Journal of Engineering Science and Technology
Special Issue on STAAUH, November (2022) 34 - 45

THE ANALYSIS OF BIM BASED MEASUREMENT FOR THE QUANTITY SURVEYING PROFESSION

LAM TATT SOON*, ZI XUAN NG,
MYZATUL AISHAH KAMARAZALY, KENN JHUN KAM

School of Architecture, Building and Design, Taylor's University, Taylor's Lakeside Campus, No. 1 Jalan Taylor's, 47500, Subang Jaya, Selangor DE, Malaysia
Liveable Urban Communities Impact Lab, Taylor's University, Taylor's Lakeside
*Corresponding Author: Lamtatt.Soon@taylors.edu.my

Abstract

Construction has a significant impact on economic growth and the living standards of people. By increasing the productivity of construction projects, Building Information Modelling (BIM) is causing a radical shift in the construction industry. BIM was introduced to accelerate the development of the construction industry. There is a need for BIM-based measurement to automate the taking-off process, which increases productivity and reduces human error in measurement and cost estimation. However, BIM-based measurement has not yet been widely adopted by the Quantity Surveying profession. The need for BIM-based measurement in the construction industry must be increased. Thus, this research examined BIM-based measurement's technical constraints and improved it based on the identified technical constraints. The case study approach was adopted, and a recent condominium project in Kuala Lumpur was used to quantify the outputs of this research, resulting in a more practical view of BIM-based measurement. The research compared the differences in quantities and identified the BIM-based measurement constraints through a quantity take-off process following the Standard Methods of Measurement Building Works 2nd Edition (SMM 2). The analysis indicated that technical constraints such as BIM component misconnection, software interoperability, high hardware requirement, and lack of BIM standard rules are affecting BIM-based measurement in the Quantity Surveying (QS) profession. To minimise the identified constraints, construction players are suggested to check for the models to prevent overlapping problems, incorporate different types of software in BIM measurement, and implement the BIM execution plan at the early stage of the construction. The findings can assist professional construction players in understanding the differences between manual and BIM-based measurements to develop their measurement protocols and strategies to minimise BIM-based measurement constraints, indirectly strengthening their professional competencies in this essential digital era.

Keywords: Benefits, Building information modelling (BIM), Constraints, Measurement.

1. Introduction

Quantity surveyors are cost experts who provide financial and commercial management services in construction projects. They operate as consultants to help various construction sectors establish whether planned projects are viable and provide excellent value for money by reviewing and comparing numerous options and tracking variations to keep costs under control as the project progresses [1]. They mainly provide services in preparing Bills of Quantities or the documents required for tendering purposes. Taking-off is the conventional measurement method to prepare Bills of Quantities. However, technology continuously evolves, and current measurement practices differ from traditional procedures [2]. Since many QS still rely on manual methods such as excel spreadsheets and 2D CAD, works are less effective and vulnerable to human mistakes, affecting accuracy [3]. As a consequence, QS performance has declined, affecting the cost outcomes of the project. Clients are, therefore, dissatisfied with QSs' traditional methods. Building Information Modelling (BIM) was introduced to the building industry to avoid those laborious and time-consuming processes and aid estimate costs [4, 5]. The industry's gradual acceptance of BIM binds all construction professions, including quantity surveying, to the paradigm shift throughout the project lifecycle [6].

The government agency for construction development in Malaysia Construction Industry Development Board (CIDB) Malaysia [7] defined BIM as the process of preparing, utilising, and sharing 3D models through digital technology that contain multiple pieces of information that can be used by all parties involved in a project to achieve its objectives during its implementation. Model-based construction is a comprehensive concept that includes digital technologies for managing building information and data [8]. BIM software can be used to plan, design, build, operate, and manage buildings and other physical infrastructures. Over time, the demand for more cost-effective, higher-quality, and environmentally friendly construction has increased, and these criteria are the primary motivators of construction technology innovation [9]. BIM's different capabilities have enabled the profession of Quantity Surveying to boost its taking-off efficacy and efficiency by providing advantages and conveniences.

