 2018. “A Review of BIM (Building Information Modeling) Implementation in Indonesia Construction Industry.” *IOP Conference Series: Materials Science and Engineering* 352(1).

The World Bank. 2017. “Zambia: Improved Rural Connectivity Project-SUF (P159330); Combined Project Information Documents/ Integrated Safeguards.” 1:1–8.

Thurairajah, N., & Goucher, D. (2013). Advantages and challenges of using BIM: A cost consultant’s perspective. 49th ASC Annual International Conference. ASC.

Tokla, Suon. 2020. “Bim-Based Simplified Approach To Automatically Estimate Building Costs for Projects in Thailand.” *International Journal of GEOMATE* 18(68):101–7.

Torp, Olav, and Ole Klakegg. 2016. “Challenges in Cost Estimation under Uncertainty—A Case Study of the Decommissioning of Barsebäck Nuclear Power Plant.” *Administrative Sciences* 6(4):14.

Trading Economics. (2017). Trading Economics. Retrieved from Trading Economics web site: https://tradingeconomics.com/sri-lanka/gdp-from-construction

Tulenheimo, Risto. 2015. “Challenges of Implementing New Technologies in the World of BIM – Case Study from Construction Engineering Industry in Finland.” *Procedia Economics and Finance* 21(Henttinen 2012):469–77.

Turk, Song Wu, Gerard Wood, Kanchana Ginige, and Siaw Wee Jong. 2014. “A Technical Review of Bim Based Cost Estimating in UK Quantity Surveying Practice, Standards and Tools.” *Journal of Information Technology in Construction* 19(March):535–63.

Ullah, K., A. H. Abdullah, S. Nagapan, S. Suhoo, and M. S. Khan. 2017. “Theoretical Framework of the Causes of Construction Time and Cost Overruns.” *IOP Conference Series: Materials Science and Engineering* 271(1).

Ullah, K., Lill, I., & Witt, E. (2019). An Overview of BIM Adoption in the Construction Industry: Benefits and Barriers. In 10th Nordic Conference on Construction Economics and Organization. Tallinn: EmaraldInsight.

Underwood , J., & sikdag, U. (2010). Handbook of Research on Building Information Modelling and Construction Informatics: Concepts and Technologies . Information Science Reference, IGI Publishing.

Vineeth Raphael, Jenifer Priyanka. 2014. “Of Engineering © Iaeme Role of Building Information Modelling (Bim) in Quantity Surveying Practice.” *International Journal of Civil Engineering and Technology(Ijciet)* 5(12):194–200.

Vitasek, S., & Zak, J. (2018). Cost estimating and building information modelling (BIM) in road construction. Proceedings of the Creative Construction Conference. Slovenia : Creative Construction Conference .

Walasek, Dariusz, and Arkadiusz Barszcz. 2017. "Analysis of the Adoption Rate of Building Information Modeling [BIM] and Its Return on Investment [ROI]." *Procedia Engineering* 172:1227–34.

Wan Mohammad, W. N. S., M. R. Abdullah, S. Ismail, and R. Takim. 2018. "Overview of Building Information Modelling (BIM) Adoption Factors for Construction Organisations." *IOP Conference Series: Earth and Environmental Science* 140(1).

Wang, Guangbin, Zhenwei Liu, and Hanchao Wang. 2016. "Key Factors Affecting BIM Adoption Is China Based on TOEaRC." (Icmmse):103–8.

Wang, T. (2020). U.S. construction sector's BIM usage 2019. Retrieved from statista.com: https://www.statista.com/statistics/1020765/uses-bim-construction-sector-us/

Wang, Xiangyu, Peter E. D. Love, and Peter Rex Davis. 2012. "Construction Research Congress 2012 © ASCE 2012 778." *Construction Research Congress* (Mathiassen 1993):778–86.

Welman, Kruger, & Mitchell. (2005). Research Methodology. Cape town: Oxford university press.

Whang, Seoung Wook, Park, and Sang Min. 2016. "Building Information Modeling (BIM) for Project Value: Quantity Take-off of Building Frame Approach." *International Journal of Applied Engineering Research* 11(12):7749–57.

Wheeller, B., Hart, T., & Whysall, P. (1990). Application of the delphi technique. Tourism Management, 121-122.

