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LEVERAGING BIM TECHNOLOGY FOR IMPROVED ACCURACY IN DETAILED COST ESTIMATION IN SRI LANKA

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Abstract: Detailed cost estimation is the process of predicting the cost of the project at workface level. However, traditional methods of detailed cost estimation encounter various challenges in achieving precise cost estimation. To address these challenges, modern techniques have emerged in the field of cost estimation. Building Information Modelling (BIM) has emerged as an efficient solution for addressing challenges in construction projects. This study investigates the adaptability of BIM for detailed cost estimation. The research adopted qualitative approach. Data were collected using two rounds of Delphi interviews with 14 experts in detailed cost estimation and BIM. Code-based content analysis was used to analyse the data. The study provides empirical evidence showcasing the potential of BIM effectively addressing the challenges encountered in detailed cost estimation. By focusing on the perspective of consultant quantity surveyors in Sri Lanka, findings underscore the significant role of BIM in enhancing the accuracy and efficiency of detailed cost estimation processes for improved project outcomes. The findings highlight further research opportunities and contribute to the understanding of BIM's impact on cost estimation. The findings can use to enhance the practical implementation of BIM by intervening to form more partnerships among application developers and industry leaders.

Keywords: *Building Information Modelling (BIM); Detailed Cost Estimation; Improved Accuracy; Sri Lanka*

1. Introduction

The construction industry plays a significant role in the economies of developing countries (Tamosaitiene et al., 2020). Cost overrun and time is critical issues in large-scale projects (Simushi & Wium, 2020). Furthermore, cost estimation is a critical process of a large-scale construction project at the preliminary design stage to estimate the project's cost within minimum project information in the planning stages (Gurcanli et al., 2015). Detailed cost estimation is known as predicting process of the construction project cost on detailed design drawings or documents with specified construction methods at the workface level (Liu et al., 2014).

Detailed cost estimation is the important method for the companies to estimate the cost of the construction projects (Duong et al., 2020). Samphaongoen (2010) stated that purpose of detailed cost estimation is considered as the real cost estimation of the project. At the same time, this estimation has low error percentage compared to other estimation methods (Venkatachalam, 2020). In addition, this estimation is important for client to know about the average cost and control the progress of the contractor (Monkaew & Choosakul, 2021). The detailed cost estimation is important for both consultant and contractor quantity surveyor as consultant quantity surveyor prepares it in the pre-tender stage to determine the budget for client (Sayed et al., 2020). In addition, Monkaew & Choosakul (2021) stated that, detail cost estimator should be an expert in construction activities as this estimation consumes more time compared to other methods. Further, author mentioned that expertise and experience of the estimator can affect the time duration for the preparation. Due to its complexity and time, currently consultant quantity surveyors faces number of challenges when preparing the detail cost estimation. On the other hand, inaccurate cost estimation can lead to cost overruns (Habibi et al., 2018).

Traditional detailed cost estimation needs some help in estimating the accurate cost of the project as it is linked with challenges, such as the uncertainty of the information, unavailability of drawings, no direct link between drawing and specification sections (El-Sawalhi & Shehatto, 2014), more time consumption, inaccurate measurements, and transferring the estimation related data from one software to another (Banihashemi et al., 2022). At the same time, there are many modern techniques used in cost estimation to overcome these challenges, such as back-propagation neural network, regression, or stochastic techniques (Rafiei & Adeli, 2018), artificial neural networks and BIM (Sitthikankun et al., 2021). Further, Sepasgozar et al. (2022) confirmed that BIM adaptation as an innovative technology to overcome the challenges in the traditional estimation process.

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BIM allows the digital representation of geometric and non-geometric data of building with the facilities of storing, managing, sharing, accessing, updating, and use of all the relevant data for the project throughout the whole life cycle of the project (Thushyanthan, 2019; Stanley & Thurnell, 2014). BIM has different levels such as 3D, 4D, and 5D for different purposes; model work with quantity taking off, construction scheduling, and cost calculations, respectively (Volk et al., 2014). The efficiency of cost estimation can be improved in the construction industry by implementing the 5D BIM (Elghaish et al., 2020). Further, BIM can be identified as a modern method to overcome the challenges of traditional cost estimation by providing reliability and accuracy (Babatunde et al., 2020).

Numerous research studies have been conducted globally on the adaptation of BIM technology for quantity surveyors in the construction industry (Wu et al., 2014; Stanley & Thurnell, 2014; Mayouf et al., 2019; Heng, 2023). In the context of the Sri Lankan construction industry, several studies have also been carried out, such as those by Adafin (2016), Kumara et al. (2017), Siriwardhana et al. (2018), and Thushyanthan (2019). However, there is a limited number of studies specifically focused on using BIM technology for detailed cost estimation, with some studies addressing broader aspects of BIM implementation (Shen & Issa, 2010; Babatunde et al., 2019; Liu & Hussein, 2014; Park & Yun, 2023). In the global context, Babatunde et al. (2020) and Liu et al. (2014) have explored the adaptation of BIM for detailed cost estimation in quantity surveying practices. Thus, this research aims to investigate the adaptability of BIM technology for improved accuracy in detailed cost estimation in Sri Lanka. Notably, this study contributes to the existing literature as the first research to specifically focus on improving detailed cost estimation using BIM from the perspective of consultant quantity surveyors.