Quantity surveyors are responsible for preparing Bills of Quantities [1], regardless of whether they work for consultants or contractors. The traditional quantity surveying method, which uses a manual or a 2D CAD method, reduces project efficiency due to its laborious and time-consuming [4]. However, by integrating BIM technology, many of the time-consuming tasks associated with traditional quantity surveying are expected to be eliminated by BIM's automated approaches [10].

Generally, preparing a bill of quantities necessitates time, work, and human error. BIM's automatic collaboration and integration features allow quantity surveyors to do their tasks efficiently [11]. The functions of automatically computing the quantities of model elements and summarising the data limit the chance of human error and time-consuming rework, such as missing components [4]. Quantity surveyors are expected to improve service quality and meet clients' expectations by installing and employing BIM measuring technologies, which can improve BQ editing, accuracy, traceability, and speed [12].

By generating and merging 3D components into a unified model with numerous views of buildings, BIM models have effectively transmitted essential information between people in the construction industry, compared to paper drawings that are difficult to integrate and coordinate [13]. BIM enables users to perceive building structures and their environments differently. Since the 3D model will match the exact proportions of the real situation, users can check, plan, and locate traffic layouts and any issues without visiting the site [14]. Consequently, the ability of BIM to facilitate the simultaneous visualisation of building models has assisted project participants in identifying incompatibilities before the installation of building systems and in minimising unnecessary disputes and redo [13].

2. Research Issues and Objectives

Globalisation and digitisation have introduced a new era of possibility. Advanced technologies are causing a transformation in the construction business. To develop a successful competitive strategy, a QS practice must assess its unique characteristics and global trends in the surrounding environment [15]. BIM is a multi-faceted, practical technology that helps add value to building projects by improving quality and efficiency, cutting costs, enhancing construction management, and boosting customer service. Due to its unique characteristics, projects are managed more effectively, and coordination among professional team members has increased. However, several barriers must be addressed for BIM may be utilised effectively. BIM must be modified to address its deficiencies to boost the probability of project success [9].

Quantity surveying is an essential discipline in the construction industry that provides services such as building measurement and Bills of Quantities preparation [16]. The entire process, from take-off through Bills of Quantities compilation, is highly intricate and time-consuming. Taking off is typically achieved by manually measuring from paper or 2D CAD designs and entering the dimensions into an Excel file for estimation. This traditional method of estimating has been criticised for its rigid characteristics and lack of flexibility [16]. There was a gap between manual and BIM-based measurements before introducing BIM. Due to the low quality and insufficient data contained in BIM models, the BIM-based measurement has yet to be fully automated [17]. It is asserted that the output data of BIM models do not adhere to the standard method of measurement (SMM) [18]. The BIM-based measurement itemisation in the Bill of Quantities does not always comply with the traditional SMM [19].

In addition, the issue was supported by the study of [16, 20], which mentioned that SMM is the challenge encountered by Quantity Surveyors while utilising BIM. In addition, Ying et al. [6] reported that the SMM had been updated to the most recent version of the New Rules of Measurement 2 (NRM2) in the United Kingdom. Malaysia continues to employ the Standard Method of Measurement 2 (SMM2). The BIM model varies from SMM because BIM's measurement method is embedded within the software [21]. The automation and accuracy of measurement are still a matter of concern as the measurement of quantities does not follow the descriptive rules in the standard method of measurement (SMM), causing potential inaccuracies and errors [22]. The current SMM issues in the Malaysian QS industry are expected to be resolved through the evolution of QS following the BIM technology trend [6]. As a result of these technical limitations, the BIM technology's ability to replace time-consuming human labour in preparing measurements and bills of quantities is compromised.