Wickramasinghe, S. (2018). Emerging construction trends in the Sri Lankan construction industry. Retrieved from blog.framecad.com: https://blog.framecad.com/blog/framecad-technology-meet-the-demands-of-the-sri-lankan-construction-market

Wijekoon, K. A., Manewa , A., & Ross, A. (2017). BIM FOR FACILITIES INFORMATION MANAGEMENT. What's New and What's Next in the Built Environment Sustainability Agenda? Colombo: The 6th World Construction Symposium 2017.

Wijekoon, S. B., and A. M. C. T. K. Attanayake. 2012. "Study on the Cost Overruns in Road Construction Projects in Sri Lanka." *International Conference on Sustainable Built Environment 2012*.

Willis, C. J., Ashworth, A., & Willis, J. A. (1994). Practice and procedure for quantity surveyor . Oxford: Blackwell science.

Witicovski, Lilian Cristine, and Sergio Scheer. 2011. “Some Improvements for BIM Based Cost Estimation.” (August 2012).

Wong, M. (2019, 12 11). esub.com. Retrieved from esub.com: https://esub.com/top-8-causes-cost-overruns-construction/

Wong, P. F., H. Salleh, and F. A. M. Rahim. 2015. “A Relationship Framework for Building Information Modeling (BIM) Capability in Quantity Surveying Practice and Project Performance.” *Informes de La Construccion* 67(540):971–76.

World Bank. (2015, September 6). World Bank, 2015. How does the World Bank classify countries? Retrieved from https://datahelpdesk.worldbank.org/knowledgebase/articles/ 378834-how-does-the-world-bank-classify-countries.

World Bank. (2015). World Bank, 2015. Country and Lending Groups. Retrieved from http://data.worldbank.org/about/country-and-lending-groups.

Wu, Chengke, Bo Xu, Chao Mao, and Xiao Li. 2017. “Overview of Bim Maturity Measurement Tools.” *Journal of Information Technology in Construction* 22(June):34–62.

Wu, Chun Liang, Kun Chi Wang, and Wei Chih Wang. 2018. “A BIM-Based Conceptual Cost Estimation Model Considering Structural Analysis and Design.” *ISARC 2018 - 35th International Symposium on Automation and Robotics in Construction and International AEC/FM Hackathon: The Future of Building Things* (Isarc).

Wu, S., Ginige, K., Wood, G., & Jong, S. W. (2014). How can Building Information (BIM) support the New Rules of Measurement (NRM1)? London: RICS.

Wu, Zezhou, Changhong Chen, Yuzhu Cai, Chen Lu, Hao Wang, and Tao Yu. 2019. “BIM-Based Visualization Research in the Construction Industry: A Network Analysis.” *International Journal of Environmental Research and Public Health* 16(18).

Xu, Shen, and Llewellyn C. M. Tang. 2011. “BIM Environment : Quantity Surveyor ’ s Information Lifecycle.” *The Innovation and the Built Environment Academy* (September 2011).

Xu, Shen, Kecheng Liu, and Llewellyn C. M. Tang. 2013. “Cost Estimation in Building Information Models.” *ICCREM 2013: Construction and Operation in the Context of Sustainability - Proceedings of the 2013 International Conference on Construction and Real Estate Management* (October):555–66.

Yahya Al-Ashmori, Yasser, Idris Bin Othman, Hisham Bin Mohamad, Yani Rahmawati, and Madzlan Napiah. 2019. “Establishing the Level of BIM Implementation - A Case Study in Melaka, Malaysia.” *IOP Conference Series: Materials Science and Engineering* 601(1).

Zainon , N., Mohd-Rahim, F. A., & Salleh, H. (2016). The Rise Of BIM in Malaysia And Its Impact Towards Quantity Surveying Practices. MATEC Web of Conferences (pp. 1-8). IBCC 2016.

Zainon, Nurshuhada, Faizul Azli Mohd-Rahim, Nur Mardhiyah Aziz, Syahrul Nizam Kamaruzzaman, and Sapturinah Puidin. 2018. “Catching Up With Building Information Modeling: Challenges and Opportunities for Quantity Surveyors.” *Journal of Surveying, Construction & Property* 9(1):19–31.

Z. Zahrizan. 2013. “Exploring the Adoption of Building Information Modelling (Bim) in the Malaysian Construction Industry: A Qualitative Approach.” *International Journal of Research in Engineering and Technology* 02(08):384–95.