The remainder of the paper is organised as follows. Section 2 details literature findings on challenges in traditional detailed cost estimation and BIM technology used for quantity surveying. Section 3 presents the methodology of the study. Section 4 details the findings which collected through two rounds of Delphi interviews. Then, conclusion section offers critical reflections on the field and possible future research paths.

2. Literature Review

2.1. CHALLENGES IN TRADITIONAL DETAILED COST ESTIMATION

Detailed cost estimation is recognised as the process of predicting the cost of a construction project based on detailed design drawings or documents, considering specific construction methods at the workface level (Liu et al., 2014). Furthermore, Kamari and Kirkegaard (2018) describe detailed cost estimation as encompassing information related to every element within a building. However, traditional detailed cost estimation encounters numerous challenges attributable to various factors. Table 1 provides an overview of 18 key challenges identified by past researchers in the field.

Table 1: Challenges for detailed cost estimation

Challenge	Sources	Challenge	Sources
Time consuming	[B] [C] [F] [K] [L] [M]	Material cost fluctuation	[A]
Inaccuracy	[B] [D] [E] [F] [H] [I] [J] [K] [L] [N]	Cost for the preparation	[B] [C] [K]
Design changes	[A]	Project abandonment	[E]
Scope changes	[A] [G]	Extreme tender price	[Q] [S] [T]
Inflation	[A]	Increase in disputes and claims	[E] [M] [N] [R]
Quantity error	[B] [D]	Estimator loss his reputation	[M] [N] [R]
Completion delay	[E]	Increment in profit margin for contractor	[Q] [S] [T]
Cost under-run	[H]		
Cost overruns	[H] [J] [M] [N] [O]		
A- (Ökmen & Öztaş, 2010) B- (Yun, 2021) C- (Rayyan, 2016) D- (Ngo, 2018) E- (Awosina et al., 2018) F- (Venkatachalam, 2020) G- (Buertey et al., 2012) H- (Ghuzdewan & Narindri , 2018) I- (Dandan et al., 2019) J- (Durdyev, 2020) K- (Hatamleh et al., 2018) L- (Alahmadi & Alghaseb, 2022) M- (Ji et al., 2019) N- (Enrica et al., 2021) O - (Flyvbjerg et al., 2007) P - (Pretorius & Amoah, 2021) Q - (Enshassi et al., 2017) R - (Mahamid & Dmaidi, 2013) S - (Sayed et al., 2020) T - (Ugochukwu et al., 2017)			

Based on the information above, it is evident that the challenges of inaccuracy, time consumption, and cost are commonly recognised by multiple authors as key issues in detailed cost estimation. Rayyan (2016) similarly acknowledges these challenges and their impact on the preparation of detailed cost estimation. Furthermore, the problem of cost overruns, which can be attributed to the inaccuracies in traditional estimation methods, is also highlighted by Enrica et al. (2021). However, Ngo (2018) suggests that these challenges can be effectively addressed through the adoption of new technologies.

2.2 APPLICATION OF BIM TECHNOLOGY IN CONSTRUCTION FOR DETAILED COST ESTIMATION

In recent years, the quantity surveying profession has experienced significant changes in the construction sector driven by technological innovation, particularly with the adoption of BIM has revolutionised and enhanced the activities of quantity surveyors, offering a potential solution to the challenges associated with traditional detailed cost estimation (Haider et al., 2020; Sepasgozar et al., 2022; Soon et al., 2019). One time-consuming aspect of cost

estimation is the quantity take-off and preparation of the Bill of Quantities (BOQ). However, the adoption of BIM-based software can significantly reduce the time required for these tasks through automatic updates from the model (Wahab & Wang, 2022). Ngo (2018) also highlights the importance of BIM-based software in detailed cost estimation for BOQ preparation and final budgeting. Additionally, the preparation of 3D models plays a crucial role in cost estimation using BIM-based technology (Haider et al., 2020). Table 2 provides an overview of various software and functions of BIM technology relevant to quantity surveying profession.