In addition, the rate of BIM implementation in Malaysia remains low. Presently, there are no relevant and quantitative case study studies that highlight the benefits of BIM. Furthermore, the industry is still struggling to comprehend the potential benefits of BIM implementation. Many construction companies are still hesitant to invest much in new technology and human resource training due to the lack of clarity surrounding their near-term growth prospects [23].

BIM is a broad phrase that refers to a variety of activities in object-oriented Computer Aided Design (CAD), such as modelling architectural elements in terms of their 3D geometric and non-geometric (functional) qualities and interactions [24]. In BIM-based measurement, model-related issues are of concern. During the design phase, modellers may not include every element and BIM object detail and may produce a model using improper approaches. This can lead to the incompletion and inaccuracy of models, which reduces the accuracy of quantities derived from models [25]. Consequently, QS must understand the calculation parameters and standards of the BIM models and system to prevent quantity take-off errors [26]. Increasing BIM knowledge in the construction industry, particularly within the QS profession, is essential to reduce technical constraints and improve BIM-based measurement.

Therefore, this research aims to analyse the technical constraints of BIM-based measurement and suggest enhancements based on the identified technical constraints to encourage the practical application of BIM in quantity surveying. The objectives of this research are as follows:

i. To identify the technical constraints of BIM in measurement tasks for the QS profession.

ii. To suggest BIM measurement enhancements based on the technical constraints identified.

3. Constraints of BIM

According to Elias et al. [23], the construction industry players in Malaysia, including quantity surveying firms, have a high awareness of BIM and a readiness to implement it. However, despite widespread knowledge and readiness to change for BIM, there is a low adoption rate of BIM. It is necessary to identify and assess the constraints of adopting BIM to promote the use of 3D modelling, which is significantly different from the traditional technique in quantity surveying.

In most cases, producing a building information model entails many parties of professionals using various software tools. This leads to data ownership ambiguities and legal problems. Because of the hazy obligations, claims will be complicated to resolve if significant losses occur due to incorrect usage of building information models. There are no standard rules governing the use of BIM on a project-by-project basis or addressing BIM standards and contracts in Malaysia; BIM is only utilised individually in separate companies. The use of BIM was judged superfluous due to the absence of legal certainty in the work contract [27].

BIM is commonly adopted to facilitate the exchange and interoperability of information into digital format. To fix the interoperability issue, BIM software requires high-performance computer hardware and systems to support the detailed and precise models in software [11]. When more inputs are added to a model without a sufficient support mechanism, slow, lag and freeze issues are typical. Essential to the efficient operation of 3D programmes and tools are high-end hardware resources and networking capabilities, such as ample RAM and high-performance graphics cards.

Furthermore, in the previous study by Harrison and Thurnell [28], BIM models were considered incompatible with estimating software tools because BIM software providers utilise non-proprietary file types that cannot be transferred with estimating software. For example, issues with data interchange, such as data loss, and erroneous information transfer from Revit files to IFC (Industry Foundation Class) and other measuring tools, may occur.

Quantity surveyors may be unable to acquire correct building works quantities using every 3D modelling application. For example, the unit of the quantity offered for certain building elements in the Autodesk programme Revit does not meet the Malaysian Standard Method of Measurement (SMM) for construction projects. The number of concrete columns in a building is calculated, but the volume is not presented. However, the unit of measurement for concrete must be volume, expressed in SMM. As a result, quantity surveyors may struggle to prepare Bills of Quantities as they must check bulk quantities to ensure that quantities are exported correctly.

In addition, BIM lacks successful cases and management standards as a point of reference, a fragmented construction industry, inadequate business models, and a lack of cooperation from other industry partners [29]. The human resources department must shift skills and procedures to integrate BIM properly into an organisation's projects [11]. Many organisations were unprepared to invest majorly in new technology and human resource development because they lacked confidence in their potential development [23].