11 Appendices

Appendix A	Ethical Approval
Appendix B	Questionnaire A
Appendix C	Questionnaire B
Appendix D	Research Participant Information
Appendix E	Interview Guidelines
Appendix F	Published Papers

Appendix A – Ethical approval

University of Salford
MANCHESTER

Research, Innovation and Academic Engagement Ethical Approval Panel

Research Centres Support Team
G0.3 Joule House
University of Salford
M5 4WT

T +44(0)161 295 5278

www.salford.ac.uk/

17 October 2017

Arachchi Rathnayake Mudiyanselage, Anushka Prasadini

Dear Anushka,

RE: ETHICS APPLICATION STR1617-43: A BIM adoption framework for Quantity Surveying firms in Sri Lanka

Based on the information you provided, I am pleased to inform you that your application STR1617-43 has been approved.

If there are any changes to the project and/ or its methodology, please inform the Panel as soon as possible by contacting S&T-ResearchEthics@salford.ac.uk

Yours sincerely,

Dr Anthony Higham
Chair of the Science & Technology Research Ethics Panel

Appendix B – Questionnaire A

Reference number

QUESTIONNAIRE A

Research Title: **A FRAMEWORK TO ENHANCE THE ADOPTION OF BUILDING INFORMATION MODELLING AMONGST SRI LANKAN QUANTITY SURVEYING ORGANISATIONS TO INCREASE THE ACCURACY OF PRE-TENDER COST ESTIMATES**

This questionnaire is based on an ongoing PhD, and the aim of this research is to develop a BIM adoption framework for the Sri Lankan quantity surveying organizations that will support better pre-tender cost estimation. The questionnaire intends to capture the required elements to develop a framework. As such this questionnaire is divided into 2 major sections based on the objectives of the research.

Section 1: General information and/or Respondents profile.

Section 2: To identify weaknesses in the conventional pre-tender cost estimate process.

PARTICIPANTS' RIGHTS:

You may decide to stop being a part of the research study at any time without explanation. You have the right to ask that any data you have supplied to that point be withdrawn/destroyed.

You have the right to omit or refuse to answer or respond to any question that is asked of you. You have the right to have your questions about the procedures answered (unless answering these questions would interfere with the study's outcome).

If you have any questions as a result of reading this information sheet, you can query the researcher before the study begins.

CONFIDENTIALITY:

The information collected will be used for the sole purpose of this study and for academic publications. The findings of the study will not be attributed to any specific personnel.

PhD Researcher

Anushka Rathnayake

School of the Built Environment,

University of Salford,

Salford M5 4WT, UK

Email: A.P.Rathnayake@edu.salford.ac.uk

Supervisor

Dr Kaushal Keraminiyage

Email: k.p.keraminiyage@salford.ac.uk

SECTION 1: Respondent's Profile

Name:

Please underline your answer from given options.

1.1 What is your position within your company?

Trainee QS (Quantity Surveyor) Assistant QS Quantity Surveyor
Senior QS Chartered QS Other (please specify

1.2 What is the highest academic qualification you have attained?

- Diploma in Quantity Surveying
- Higher National Diploma in Quantity Surveying
- Bachelor's degree in Quantity Surveying
- Master's degree in Quantity Surveying
- Other (please specify)

1.3 Who do you work for?

- Client
- Contractor
- Consultant
- Other (please specify):

1.4 In which geographical locations does your company carry out work?

Sri Lanka Only UK only Other (please specify):

1.5 How long have you been working as a QS?

1.6 How long you are working for the current organisation?

1.7 How long you being working in your current position?

1.8 What types of estimates or costing works you engaged within your company?

Pre-Contract work Post contract Work Both pre and post
Other (please specify):

1.9 What are the main areas you involve within your job?

- Estimation
- Taking-off measurements and quantification
- Tendering
- Cost planning
- Procurement advice
- Document preparation, especially bills of quantities
- Cost control during construction
- Interim valuations and payments
- Other (please specify):

1.10 What types of estimates are you preparing within your job role?

- Oder of cost estimates
- Cost plan 1
- Cost plan 2
- Approximate quantities
- BOQ
- Interim Valuations
- Other (please specify):