Table 2: BIM Software for cost estimation

BIM Software	Source	BIM Software	Source
Navisworks	[A] [B] [C] [D] [E]	Revit	[C] [D]
Revizto	[AH] [AI]	Tekla Structures	[N]
ITWO CostX	[A] [B] [C] [D] [E]	Cost estimation BIM (5D)	[D]
Innovaya	[A] [B] [D]	Vico	[B] [D] [E]
On-Screen Takeoff	[F]	BIM Track	[R]
Autodesk Assemble	[G]	Aconex	[O]
Trimble Accubid	[H]	Procore	[P]
Causeway Estimating	[I]	PlanGrid	[Q]
Buildertrend	[AE]	Solibri Model Checker	[W] [X] [Y]
Graphisoft Archicad	[L] [M]	BIM 360	[S]
Synchro Pro	[Z] [AA] [AB]	Viewpoint	[T]
Bluebeam Revu	[AC]	Sage Estimating	[U]
PlanRadar	[AD]	WinEst	[V]
Bentley AECOsim Building Designer	[J] [K]	BIMcollab	[AF] [AG]

A - (Alzraiee, 2020) B - (Abanda et al., 2015) C - (Keung, 2019) D - (Ahmed & Ajaban, 2017) E - (Manjunatha et al., 2019) F – (Aibinu & Venkatesh, 2014) G - Staub-French et al., 2018 H - Poirier et al., 2015 I - Wu et al., 2014 J - Khaddaj & Srour., 2016 K - Amoaha & Nguyenb, 2019 L - Sampaio et al., 2021 M - Nugraha et al., 2013 N - Zhang et al., 2013 O - Tabadkani, 2020 P - Toan et al., 2022 Q - Graham, 2019 R - Marzouk & Zaher, 2015 S - Lin et al., 2019 T - Ku & Taiebat, 2011 U - Forgues et al., 2012 V - Sepasgozar et al., 2022 W - Liu & Issa, 2014 X - Getuli et al., 2017 Y - Soliman-junior et al., 2020 Z - Nechyporchuk & Bašková, 2020 AA - Messi et al., 2022 AB - Ciribini et al., 2016 AC - Huang, 2018 AD - Paculík & Papulová, 2022 AE - Mollaoglu et al., 2016 AF - Biancardo et al., 2020 AG - Andújar-Montoya et al., 2020 AH - Mehrbod et al., 2019 AI - Panya et al., 2023

According to the above Table 2, five authors mentioned that “Navisworks” and “iTWO” software are most suitable for detailed cost estimation. As per Table 2, various software options are available in the market that caters to different aspects of cost estimation. These tools provide a centralised platform where quantity surveyors, architects, engineers, and contractors can collaborate, share information, and address design changes or modifications promptly. This streamlined communication helps in resolving discrepancies, reducing rework, and minimising cost overruns.

The utilisation of BIM software in detailed cost estimation offers several avenues for improving the overall process. Firstly, these software solutions provide automated quantity take-off capabilities, allowing for faster and more accurate measurement of quantities from 3D models. This reduces the reliance on manual measurement methods, minimising the potential for errors and discrepancies. Additionally, BIM software facilitates seamless integration between the 3D model and the cost estimation process, enabling real-time updates and improved coordination among project stakeholders. Furthermore, the use of BIM software enables greater transparency and visibility throughout the cost estimation process. The software allows for easy tracking and monitoring of cost data, facilitating better cost control and management. Estimators can access up-to-date information and make informed decisions based on accurate and reliable data, enhancing the overall quality and accuracy of cost estimation.

2.3 IMPORTANCE OF BIM TECHNOLOGIES FOR DETAILED COST ESTIMATION

Detailed cost estimation is essential for maintaining the accuracy level of the tender process in construction industry (Duong et al., 2020; Ngo, 2018; Le et al., 2021). Consultant quantity surveyors are preparing the detailed cost estimation of the construction project in pre-tender stage irrespective of many challenges (Seidu et al., 2020; Nisansala et al., 2018; Venkatachalam, 2020). New technology can help to the consultant quantity surveyors to provide more efficient cost estimation such as, BIM, AI and nerual networks (Rafiei & Adeli, 2018; Seidu et al., 2020). BIM can specially speed up the work which is done by the consultant quantity surveyors in traditional method such as, preparation of detailed cost estimation, taking-off quantities and BOQ preparation (Zainon et al., 2018). Further, 3D and 4D modelling facilities of BIM enable the automatic detailed cost estimation for a construction project (Assarehpour, 2022; Forgues et al., 2012). In addition, BIM provides the software only focusing the detailed cost estimation such as, Navisworks, Innovaya Composer, Solibri Model Checker 8, CostX, iTWO, Vico, d-profiler, Balfour Technologies, ProjectWise Navigator and Bentley ConstrucSim (Alzraiee, 2020; Babatunde et al., 2020). Therefore, BIM technology can boost up the cost estimation process by adopting it into the quantity surveying companies (BCIS, 2011; Zainon et al., 2018). Further, there are frameworks to adopt the BIM for detailed cost estimation in developed countries (Tamosaitiene et al., 2020; Soon et al., 2016). The research on the adaptability of BIM technology for detailed cost estimation in the Sri Lankan construction industry is relatively scarce, indicating a significant research

gap in this area. Specifically, there is a lack of studies examining the adaptability of BIM technology from the perspective of consultant quantity surveyors. Consequently, this research is crucial in addressing this gap and exploring the potential of BIM technology for improving detailed cost estimation in the Sri Lankan construction industry. By identifying the adaptability of BIM for detailed cost estimation, this study aims to contribute valuable insights to enhance cost estimation practices in the Sri Lankan construction industry.

