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基於 BIM 的 Quantity Takeoff 方法與傳統方法在工程
造價估算中的比較標準

Comparison criteria between BIM-based Quantity
Takeoff method and Traditional method in Cost
Estimation

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基於BIM的QTO方法與傳統方法在工程造價估算中的比較標準
Comparison Criteria between BIM-based QTO method and
Traditional metho in Construction Cost Estimation

本論文係黃寶玉(R09521723)在國立臺灣大學土木工程學系營建工程與管理組完成之碩士學位論文，於民國111年8月19日承下列考試委員審查通過及口試及格，特此證明。

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ABSTRACT



This research focuses on the comparison of effectiveness between BIM-based QTO method and Traditional method, in terms of these method's suitability on Vietnam cost estimation process and the accuracy of quantity results extracted of these two approaches. Therefore, to conduct the comparison of these two technique's suitability on the QTO and cost estimates in Vietnam, an online survey was distributed in order to find out the perspective of two group of people: People applying Traditional method (Group 1) and People applying BIM-based QTO method (Group 2). At the same time, a case study was conducted to compare and evaluate the accuracy of quantity results extracted from the Traditional method and BIM-based QTO method. Overall, the study indicated that BIM-based method and Manual QTO method both have their own strong points. BIM-based takeoff technique surpasses manual takeoff measurement in terms of Visualization, Reduction of measurement mistakes, and Ability to update and synthesize information. Meanwhile, these criterions "Compatibility with Vietnam construction norm system" and "Suitability for quantities appraisal" are the aspects that made Conventional takeoff method defeats the BIM-based method - this can be explained why the manual method using 2D drawings is currently the most popular method in use in Vietnam, instead of Automated BIM-based method. In addition, the study's result showed that if the modeling process was completed properly, the quantity returned from the BIM model are, in most situations, as accurate as conventional methods and are unaffected by human mistake in the QTO process.

Keywords: Quantity takeoff (QTO), Cost Estimation, BIM-based QTO, Traditional method

TABLE OF CONTENTS

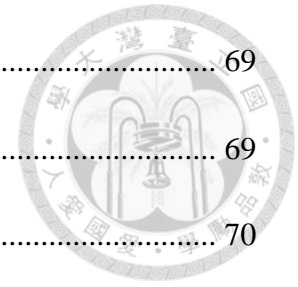


MASTER THESIS CERTIFICATION BY ORAL DEFENSE COMMITTEE.....	i
ABSTRACT	ii
TABLE OF CONTENTS	iii
LIST OF TABLES.....	vi
LIST OF FIGURES.....	viii
CHAPTER 1 INTRODUCTION.....	1
1.1 Research background.....	1
1.2 Problem statement	2
1.3 Research objective.....	4
1.4 Research method.....	4
CHAPTER 2 LITERATURE REVIEW.....	6
2.1 BIM background.....	6
2.1.1 Definition of Building Information Modeling (BIM).....	6
2.1.2 Evolution of BIM in the AEC Industry	10
2.1.3 Legal framework about BIM in Vietnam	15
2.2 Traditional QTO and Cost Estimation.....	16
2.2.1 Definition of QTO and Cost Estimation.....	16
2.2.2 Traditional QTO and Cost Estimation method.....	17
2.2.3 Traditional QTO and cost estimation process	20
2.2.4 Disadvantages of Traditional QTO method.....	24

2.3 BIM-based QTO	24
2.3.1 BIM-based QTO method	24
2.3.2 BIM-based QTO process	27
2.3.3 BIM-based QTO workflow	30
2.3.4 Advantages and Disadvantages of BIM-based QTO.....	32
CHAPTER 3 RESEARCH METHODOLOGY	36
3.1 Hypotheses to test.....	36
3.2 Methodology of survey.....	37
CHAPTER 4 SURVEY IMPLEMENTATION	40
4.1 Survey data description	40
4.2 Findings of Quantity takeoff method in use	43
4.3 Findings of perspectives of two groups on Traditional method and BIM-based QTO method	46
4.3.1 Group 1: People applying Traditional QTO method	46
4.3.2 Group 2: People applying BIM-based QTO method.....	48
4.4 Survey Analysis.....	51
CHAPTER 5 CASE STUDY	62
5.1 2D model development.....	62
5.2 3D BIM Model Development.....	63
5.2.1 Architectural 3D BIM Model	63
5.2.2 Structural 3D BIM Model.....	66
5.2.3 Quality Check of 3D BIM Models	67