1.11 What methods are you using to prepare estimates?

Unit Method	Cube Method	Composite Rates
Superficial area method	Elemental method	Other (please specify):

1.12 What types of drawings are you dealing with?

- 2D Auto CAD drawings
- 3D Auto CAD drawings
- BIM models
- Other (please specify):

1.13 Which tools (software) do you mostly use to take off quantities and to prepare estimates?

- Microsoft Excel
- Interactive Cost Estimating (BIM tool)
- AutoCAD
- IFC Take-off for Microsoft Excel (BIM tool)
- Autodesk Quantity Take-off (BIM tool)
- CostX Take-off (BIM tool)

- Other (please specify):

1.14 How would you describe your current knowledge about Building Information Modelling (BIM)?

Novice Intermediate Advanced
Other (please specify)

1.15 Has/is your current organisation …

- Already adopted BIM
- In the process of adopting BIM
- Not yet adopted and not in a process of adopting in near future

SECTION 2: Factors Affecting the Accuracy of Pre-Tender Cost Estimation

Please tick (√) to indicate your answer to each question in the following table, where necessary.

Factors affecting the accuracy of pre-tender estimate	**Root Causes**	**Strongly Agree**	**Agree**	**Neutral**	**Disagree**	**Strongly Disagree**
The use of 2D drawings	2D drawings have individual views and change in one view will not automatically reflect in other views.					
	Editing of plans, sections or elevations in 2D drawings required that all other sections be checked and updated manually.					
	Manual revisions in Drawings are time-consuming and delays entire estimation process.					
	Wrong assumptions and decisions made by QS based on drawings would directly affect the accuracy of cost estimates.					
	Errors and omissions in drawings significantly affects the accuracy of cost estimates.					
	Identify and reflect on design changes and incorporate them within the estimate or measurements is the most time-consuming task.					
	If changes do not update in all drawings, tendency to miss out some elements will affect the accuracy of cost estimates.					
	As 2D drawings does not allow any relationship between the components of the drawings (Ex:					

	wall and window) it is difficult to map the costs to each element in the drawings.					
	2D drawings provide limited visualization and make it more complex for Quantity Surveyor to interpret.					
	Lack of visualization in 2D drawings could mislead the QS to make wrong assumptions during QTO.					
Lack of Information	Accuracy of cost estimates positively correlated with the level of given or available information.					
	Insufficient information increases the inaccuracy of cost estimates and lead to inaccurate decisions / assumptions made by the QS.					
	Level of Quality and appropriateness of information is impact on the accuracy of estimates.					
	Paper based manual information exchange practices increase the inaccuracies of cost estimates.					
	Poor information flow during the estimation process, which increases the inaccuracy of cost estimates.					
Software's and tools	Generic systems such as Microsoft Excel used for estimation, is a major reason for reducing accuracy of estimates.					
	Current computer programs tend to overestimate unrealistically. E.g. Excel impose higher risk allowances compared to estimates with human interactions.					
	Generic software, such as Excel, needs to be programmed manually by the QS before can be used effectively in estimation. Excel is compromised with lots of mathematical commands and formulas where QS's has to do assumptions.					
	Human errors in defining repetitive functions and summations in excel could lead to miscalculations measurements, which increases the inaccuracy of cost estimates.					
Cost estimating methods	Unit method brings inaccuracy and uncertainty to the cost estimates.					
	Cube method brings inaccuracy and uncertainty to the cost estimates.					
	Composite rates brings inaccuracy and uncertainty to the cost estimates.					
	Superficial area method brings inaccuracy and uncertainty to the cost estimates.					
	Elemental method brings inaccuracy and uncertainty to the cost estimates.					