4. BIM Enhancement

According to Elias et al. [23], the construction industry's low adoption of new technology and techniques has resulted in its ineffectiveness and low productivity. BIM is described in the report as an advanced information and communications technology (ICT) with the potential to improve Malaysia's construction industry's performance. However, the low adoption rate after introducing a new technology, BIM, suggests that industry players are having difficulty implementing BIM. Several researchers have proposed a number of BIM enhancements to ensure BIM is advantageous to the construction industry's progress. Enhancements of BIM proposed by previous researchers are shown in Table 1.

Table 1. Summary of BIM enhancement.

Enhancements	Researchers
Suggested other interoperable standards other than IFC (Industry Foundation Classes), such as IDM (Information Delivery Manuals), MVD (Model View Definitions) and IFD (International Framework for Dictionaries).	Volk et al. [30]
QS to utilise their expertise to assess the information applicable to the estimating and procurement processes.	Wu et al. [31]
Governments, industry associations, and corporations need joint efforts to promulgate better laws, regulations, and contract systems for BIM applications.	Sun et al. [29]
With the assistance of the proposed BIM execution plans, the implementation of BIM can be more effective.	Lin et al. [32]
The Malaysian government should provide a guideline on BIM or an approach model to assist BIM implementation in construction projects among construction players.	Latiffi et al. [33]

5. Research Methodology

A quantitative technique was used in this study to compare the accuracy of quantities obtained from the manual measurement and BIM software, which are Glodon TAS and Autodesk Revit software. To examine the usage of BIM software in QS measurement tasks, a building project was chosen to complete quantity take-off using manual measurement and BIM software measurement. Like other research methodologies, document analysis necessitates examining and interpreting data to extract meaning, gain insight, and develop empirical knowledge [34]. This study used document analysis to conduct research by assessing documents. A case study research method was employed, and a multi-storey residential building (condominium) project in Kuala Lumpur was used. However, only the apartment tower section of the skyscraper was modelled for analysis purposes. Several fundamental components were developed to analyse a sample project to determine the limitations and advantages of BIM software while taking off quantity using different measuring approaches.

Autodesk Revit and Glodon TAS were the BIM software used in this study. A model was created in the Revit software and exported to Glodon TAS to perform Model checks and quantities summary. The software's output was compared with output from manual measurement methods and Glodon TAS to determine how much of a difference from each method. It will be acceptable to have a 5% discrepancy between the quantities acquired using each approach. Any difference greater than 5% will be analysed to determine how to improve the BIM software's application limitations. Hancock et al. [35] defined data analysis as the summarisation of a significant amount of data and the presentation of findings in a way that effectively conveys the key points. The taking-off quantity will be observed in this study using various measurement techniques. The findings from each method were compared to determine how different methods affected the QS profession's measuring tasks.

6. Analysis and Discussion

This chapter analyses and discusses the findings obtained from comparing process and quantity results using manual measurement and BIM software. With the application of the quantitative research method, this hypothetical case study reviews the common constraints faced when using BIM, and the enhancements of BIM application based on the constraint identified are outlined in this chapter.

6.1. Comparison of Quantities and Discussion

This section shows the quantities obtained through manual measurement of the real construction project compared with those adopted from the Glodon TAS and Autodesk Revit software applications. The quantities of the fundamental architectural and structural elements taken off for this case study include beams, structural walls, upper floor slabs, brick walls, polycarbonate and laminated glass roofing, floor finishes, and ceiling finishes.

Table 2 shows that the elements of reinforced concrete beams and brick walls exceeded 5%, which are 6% and 9%, respectively. Even though the slabs were modelled after the beams, it was observed that their joints were inconsistent. Few slabs and beams were improperly joined at the interfaces, indirectly affecting the quantities of concrete beams. Hence, it is essential to check the connection of elements in the modelling process. The automatic joining feature has misconnected some of the elements in the model. Therefore, QS must understand the calculation parameters and rules of the BIM modelling system to prevent errors in quantity take-off [26]. In short, the technical limitation of misconnection between measuring components may affect the BIM measurement quantities.

Table 2. Summary of BIM enhancement.