3. Methodology

The research reviewed literature on BIM, its technologies, applications, and challenges in traditional cost estimation. Given the emerging cultural shift in the construction industry, BIM implementation in detailed cost estimation is still in the infancy stage, particularly in Sri Lanka. In circumstances characterised by limited existing knowledge within a specific subject area and restricted opportunities to gather a sisable sample of interviewees, scholarly literature recommends the adoption of a qualitative research approach (Mehrad & Zangeneh, 2019). Consequently, given these circumstances, the qualitative approach was chosen as the most appropriate methodology for this study.

The Delphi technique helps to collect the opinions of a group of experts on a specific subject (Mansour et al. 2020; Yousuf, 2007; Kamaruddin et al., 2021) while enabling them to reach a consensus on the subject (Hsu and Sandford 2007). According to Xia and Chan (2012), at least two Delphi rounds are required to make a proper conclusion and according to Ameyaw et al. (2016), in most Delphi studies on construction and management, a consensus can be reached after the second round. Following Perrenoud's (2020) suggestion, the Delphi method can be employed for BIM related research. Thus, the study used two Delphi rounds with experts due to its systematic nature, making it applicable for studying BIM adaptation. Table 3 presents the profile of experts of the Delphi rounds.

Table 3: Profile of the experts of the research

Expert code	Designation	Years of experience			Delphi Round	
		Construction >10 years	Detailed cost estimation >05 years	BIM >03 years	R1	R2
E01	Project Manager	20	20	3	R1	R2
E02	Technical Manager - 5D BIM	10	05	5	R1	R2
E03	Senior Quantity Surveyor	10	10	3	R1	R2
E04	Senior Quantity Surveyor	13	13	4	R1	R2
E05	Director	20	20	4	R1	R2
E06	Quantity Surveyor	10	05	3	R1	R2
E07	Contract Manager	21	21	4	R1	R2
E08	Senior Lecturer	14	14	3	R1	R2
E09	Chartered Quantity Surveyor	12	08	3	R1	
E10	Academic researcher	11	06	3	R1	R2
E11	Chartered Quantity Surveyor	09	09	4	R1	R2
E12	Senior Quantity Surveyor	10	05	3	R1	R2
E13	Quantity Surveyor	10	05	3	R1	
E14	Quantity Surveyor	10	05	3	R1	R2

The expert panel, selected through purposive sampling based on having more than 10 years experiences in construction industry, more than 05 years experiences in detailed cost estimation and more than 03 years experiences in BIM technology, consisted of 14 Quantity Surveyors. The first round of semi-structured interviews aimed to identify challenges for cost estimation and identify BIM applications and technologies relevant to this field. The second round focused on critical issues and determining BIM tools to address them. The collected data was analysed using code based content analysis. Microsoft Visio was used to present the findings of the research.

4. Research Findings

The key research findings and their discussions are elaborated on this section following the research objectives.

4.1 IMPEDIMENTS OF DETAILED COST ESTIMATION (ROUND 1, PHASE 1)

Twelve (12) numbers of challenges in preparing the detailed cost estimation were identified from the literature. First question of the interview round one was to select major problems which can be solved by using BIM. Experts confirmed nine (9) challenges from the literature findings. The professionals noted that the BIM implementation does not exhibit a direct correlation with the construction project cost. Therefore, three factors, as indicated by strike-through letters, were excluded. Further, 4 problems were amalgamated into two problems, and it will display in italic characters. Furthermore, experts mentioned two new problems into the list, and it will display in bold letters. Therefore, Table 4 shows the challenges of preparing detailed cost estimation in traditional method, which can be solved by BIM technology.

Table 4: challenges in preparation of detailed cost estimation after Delphi round 1.

No	Challenges	Response
1	Time consuming	E1, E2, E3, E4, E5, E6, E7, E8, E9, E10, E11, E12, E13, E14, E15, E16
2	*Inaccuracy*	E2, E3, E4, E6, E7, E8, E9, E10, E11, E12, E13
3	~~Cost for the preparation~~	E14, E15, E16
4	*Design changes*	E1, E2, E3, E4, E5, E6, E7, E8, E9, E10, E11, E12, E13, E14, E15
5	~~Material cost fluctuation~~	E1
6	*Scope changes*	E1, E2, E3, E4, E5, E6, E7, E8, E9, E10, E11, E12, E13, E14, E15, E16
7	~~Inflation~~	E2
8	*Quantity error*	E2, E3, E4, E6, E7, E8, E9, E10, E11, E12, E13
9	Poor work quality	E2, E4, E6, E7, E8, E9, E10, E11, E13
10	Cost underrun	E6, E7, E8, E9, E10, E11, E13, E14, E16
11	Cost overruns	E1, E2, E3, E4, E6, E7, E8, E9, E10, E11, E12, E13, E14, E15, E16
12	Estimator loss his reputation	E1, E2, E4, E6, E7, E8, E9, E10, E11, E13, E14, E15, E16
13	**Lack of reliable cost data**	E1, E4, E6, E7, E8, E9, E11, E13, E14, E15, E16
14	**Lack of coordination**	E1, E2, E3, E4, E5, E6, E8, E9, E10, E11, E12, E13, E14, E15, E16