Communication	Communication and data sharing challenged due to intense competition ultimately result in less accurate cost estimates.					
	Communication and data sharing challenged due to lack of trust ultimately result in less accurate cost estimates.					
	Communication and data sharing challenged due to selfishness ultimately result in less accurate cost estimates.					
	Communication and data sharing challenged due to short-term relationship ultimately result in less accurate cost estimates.					
	Miscommunication due to Paper-based manual information sharing will affect the accuracy of cost estimates.					
	Formal feedback from project participants such as design team and estimating team is essential where changes to be made during the estimation process					
	Isolated working culture is a major reason for poor communication.					
	Most people do not prefer online meetings or emails for communication, which will lead to less accurate cost estimates.					
	Most people require traditional face to face meeting which will which will lead to less accurate cost estimates					
Coordination	The lack of coordination between cost management, design and construction cause difficult in cost estimating.					
	Lack of coordination resulting delays and disruption in the process or plan, inaccurate measurement of works, variations in work or material will create less accurate cost estimates.					
	Low level of coordination amongst project participants result in low level of communication and information sharing.					
	Poor documentation among project members leads to repetitive work during the preparation of cost estimates.					
	Lack of interactivity among project members leads to repetitive work during the preparation of cost estimates.					
Time constraints	Limited time given for the preparation of cost estimate reduces the accuracy of cost estimates.					
	QS's tempt to take shortcuts such as guess estimation, when under pressure because of time limits in which to complete the cost estimate.					
	Limited time availability to the estimator to verify assumptions increases the inaccuracy of cost estimates.					

Knowledge, skills and experience of an estimator	Accuracy of an estimate highly depends on the level of estimator experience.					
	Even though different tools are available for estimation, professional experience and knowledge is essential to operate them appropriately to achieve accuracy of estimates.					
	Lack of construction technology knowledge will lead to inaccurate cost estimates, due to wrong assumptions made by QS.					
Quantity Take-Off (QTO)	Manual quantity take-off and calculations are more time-consuming tasks in the estimation process.					
	QS need to track and accounts for design changes in drawings and update quantities and costing during the MQTO.					
	Design changes will demand re-measurement, which is a tedious task which can lead to produce inaccurate estimates.					
	Risk of double counting's are more likely to happen during the manual take-off.					
	Conventional QTO does not allow to prepare various cost estimates for different design alternatives, without the need to go through a substantial rework.					
Site Visits	Failure to visit project site may also lead to take incorrect measurements and to prepare inaccurate cost estimates.					
	Estimator must have prior knowledge of site conditions such as ground condition, site access, etc to produce an accurate cost estimate.					

If there are any other weaknesses, which you are facing during the estimation process please specify here:

Appendix C – Questionnaire B

Reference number

QUESTIONNAIRE B

Research Title:

A FRAMEWORK TO ENHANCE THE ADOPTION OF BUILDING INFORMATION MODELLING AMONGST SRI LANKAN QUANTITY SURVEYING ORGANISATIONS TO INCREASE THE ACCURACY OF PRE-TENDER COST ESTIMATES.

This questionnaire is based on an ongoing PhD, and the aim of this research is to develop a BIM adoption framework for Sri Lankan quantity surveying organisations that will support better pre-tender cost estimation. The questionnaire intends to capture the required elements to develop a framework. As such this questionnaire is divided into 2 major sections based on the objectives of the research and it will not take more than 15 minutes.

Section 1: Respondent profile and Organisation profile.

Section 2: To identify the drivers for BIM adoption.

Section 3: To identify the barriers for the BIM adoption.

PARTICIPANTS' RIGHTS

You have the right to:

Stop being a part of the research study at any time without explanation.

Ask that any data you have supplied to be withdrawn/destroyed.

Omit or refuse to answer or respond to any question that is asked of you.

Have your questions about the procedures answered (unless answering these questions would interfere with the study's outcome).

Query the researcher before the study begins if you have any questions as a result of reading this information sheet.

CONFIDENTIALITY:

The information collected will be used for the sole purpose of this study and for academic publications. The findings of the study will not be attributed to any specific person.

PhD Researcher

Anushka Rathnayake

School of the Built Environment,
The University of Salford,
Salford M5 4WT, UK

Email: A.P.Rathnayake@edu.salford.ac.uk

Supervisor

Dr. Kaushal Keraminiyage

Email: k.p.keraminiyage@salford.ac.uk

SECTION 01: Respondent's and Organisation Profile

Please underline your answer from given options.