Item Description	Unit	Quantities differences of software and manual measurement (%)		Is the difference of quantity acceptable?
		Glodon TAS	Autodesk Revit Software	
Frame:				
Reinforced Concrete Grade 30 Beams	M3	-1%	-6%	Issues identified
Structural Wall	M3	-4%	3%	Acceptable
Upper Floor Slab & Flat Roof:				
Reinforced Concrete Grade 30	M3	-4%	1%	Acceptable
External and Internal Wall:				
Brick wall	M2	9%	-2%	Issues identified
Roof Finishes:				
Polycarbonate Roofing	M2	2%	-	Data loss issues
Laminated Glass Roofing	M2	2%	-	Data loss issues
Floor Finishes:				
600mm x 600mm ceramic floor tiles	M2	0%	3%	Acceptable
300mm x 300mm ceramic floor tiles	M2	-1%	3%	Acceptable
300mm x 600mm porcelain tiles	M2	4%	-0.01%	Acceptable
Ceiling Finishes:				
Suspended Ceiling	M2	2%	5%	Acceptable

In order to obtain the quantity from Revit, the model created in Revit was exported to IFC/Dwfx file and imported into QS software to prepare the model checking and calculation. Some of the roof finish items, notably polycarbonate and laminated glass roofing elements, could not be extracted based on the unit of measurement stated in SMM2 (area-m2). The result corresponded with the study by Liu et al. [22], which asserted that the calculation of quantities does not follow the descriptive rules in the SMM. Hence, the technical constraints of software interoperability in data exchange, such as data loss and erroneous information transfer from Revit files to IFC (Industry Foundation Class) and other measuring tools, may occur in certain building components/BIM objects. Thus, selecting BIM objects in the model is vital to reduce the chances of data loss. Harrison and

Thurnell [28] claimed that transmitting data with diverse file types might lead to data loss and erroneous information transfer, which happened in this study. Therefore, quantity surveyors require more time to address the data loss and information gap [6]. Minor discrepancies in the quantities of structural walls, upper floor slabs, floor finishes, and ceiling finishes are attributed to varied measurement methods and software. How an element is measured and modelled will affect the precision of its quantities. Consequently, a minor variance within 5% can be accepted under these conditions.

Moreover, QS must understand the calculation parameters and rules of the BIM modelling system to produce accurate element quantities. For instance, some building elements, such as the formwork of beams and slabs, cannot be generated due to limitations of software function in the BIM software. Structural components, notably beams and slabs, are created in the BIM models. Dimensions of length, width and depth can be identified separately in the structural components of the software. However, the formworks quantities, which can be calculated based on the dimension of the structural components, cannot be auto-extracted from the BIM model. The gaps existed between the structural component's dimensions and formwork quantities, and the users of BIM software must be skilful and knowledgeable enough to utilise the dimensions manually to obtain the formwork quantities based on the SMM. Hence, Yan and Demian’s [36] research suggested that companies must allocate lots of time and human resources for the BIM implementation process training.

According to Zainon et al. [11], precise interoperability and high computer hardware and systems performance are essential to support software's intricate and complicated models. In this study, models were created using laptops, and lag and hang of software commonly occurred once more data were input. Furthermore, after calculating, the quantities displayed in the software do not classify the elements into different attributes or total up the quantities of elements. There are no standard rules that govern the use of BIM. In this case, users must spend more time organising the quantity extracted from the software. Thus, quantity surveyors will encounter this technical constraint while preparing Bills of Quantities as they must check the quantity to extract the quantities correctly. In summary, technical constraints such as misconnected BIM components, software interoperability, high hardware requirements, and a lack of BIM standard rules affect the BIM-based measurement in the QS profession.