According to the Table 4, nine (9) challenges are chosen for round 2 based on more than 75% of respondents' confirmation. The existing research has identified two primary challenges in traditional cost estimation methods: the lack of reliable cost data and inadequate coordination. However, it is worth noting that three experts have disagreed with the notion that reliable cost data is an issue, even when utilising BIM technology. According to E2, the use of past cost data for new projects becomes problematic if there is a high inflation rate in the country. Conversely, E5 and E9 have suggested that previous project cost data should be manually inputted into the software since BIM technology alone cannot resolve this issue. In contrast, the majority of experts have specifically mentioned that if the prices for materials and labour remain unchanged, BIM software can directly utilise historical data for cost estimation.

4.2. BIM SOFTWARE FOR DETAILED COST ESTIMATION (ROUND 1, PHASE 2)

In Delphi round 1, experts were asked to discuss BIM software that can be used for detailed cost estimation. Following the identification of problems in preparing detailed cost estimations, the experts were tasked with identifying BIM software that could potentially address these issues from a consultant Quantity Surveyor's perspective. Many experts highlighted that BIM software plays a crucial role in addressing the challenges faced in traditional detailed cost estimation. According to them these software solutions integrate with BIM models and provide functionalities such as automated quantity take-off, accurate cost estimation, and improved collaboration among project stakeholders. Table 5 presents the findings for the BIM software that can be used for detailed cost estimation as specified by the experts of the study.

Table 5: BIM software for detailed cost estimation

	Challenges	BIM software	Response
1	Time consuming	CostOS	E2, E3, E5, E6, E7,E10, E11, E12
		On-Screen Takeoff	E2, E3, E4, E5, E6, E7,E10, E11, E12
		Innovaya Estimating	E2, E3, E5, E6, E7,E10, E11, E12
		CostX	E1, E2, E3, E4, E5, E6, E7, E8, E9, E10, E11, E12, E13, E14
		Revit	E1, E2, E3, E4, E5, E6, E7, E8, E9, E10, E11, E12, E13, E14
		Cubicost	E1, E2, E3, E4, E5, E6, E7, E8, E9, E10, E11, E12, E13, E14
2	*Inaccuracy/ Quantity error*	Trimble Accubid	E4, E6, E7,E10, E11, E12
		Autodesk Assemble	E2, E4, E5, E6, E7,E10, E11, E12
		Causeway Estimating	E2, E3, E4, E6, E7,E10
		CostX	E1, E2, E3, E4, E5, E6, E7, E8, E9, E10, E11, E12, E13, E14
		Revit	E1, E2, E3, E4, E5, E6, E7, E8, E9, E10, E11, E12, E13, E14
		Cubicost	E1, E2, E3, E4, E5, E6, E7, E8, E9, E10, E11, E12, E13, E14
3	*Scope and design changes*	Bentley AECOsim Building Designer	E6, E7,E10, E11, E12
		Graphisoft Archicad	E3, E4, E5, E6, E7,E10, E11, E12
		Tekla Structures	E2, E6, E7,E10, E11, E12
		CostX	E1, E2, E3, E4, E5, E6, E7, E8, E9, E10, E11, E12, E13, E14
		Revit	E1, E2, E3, E4, E5, E6, E7, E8, E9, E10, E11, E12, E13, E14