1. What is your current role in your company?

   Trainee QS (Quantity Surveyor) Assistant QS Quantity
   SurveyorSenior QS Chartered Assistant QS Chartered QS
   Chartered Senior QS Other (please specify)

2. What is the size of your company?

   CS2 CS1 C1 C2 C3 C4
   C5 Other (please specify)

3. In which geographical locations does your company carry out work?

   Sri Lanka Only UK only Other (please specify):

4. What is your level of BIM use?

   - Have used BIM
   - Using BIM
   - Intending to use BIM in near future

- Not using BIM or Not in a process of using BIM in near future (*Please go to question 11*)
- Other (please specify):

5. If you have or currently using BIM, how long have you been using it?

- Less than 1 year
- Up to 1 year
- 1-2 years
- 3-4 years
- 5+ years
- Not applicable
- Other (please specify):

6.What best describes your current level of BIM working practice? You can select more than one answer.

a. Learning BIM software
b. Using BIM software
c. Using BIM software solo on a live project
d. Using BIM model with one or more other disciplines i.e. Structural Engineer / M&E / Contractor. Please specify here:
e. Using a BIM model within a fully collaborative process with integrated data i.e. design team, specialists, contractor, supply chain. Please specify here:
f. Other (please specify):

7. What type of software was used on your past BIM projects as a BIM platform? (You can choose more than one option)

a. Revit
b. Bentley Systems
c. ArchiCAD
d. Digital Project
e. Vectorworks
f. Tekla Structures
g. CostX
h. Other (please specify)

8. What type of software was used on your past BIM projects for quantity take-off? (You can choose more than one option)

a. Autodesk's QTO
b. Exactal CostX
c. Innovaya
d. Vico Take-off Manager
e. None
f. Other (please specify)

9. What type of software was used on your past BIM projects for cost estimating? (You can choose more than one option)

   a. WinQS via DimensionX
   b. Nomitech
   c. Vico Estimator
   d. None
   e. Other (please specify)

10a. With the implementation of BIM, did your company experience, or do you anticipate it experiencing, a loss of productivity/ gain of productivity?

   Yes No

10b. In your opinion what are, or would be, the main reasons for loss or gain of productivity?

11. Have you ever heard about BIM?

   Yes No

12. How did you get to know about BIM? (You can choose more than one option)

   a. Professionals in the Industry
   b. Workshops
   c. Seminars
   d. Conferences
   e. Websites
   f. None
   g. Other (please specify):

13. What does BIM stand for?

   a. Building information modelling
   b. Building Information Model § Building Information Management § Other (please specify):

14. How would you describe BIM? (You can choose more than one option)

   a. BIM is a software
   b. BIM is a technology
   c. BIM is a process
   d. BIM provides a smooth flow of information
   e. BIM is both software and technology
   f. BIM is both technology and process
   g. BIM gets people and information working together effectively and efficiently through defined processes and technology.
   h. Other (please specify):

15. Are you aware of BIM benefits and drawbacks?

a. Yes
b. No
c. Other (please specify):

16. In your opinion, how will the implementation of BIM affect the role of the Quantity Surveyor?

- Application of BIM will not affect the role of quantity surveyor
- Application of BIM will redefine the role of quantity surveyor
- Application of BIM will Extinct the role of quantity surveyor

17. The role of the quantity surveyor changed during projects when BIM was used.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree

18. In what way do you think the implementation of BIM will affect the following key tasks performed by the Quantity Surveyor? (You can choose more than one option).

- Preparation of cost estimates
- Cost analysis and lifecycle costing
- Establishing client requirement and feasibility studies
- Identifying, analysing and developing responses to risks
- Analysing proposed outcomes
- Valuing completed work and arranging payments
- Other (please specify):

19. The traditional responsibilities of a quantity surveyor will become less as the use of BIM increases.

Strongly disagree Disagree Neutral Agree Strongly agree

20. The use of BIM generally improves the ability of the quantity surveyor to provide good cost advice during early design development.

Strongly disagree Disagree Neutral Agree Strongly agree

21. The use of BIM generally improves the accuracy of cost estimates.

Strongly disagree Disagree Neutral Agree Strongly agree

22. Quantity Surveying companies will be left behind and/or struggle to survive if they do not adopt BIM quickly enough.

Strongly disagree Disagree Neutral Agree Strongly agree

23. Clients will increasingly insist on BIM adoption?

Strongly disagree Disagree Neutral Agree Strongly agree

24. BIM is the “future of project information management”

Strongly disagree Disagree Neutral Agree Strongly agree

25. Will you be willing to participate in a BIM-based interview?

Yes No

If yes, please provide the following details:

Name:

Email address:

Phone number:

SECTION 2: DRIVERS FOR BIM ADOPTION

Please tick (√) to indicate your answer to each question in the following table, where necessary. Please note: SA – Strongly Agree, AG – Agree, Nu – Neutral, DA – Disagree, SD – Strongly Disagree.