6.2. Enhancement

This section discusses several enhancements based on the identified technical constraints, notably BIM component misconnection, software interoperability, and lack of BIM standard rules affecting the BIM-based measurements. Based on this research analysis, the misconnection issues of some building elements can be solved through manual checking in the BIM model, as visual checking on the BIM model is a good practice to confirm the reliability of quantities. Before quantity extraction, the connection of elements should be manually checked to ensure that the elements are correctly joined, and errors can be corrected if they are discovered. According to Khosakitchalert et al. [25], the split element tool solves overlapping problems. The split element tool can modify the connection between elements in the case study. Although Revit has automatic clash detection for overlaps, the software does not automatically correct the error. Hence, manual checking and corrections are required to ensure the accuracy of BIM-based quantities in the software. In addition, the data of the elements in the BIM model are not compliant with SMM, which has indirectly caused the quantities of the elements to be inapplicable to the preparation of the bill of quantities. The manual measurement method in spreadsheets can be utilised for elements whose quantities cannot be automatically extracted from the BIM model.

Additionally, it was suggested to incorporate different types of BIM software with different interoperable standards, such as Industry Foundation Classes (IFC) and Design and Web Format XPS (DWFx), in the BIM-based measurement process to minimise the software interoperability issues. The study revealed that quantities such as polycarbonate and laminated glass roofing could be generated after the BIM model has been exported into the QS software. Hence, the software interoperability issues can be reduced if different types of BIM software with different interoperable standards are implemented. Generally, the temporary elements, such as structural formworks, are not created in the BIM model, which causes the quantities are not extractable in the designer software. These problems can be solved by exporting the BIM model into the QS software. It was found that measuring the formwork in the QS software is easier and faster than creating the formwork elements with the alternative tools in the designer software.

Finally, the BIM execution plan should be implemented at the early stage of the construction to provide constant agreement among the team members to develop the BIM model and execute work effortlessly. With the assistance of the proposed BIM execution plans, the implementation of BIM can be more effective [32]. The lack of BIM standard rules and misconnection issues of some building elements in the BIM model could have been prevented because the design team and QS understood the BIM model's development method. The modellers can always refer to the mature agreed guideline while creating BIM models to ensure that the quantities extracted conform to SMM. The BIM execution plan (BEP) and model-related queries included in the BIM guideline published by RICS can serve as a resource for non-technical end-users of the BIM model.

7. Conclusion

In summary, there are still challenges to the mass adoption of BIM software in the Malaysian construction industry, including technical constraints such as BIM component misconnection, software interoperability, high hardware requirements, and a lack of BIM standard rules. There are additional unforeseen issues that have not yet been identified. In order to advance the Malaysian construction industry, the government and construction industry players are suggested to check for the models to prevent overlapping problems, incorporate different types of software in BIM measurement, as well as implement the BIM execution plan at the early stage of the construction. To identify the limitations and potential solutions, more quantitative research and case studies should be conducted on implementing BIM software in measurement tasks for the QS profession. With additional case studies and data, a framework and/or workflow can be developed to guide new BIM users and strengthen the QS professional competencies for BIM implementation.

References

1. Cunningham, T. (2014). The work and skills base of the quantity surveyor in Ireland - An introduction. *Technological University Dublin, Business Commons*.