	Challenges	BIM software	Response
		Cubicost	E1, E2, E3, E4, E5, E6, E7, E8, E9, E10, E11, E12, E13, E14
4	Cost overruns	Aconex	E2, E4, E5, E6, E7,E10, E12
		Procore	E5, E6, E7,E10, E11, E12
		PlanGrid	E6, E7,E10, E11, E12
		CostX	E1, E2, E3, E4, E5, E6, E7, E8, E9, E10, E11, E12, E13, E14
		Revit	E1, E2, E3, E4, E5, E6, E7, E8, E9, E10, E11, E12, E13, E14
		Cubicost	E1, E2, E3, E4, E5, E6, E7, E8, E9, E10, E11, E12, E13, E14
5	Estimator loss his reputation	BIM Track	E4, E5, E6, E7,E10, E11, E12
		BIM 360	E5, E6, E10, E11, E12
		Viewpoint	E2, E3, E4, E5, E6, E7,E10, E11, E12
		CostX	E1, E2, E3, E4, E5, E6, E7, E8, E9, E10, E11, E12, E13, E14
		Revit	E1, E2, E3, E4, E5, E6, E7, E8, E9, E10, E11, E12, E13, E14
		Cubicost	E1, E2, E3, E4, E5, E6, E7, E8, E9, E10, E11, E12, E13, E14
6	Lack of reliable cost data	Sage Estimating	E2, E3, E4, E5, E6, E10, E11
		WinEst	E2, E3, E4, E5, E6, E7, E10
		Costimator	E2, E3,E10, E11, E12
		CostX	E1, E2, E3, E4, E5, E6, E7, E8, E9, E10, E11, E12, E13, E14
		Revit	E1, E2, E3, E4, E5, E6, E7, E8, E9, E10, E11, E12, E13, E14
		Cubicost	E1, E2, E3, E4, E5, E6, E7, E8, E9, E10, E11, E12, E13, E14
7	Lack of coordination	Solibri Model Checker	E2, E4, E5, E6, E7,E10, E12
		Synchro Pro	E2, E4, E5, E7,E10, E11, E12
		Bluebeam Revu	E2, E3, E5, E6, E7,E10
		CostX	E1, E2, E3, E4, E5, E6, E7, E8, E9, E10, E11, E12, E13, E14
		Revit	E1, E2, E3, E4, E5, E6, E7, E8, E9, E10, E11, E12, E13, E14
		Cubicost	E1, E2, E3, E4, E5, E6, E7, E8, E9, E10, E11, E12, E13, E14
8	Cost underrun	PlanRadar	E2, E3, E4, E5, E7, E11, E12
		ProEst	E2, E3, E4, E5, E6, E7,E10, E11, E12
		Buildertrend	E2, E4, E5, E6, E10, E11
		CostX	E1, E2, E3, E4, E5, E6, E7, E8, E9, E10, E11, E12, E13, E14
		Revit	E1, E2, E3, E4, E5, E6, E7, E8, E9, E10, E11, E12, E13, E14
		Cubicost	E1, E2, E3, E4, E5, E6, E7, E8, E9, E10, E11, E12, E13, E14
9	Poor work quality	BIMcollab	E2, E3, E4, E5, E6, E10, E11
		Revizto	E2, E3, E4, E5, E6, E10, E11
		Solibri Model Checker	E2, E3, E4, E5, E6, E10, E11
		CostX	E1, E2, E3, E4, E5, E6, E7, E8, E9, E10, E11, E12, E13, E14
		Revit	E1, E2, E3, E4, E5, E6, E7, E8, E9, E10, E11, E12, E13, E14
		Cubicost	E1, E2, E3, E4, E5, E6, E7, E8, E9, E10, E11, E12, E13, E14

All experts identified, CostX, Revit and Cubicost as the most common BIM software among quantity surveyors. Experts highlighted that by leveraging the capabilities of these BIM software tools, professionals in the construction industry can benefit from features such as 3D model integration, automatic quantity extraction, real-time project coordination, data synchronisation, and accurate cost tracking. One of the newly identified software options is 'cubicost,' which was proposed by E2. Following E2's recommendation, all subsequent experts were asked to consider cubicost for detailed cost estimation. E2 further explained that cubicost allows for the extraction of all quantities from the 3D model within 5 to 10 minutes using measurement rules, similar to the capabilities of 'revit' and 'navisworks' software. E2 also highlighted that all quantities can be directly linked to the Bill of Quantities (BOQ) in cubicost. Additionally, E2 mentioned that 'archicad' is considered the oldest BIM software in the world. Most software found under literature are not practically used by experts from Sri Lanka. But E08 and E10 stated that these software solutions enhance the speed and efficiency of quantity takeoff and cost estimation tasks, while also reducing errors

and improving the overall quality of work. Furthermore, they stated the use of software such as Aconex, BIMcollab and BIM 360 contributes to the reliability and accessibility of cost data with availability of comprehensive databases, customisable templates, and cloud-based storage. The use of Sage Estimating, Costimator and ProEst in detailed cost estimation enables quantity surveyors to overcome traditional challenges, such as time-consuming manual processes, lack of coordination, inaccuracies in measurement, and difficulties in adapting to design changes.

Experts newly added CostOS, Costimator and ProEst to the findings. Further experts mentioned that the software such as Tekla Structures, Solibri Model Checker, Synchro Pro, Bluebeam Revu and PlanRadar, allows for easy tracking and monitoring of cost data, facilitating better cost control and management. Estimators can access up-to-date information and make informed decisions based on accurate and reliable data, enhancing the overall quality and accuracy of cost estimation. By harnessing the power of BIM technology and these software solutions, professionals can achieve greater efficiency, accuracy, and productivity in their cost estimation workflows.