Question: Did any of the following factors encourage you to adopt BIM or will any of the following factors enhance you to adopt BIM?

BIM DRIVERS	Root Causes	SA	AG	Nu	DA	SD
The use of BIM model	Improve design quality					
	Reduce re-design issues					
	Provisions of clear workable model for end users					
	Design changes reflected consistently in all drawing views.					
	Improving rich three-dimensional (3D) context by aiding QS to identify significant cost-sensitive design features.					

	Any changes made to the model such as editing of plans, sections or 3D view within the model automatically made to all other documentation, drawings, and outputs by saving time for the manual revisions.					
If other state here						
Improved visualisation	Earlier and more accurate design visualisation					
	Improve clash detection					
	QS can carry out a 3D virtual walk-through and make sure everything in the model is factored in the QTO.					
If other state here						
Easy Access to Information	QS can to extract and distinguish information from the 3D model					
	Quantity surveyors can upload or download any information at any stage of the project from these models.					
	Information can be filtered					
If other state here						
Improved Information Management	Efficiencies from reuse of data					
	Improved documents management					
	Intelligent information management allows data to be stored in a centrally coordinated model.					
If other state here						
Improved communication	Improved communication between project parties					
If other state here						
Improved Coordination	Better coordination between stakeholders					
If other state here						
Automate Quantity Take-off	Cost implications of design changes can be generated easily without manually re-measurement.					
	Easily generate accurate cost estimates for various design alternatives.					
	Preliminary cost plan can be prepared by extracting quantities from the model.					
If other state here						
Client Demand						

Government Intervention						
Professional bodies						
Industry Demand						
BIM-based education						
Organizational pressure						
If any other, please specify here:						

SECTION 3: BARRIERS TO BIM ADOPTION

Please tick (√) to indicate your answer to each question in the following table, where necessary. Please note: SA – Strongly Agree, AG – Agree, Nu – Neutral, DA – Disagree, SD – Strongly Disagree.

Question: Did any of the following factors hinder the adoption of BIM or will any of the following factors hinder the acceptance of BIM in your organisation?

BIM BARRIERS	**Root Causes**	**SA**	**AG**	**NU**	**DA**	**SD**
Client	Lack of client demand					
	Client limitations due to high cost.					
	Lack of client awareness					
Government	Lack of government direction					
	Absence of BIM mandate					
	Insufficient BIM standards and protocols					
	Absence of BIM Implementation plan					
Market Demand	Perceived lack of industry adoption					
	All the practitioners are not on BIM platform					
Professional Bodies	Lack of Professionals involvement					
	Lack of professional bodies involvement					

Legal Issues	Data ownership is still being developing and therefore too risky.					
	Design responsibility is still being developing and therefore too risky.					
	The legalities in terms of contracts are still being developing and therefore too risky.					
	Liabilities are still being developed and therefore too risky.					
	Lack of interoperability					
Unawareness	Lack of BIM related Continuous professional development (CPD), seminars and conferences					
	Lack of BIM what it will actually achieve					
	Lack of understanding of BIM benefits					
	Lack of BIM related trainings					
	Lack of education programmes on BIM					
Financial	Cost for new hardware and software					
	Cost of training existing staff					
	Cost of software updates					
Lack of internal pressure	Lack of details regarding implementation					
	Lack of support from senior management					
	Fear of extinction of the QS role					
	People refusal/reluctance to learn					
	Inflexible mind-set of staff					
	Weak cooperation between different disciplines					
	The strong resistance to change					
Lack of BIM Resources	Lack of resources within the organisation					
	Lack of suitably BIM skilled staff					
	Shortage of experts in BIM field					

	Lack of internet facilities					
	Absence of Common database in construction industry.					
If any other, please specify here:						

Appendix D – Research Participant Information

Research Participant Information

Building Information Modelling (BIM): A framework to promote BIM adoption to improve the accuracy of pre-tender cost estimates in Sri Lanka

CONFIDENTIALITY STATEMENT

All responses given as a part of interviews and questionnaire survey will be treated with utmost confidentiality and will be available only to the researcher and supervisor of the project. Excerpts from the interviews and questionnaire will be used for research publications, but under no circumstances will your name or any identifying characteristics be disclosed in such publications.