2. Chen, K.Y. (2013). Measurement methods in quantity surveying consultant firms. Retrieved September 25, 2021, from https://bic.utm.my/files/2018/11/MEASUREMENT-METHODSIN-QUANTITY-SURVEYING-CONSULTANT-FIRMS-.pdf
3. Rahmani, I.; and Herumanta, B. (2022). Comparison of estimation of reinforced concrete structure working costs based on the concept of Computer-Aided design (CAD) and Building Information Modeling (BIM). *Indonesian Journal of Multidisciplinary Science*, 10, 1237-1244.
4. Fung, W.P.; Salleh, H.; and Rahim, F.A.M. (2014). Capability of building information modelling application in quantity surveying practice. *Journal of Surveying, Construction and Property*, 5(1), 1-13.
5. Sandaruwan, M.T.; and Jayasena, H.S. (2018). Compatibility of BIM based BOQ for Sri Lankan construction industry. *Proceedings of the 7th World Construction Symposium 2018: Built Asset Sustainability: Rethinking Design, Construction and Operations*. Colombo, Sri Lanka.168-174.
6. Ying, T.Y.; Kamal, E.M.; and Esa, M. (2022). Building Information Modelling (BIM) implementation: Challenges for quantity surveyors. *International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies*, 13(3), 1-10.
7. CIDB Malaysia (2021). What is BIM. Construction Industry Development Board. Retrieved September 25, 2021, from https://www.cidb.gov.my/index.php/en/constructioninfo/technology/building-information-modeling-bim/what-bim
8. Penttilä, H.; Rajala, M.; and Freese, S. (2007). Building information modelling of modern historic buildings. *Proceedings of the 25th eCAADe Conference*. Frankfurt, Germany, 607-613.
9. Gee, C. (2011). The influence of building information modelling on the quantity surveying profession. B.Sc. Thesis. University of Pretoria, Hatfield, South Africa.
10. Perera, S.; Park, R.; Udeaja, C.; Zhou, L.; and Rodrigo, A. (2012). Mapping the e business profile and trends in cost management in the UK construction industry. *Proceedings of the 7th International Conference on Innovation in Architecture, Engineering & Construction (AEC 2012).* São Paulo, Brazil, 1-13.
11. Zainon, N.; Mohd-Rahim, F.A.; and Salleh, H. (2016). The rise of BIM in Malaysia and its impact towards quantity surveying practices. *Proceedings of the MATEC Web of Conferences*. Kuala Lumpur, Malaysia, 66(00060), 1-8.
12. Keng, T.C.; and Ching, Y.K. (2012). A study on the use of measurement software in the preparation of bills of quantities among Malaysian quantity surveying firms. *IEEE Proceedings of the Ninth International Conference on ICT and Knowledge Engineering*. Bangkok, Thailand, 53-58.
13. Ismail, N.A.A.B.; Drogemuller, R.; Beazley, S.; and Owen, R. (2016). A review of BIM capabilities for quantity surveying practice. *Proceedings of the 4th International Building Control Conference 2016 (IBCC 2016)*. EDP Sciences, France, 66, 1-7.
14. Rajeswara, R.N.P. (2018). A study on the barriers & benefits in adoption of QS software using ISM methodology. *Research Gate*. Retrieved October 25, 2021, from https://www.researchgate.net/publication/324173859_a_study_on_the_barriers_benefits_in_adoption_of_qs_software_using_ism_methodology