4.3. BIM TECHNOLOGY TO MINIMISE THE CHALLENGES OF DETAILED COST ESTIMATION (ROUND 2)

In Delphi round 2, experts were asked to suggest the most suitable BIM software to solve or reduce each challenge. Further, experts were requested to provide explanation on how BIM software can minimise these challenges. Figure 1 presents the outcome of the Delphi Round 2.

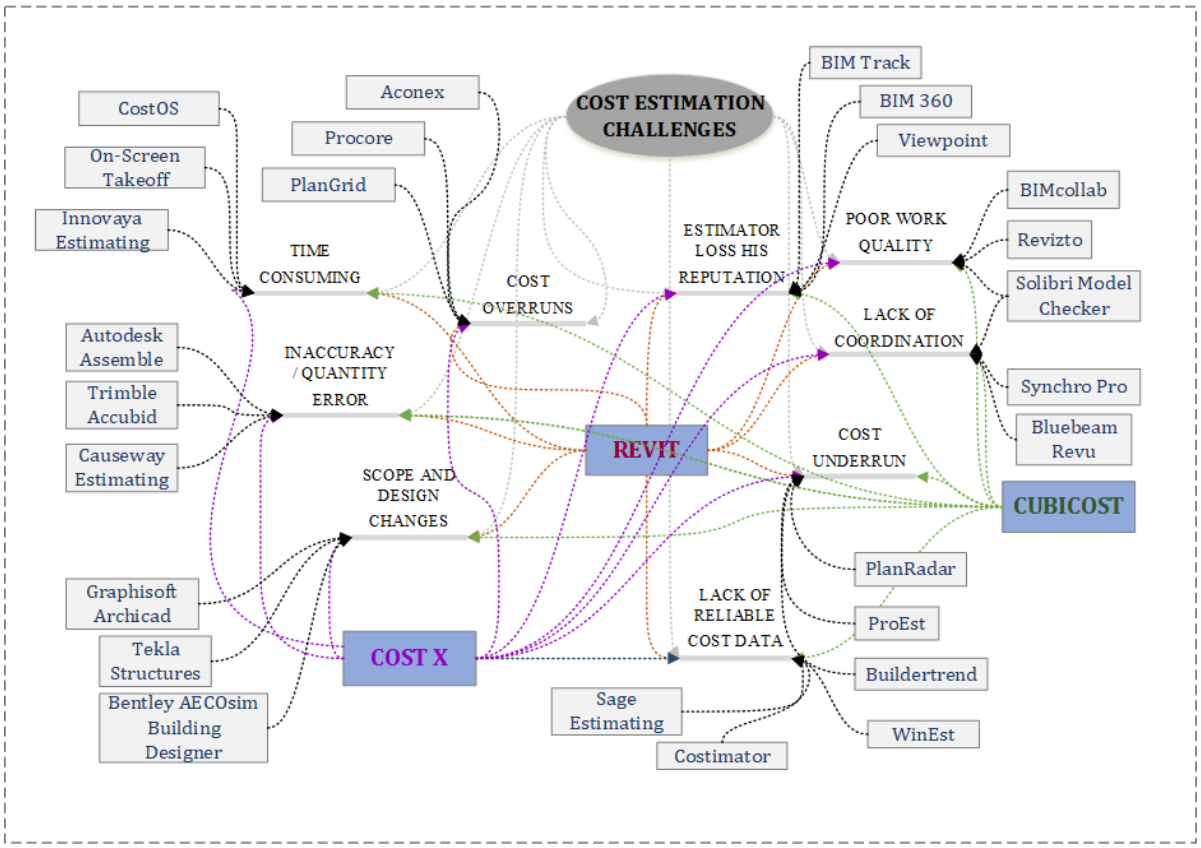

Figure 1: BIM software to minimise the challenges of traditional cost estimation

According to the Figure 1, three main types of BIM software, namely costX, Cubicost, and Revit, have been identified as potential solutions for reducing challenges in traditional detailed cost estimation in Sri Lanka as shown in the blue colour boxes in the middle. These are currently practicing in an ad-hoc manner in the industry. However, it is important to note that Revit is not used specifically for the estimation part. The reliability of cost data is significantly increased in BIM software, as it enables the integration of cost databases. BIM software such as costX and Cubicost has the capability to link with cost databases, and Cubicost even provides cloud storage for this cost data. E6 specifically mentioned that all prices for items are stored with codes in the database, allowing for direct linkage between the BOQ and the cost database in costX. While E3 and E11 acknowledged the importance of maintaining proper historical data for achieving reliability in traditional detailed cost estimation, the majority of experts agree that BIM software addresses this challenge effectively. Furthermore, BIM software solves the issue of coordination by enabling different teams to work within the same model from various working areas. All experts support this notion. Based on the experts' responses, it can be concluded that Cubicost and Revit are the most suitable BIM software options for resolving or reducing the challenges identified in the research. Moreover, the ash colour boxes in the Figure 1 presents the other BIM software which can be used to minimise the challenges of detailed cost estimation in the Sri Lankan context. It is evident from the research that, other BIM software are yet to be implemented in the Sri Lankan construction industry to be succeeded in BIM implementation for detailed cost estimation.