This confidentiality statement will be signed by both the participant and the researcher in order to ensure that data obtained will only be used for the above research, and will not be disclosed to any other person, or be used for other purposes.

Name of participant:

Name of researcher: Anushka Rathnayake

Signature:

Signature:

Date:

Date:

Thank you for your cooperation

RESEARCH PARTICIPANT CONSENT FORM

Building Information Modelling (BIM): a framework to promote BIM adoption to improve the accuracy of pre-tender cost estimates in Sri Lanka

Research Team Contacts

Anushka Rathnayake

A.P.Rathnayake@edu.salford.ac.uk

Dr. Kaushal Keraminiyage

K.P.Keraminiyage@salford.ac.uk

STATEMENT OF CONSENT

By signing below, you are indicating that you:

- Have read and understood the information sheet for the above study and what my contribution will be.
- Have been given the opportunity to ask questions (face to face, via telephone, e-mail and WhatsApp).
- Have agreed to take part in the interview/questionnaire survey
- Have agreed to the interview discussion being tape recorded
- Have understood that your participation is voluntary
- Have understood that you can withdraw from the research at any time without giving any reason
- Have understood that if you withdraw from the research, responses given will not be used for the study.

Name: ……………………………………………………………………………….

Signature: …………………………………………………………………………

Date: ………………………………………………………………………………

Please return this sheet to the investigator.

Appendix E - Interview Guidelines

Research Title: **A FRAMEWORK TO ENHANCE THE ADOPTION OF BUILDING INFORMATION MODELLING AMONGST SRI LANKAN QUANTITY SURVEYING ORGANISATIONS TO INCREASE THE ACCURACY OF PRE-TENDER COST ESTIMATES**

This interview is based on an ongoing PhD, and the aim of this research is to develop a BIM adoption framework for the Sri Lankan quantity surveying organizations that will support better pre-tender cost estimation. The questions intend to capture the required elements to develop a framework. As such following questions will be ask during the interview.

Interview questions:

1. Is there any drivers within your organizations to adopt BIM? if so, what are they?

2. Are they are any barriers for you to adopt BIM within your organization?

3. Why do you identified it as a barrier?

4. What did you do to overcome the identified barriers?

PARTICIPANTS' RIGHTS

You have the right to:

Stop being a part of the research study at any time without explanation.

Ask that any data you have supplied to be withdrawn/destroyed.

Omit or refuse to answer or respond to any question that is asked of you.

Have your questions about the procedures answered (unless answering these questions would interfere with the study's outcome).

Query the researcher before the study begins if you have any questions as a result of reading this information sheet.

Appendix F – Published Papers

Published papers

Rathnayake, A; Kulatunga, U and Coates, P (2017), Building information modelling (bim) educational framework for the quantity surveying students: Sri Lankan perspective, In *Proceedings for the CIB 2014 International Postgraduate Research Conference,* 14th-15th September 2017, University of Salford, Salford.

Mollasalehi S., Rathnayake A., Aboumoemen A., Underwood J., Fleming A., Kulatunga U., and Coates P. (2017). "How BIM-LEan integration enhances the information management process in the construction design." In: *Proc. Lean & Computing in Construction Congress (LC*3*)*, Vol. 1 (CIB W78), Heraklion, Greece.

Rathnayake, A., & Samir, H. (2019). Current Status of Awareness and Readiness Towards Building Information Modelling (BIM) Among Sri Lankan Quantity Surveyors. CITC. London: Sprigfield.

Rathnayake, A., Mollasalehi,, S., Aboumoemen , A., Kulatunga, U., & Samir , H. H. (2019). Building Information Modelling Adoption for better cost estimation: Sri Lankan perspective. The Tenth International Conference on Construction in the 21st Century (CITC-10). Colombo: CITC.

Mollasalehi, S., A. A. Aboumoemen, A. Rathnayake, A. Fleming, and J. Underwood. 2018. "Development of an Integrated BIM and Lean Maturity Model." in *IGLC 2018 - Proceedings of the 26th Annual Conference of the International Group for Lean Construction: Evolving Lean Construction Towards Mature Production Management Across Cultures and Frontiers*. Vol. 2.