15. Jennings, M.J.; and Betts, M. (1996). Competitive strategy for quantity surveying practices: the importance of information technology. *Engineering, Construction and Architectural Management*, 3(3), 163-186.
16. Olatunji, O.A.; Sher, W.; and Gu, N. (2010). Building information modelling and quantity surveying practice. *Emirates Journal for Engineering Research,* 15(1), 67-70.
17. Monteiro, A.; and Martins, J.P. (2013). A survey on modeling guidelines for quantity takeoff-oriented BIM-based design. *Automation in construction*, 35, 238-253.
18. Kulasekara, G.; Jayasena, H. S.; and Ranadewa, K.A.T.O. (2013). Comparative effectiveness of quantity surveying in a building information modelling implementation. *Proceedings of the Second World Construction Symposium*. Columbo, Sri Lanka, 101-107.
19. Naweed, A.; Gupta, S.; and Dash, A.K. (2020). Application of 4d-Building information modeling and its challenges in AEC industry. *Journal of Emerging Technologies and Innovative Research (JETIR)*, 7(6), 539-551.
20. Lu, W.; Lai, C.C.; and Tse, T. (2018). *BIM and big data for construction cost management* (1st ed.). London: Routledge.
21. Nadeem, A.; Wong, A.K.D.; Akhanova, G.; Azhar, S.; and Wong, S.N. (2018). Application of building information modeling (BIM) in site management—material and progress control. *Proceedings of the 21st International Symposium on Advancement of Construction Management and Real Estate.* Springer Singapore, 289-297.
22. Liu, H.; Cheng, J.C.; and Gan, V.J. (2021). Developing a Knowledge-based system for semantic enrichment and automatic BIM-based quantity take-off. In ISARC. *Proceedings of the 38th International Symposium on Automation and Robotics in Construction*. Dubai, UAE, 169-175.
23. Elias, I.; Zuhairi, A.H.; Noraini, B.; Ahmad, F.M.; Ahmad, F.R.; Maria, Z.M.Z.; Mohd, K.G.; Nurulhuda, M.K.; Natasha, D.; Jasni, I.; Mazieana, C.A.; Rofizlan, A.; and Sharifuddin, U. (2017). Malaysia Building Information Modelling Report 2016. *CIDB Malaysia*.
24. Ghaffarianhoseini, A.; Tookey, J.; Ghaffarianhoseini, A.; Naismith, N.; Azhar, S.; Efimova, O.; and Raahemifar, K. (2017). Building information modelling (BIM) uptake: Clear benefits, understanding its implementation, risks and challenges. *Renewable and Sustainable Energy Reviews*, 75, 1046-1053.
25. Khosakitchalert, C.; Yabuki, N.; and Fukuda, T. (2019). Improving the accuracy of BIM-based quantity take-off for compound elements. *Automation in Construction*, 106 (102891), 1-20.
26. Tee, Y.Y.; and Kamal, E.M. (2021). The revolution of quantity surveying profession in building information modelling (BIM) era: The Malaysian perspective. *International Journal of Sustainable Construction Engineering and Technology*, 12(1), 185-195.
27. Sriyolja, Z.; Harwin, N.; and Yahya, K. (2021). Barriers to implement building information modeling (BIM) in construction industry: A critical review. *IOP Conference Series: Earth and Environmental Science*, 738 (012021), 1-9.
28. Harrison, C.; and Thurnell, D. (2015). BIM implementation in a New Zealand consulting quantity surveying practice. *International Journal of Construction Supply Chain Management*, 5(1), 1-15.

29. Sun, C.; Jiang, S.; Skibniewski, M.J.; Man, Q.; and Shen, L. (2017). A literature review of the factors limiting the application of BIM in the construction industry. *Technological and Economic Development of Economy*, 23(5), 764-779.
30. Volk, R.; Julian, S.; and Frank, S. (2014). Building information modeling (BIM) for existing buildings - Literature review and future needs. *Automation in Construction*, 38 (2014), 109-127.
31. Wu, S.; Ginige, K.; Wood, G.; and Jong, S.W. (2014). How can building information modelling (BIM) support the new rules of measurement (NRM1). *Royal Institution of Chartered Surveyors Research Report*, London, RICS.
32. Lin, Y.C.; Chen, Y.P.; Huang, W.T.; and Hong, C.C. (2016). Development of BIM execution plan for BIM model management during the pre-operation phase: A case study. *Buildings (special issue): BIM in Building Lifecycle*, 6(8), 1-14.
33. Latiffi, A.A.; Mohd, S.; and Rakiman, U.S. (2015). Potential improvement of building information modeling (BIM) implementation in Malaysian construction projects. *Proceedings of the 12th IFIP International Conference on Product Lifecycle Management*. Doha, Qatar, 149-158.
34. Bowen, G.A. (2009). Document analysis as a qualitative research method. *Qualitative Research Journal*, 9(2), 27-40.
35. Hancock, B.; Ockleford, E.; and Windridge, K. (2001). *An introduction to qualitative research*. London: Trent focus group.
36. Yan, H.; and Demian, P. (2008). Benefits and barriers of building information modelling. *Proceedings of the 12th International Conference on Computing in Civil and Building Engineering (ICCCBE XII) & 2008 International Conference on Information Technology in Construction (INCITE 2008)*. Beijing, China, 1-5.