In the practical implementation of BIM software on construction sites, the benefits extend beyond the office environment and into the field. With the aid of mobile devices and cloud-based platforms, construction teams can access BIM models and related cost estimation data directly on-site. This facilitates real-time collaboration and communication between quantity surveyors, project managers, and field personnel, ensuring that everyone is working from the most up-to-date information.

Construction professionals can leverage BIM software to perform on-site quantity checks, compare actual quantities with estimated quantities, and identify any discrepancies or potential issues promptly. By overlaying the BIM model on the actual construction site, teams can visualize the project in its real-world context, making it easier to assess progress, identify potential clashes or interferences, and make necessary adjustments. Furthermore, BIM software enables construction teams to track and manage costs in real-time, allowing for better cost control and budget management. By inputting actual cost data and comparing it against the estimated costs, teams can monitor expenditure, identify any deviations, and take proactive measures to mitigate cost overruns or under-runs. This level of visibility and control enhances decision-making on the construction site, resulting in improved project performance and financial outcomes.

In summary, the practical use of BIM software on construction sites empowers project teams to access accurate information, collaborate effectively, identify and resolve issues promptly, and maintain better cost control. By leveraging the capabilities of BIM software in the field, construction professionals can streamline workflows, enhance communication, and ultimately improve project efficiency and success.

Implementing the above recommendations would not only enable industry practitioners to maximise their return on investment but also empower Quantity Surveyors to work with greater proficiency in cost management throughout the project lifecycle. It is further suggested to utilise the research findings in the development of a comprehensive code of conduct for professional institutes of Quantity Surveyors. This code of conduct can serve as a guideline that establishes the competency requirements for future Quantity Surveyors involved in BIM-implemented projects. Thus, Quantity Surveyors will be equipped to elevate their roles, optimise project outcomes, and contribute to sustainable development at a national level.

The establishment of a code of conduct will provide a standardised framework for Quantity Surveyors to adhere to when utilising BIM technology, ensuring consistent practices, and upholding professional standards. This will not only enhance the credibility and reputation of Quantity Surveyors but also promote a higher level of trust and confidence in their abilities within the industry. Ultimately, the incorporation of BIM-related competencies into the code of conduct will facilitate the growth and advancement of Quantity Surveyors, enabling them to effectively contribute to the success and sustainability of construction projects. While there have been numerous studies on BIM, the specific area of improving cost estimation has received relatively less attention. This research, however, aimed to fill this gap in the literature by addressing this specific aspect. It is important to acknowledge the limitations of the study, as it focused primarily on the perspective of consultant Quantity Surveyors due to the limited availability of experts with knowledge in both Quantity Surveying and BIM. Consequently, there is room for further research to delve into the potential of BIM in addressing the individual problems associated with the current methods of detailed cost estimation and enhancing accuracy and efficiency.

Future studies can explore various dimensions such as the impact of BIM on cost estimation from different stakeholder perspectives, the integration of BIM with other project management processes, and the evaluation of BIM implementation in real-world construction projects. By expanding the scope of research, a more comprehensive understanding of BIM's potential in improving cost estimation can be achieved, contributing to the advancement of the construction industry as a whole

5. Conclusions

The aim of this research is to explore the various approaches available for facilitating cost estimation through the utilisation of BIM Technology and a qualitative research approach was employed. During the first round of semi-structured interviews, the research aimed to summarise the key challenges encountered in detailed cost estimation that could potentially be mitigated through the use of BIM. Additionally, the research identified a total of 27 different BIM applications and technologies relevant to cost estimation. Building on the insights gained from the initial round of interviews, the second round of interviews focused on identifying critical issues specific to detailed cost estimation that could be effectively addressed through BIM. Furthermore, the interviews sought to identify the specific tools and functionalities within BIM that could be utilised to resolve these identified issues. The research findings hold significant implications for enhancing awareness and practical implementation of BIM technology to improve the detailed cost estimation process. Government intervention can play a crucial role in fostering partnerships between application developers and industry leaders, facilitating the development of commercially viable solutions that align with industry demands. Furthermore, software developers can contribute by incorporating extensions and developing new software updates that specifically address the prevailing industry requirements in the realm of cost estimation. In summary, this research contributes to the body of knowledge by offering a unique framework, redefining professional roles, and providing insights into BIM's potential. By incorporating these findings into

education and conducting future research, the construction industry can continue to benefit from BIM advancements and foster growth on a global scale. Future research endeavours can be directed towards applying this novel BIM implementation framework to other professions within the construction industry.

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