5.3 Results and Discussion	69
5.3.1 Preparation of BIM-based Automated QTO	69
5.3.2 Comparison of QTO Results	70
CHAPTER 6 CONCLUSION.....	88
CHAPTER 7 LIMITATION AND RECOMMENDATION FOR FUTURE WORK	92
REFERENCES	94



LIST OF TABLES



Table 1. Error variation among several kinds of estimations	23
Table 2. Time saved by utilizing the BIM for quantity take-off	33
Table 3. Type of organization of collected samples	41
Table 4. Roles of respondents' jobs	42
Table 5. The respondents' years of work experience in the construction business	43
Table 6. Current QTO and cost estimating techniques in sample data.....	44
Table 7. Current method of QTO and cost estimation in collected samples	44
Table 8. Software in use for Traditional QTO method.....	45
Table 9. Results regarding advantages of Traditional method in Group 1	46
Table 10. Results regarding disadvantages of Traditional method in Group 1	47
Table 11. Results regarding advantages of BIM-based QTO method in Group 2	49
Table 12. Results regarding disadvantages of BIM-based QTO method in Group 2.....	50
Table 13. Functionality to compare between BIM-based QTO method and Traditional method in both groups	51
Table 14. Regression Statistic for the simple regression model for Hypothesis 1	54
Table 15. Regression Statistic for the simple regression model for Hypothesis 2	55
Table 16. Regression Statistic for the simple regression model for Hypothesis 3	56
Table 17. Regression Statistic for the simple regression model for Hypothesis 3	57
Table 18. Regression Statistic for the simple regression model for Hypothesis 3	57
Table 19. Hypotheses testing's results	58
Table 20. Comparison of column concrete volumes volume between Revit model before revised and Traditional method (m3)	71
Table 21. Comparison of column reinforcement weight volume between Revit model before revised and Traditional method (kg)	71

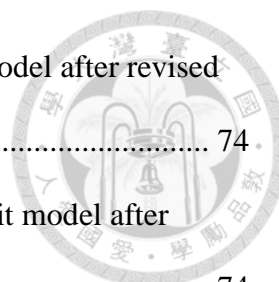


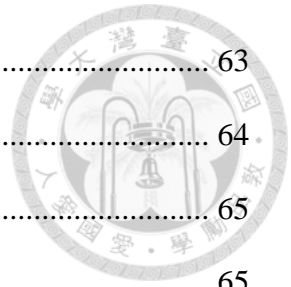
Table 22. Comparison of column concrete volumes between Revit model after revised and Traditional method (m3).....	74
Table 23. Comparison of column reinforcement weight between Revit model after revised and Traditional method (kg)	74
Table 24. Comparison of beam concrete volume between Revit model before revised and Traditional method (m3).....	76
Table 25. Comparison of beam reinforcement weight between Revit model before revised and Traditional method (kg)	77
Table 26. Comparison of beam concrete volume between Revit model after revised and Traditional method (m3).....	79
Table 27. Comparison of beam reinforcement weight between Revit model after revised and Traditional method (kg)	80
Table 28. Comparison of slab concrete volume between Revit model before revised and Traditional method (m3).....	82
Table 29. Comparison of slab reinforcement weight between Revit model before revised and Traditional method (kg).....	83
Table 30. Comparison of slab concrete volume between Revit model after revised and Traditional method (m3).....	86
Table 31. Comparison of slab reinforcement weight between Revit model after revised and Traditional method (kg).....	87

LIST OF FIGURES



Figure 1. Proposed Research Method.....	5
Figure 2. BIM - A single project-wide source of information.....	9
Figure 3. Bew-Richards BIM development model.....	12
Figure 4. Global BIM implementation status	13
Figure 5. General Contractor Ratings of top BIM Impacts on Industry	14
Figure 6. General Contractor Ratings of Lower BIM Impacts on Industry	15
Figure 7. Schematic illustration of the BIM quantity takeoff and estimate process	21
Figure 8. BIM component definitions and estimation of assembly pieces and procedures	26
Figure 9. Workflow conceptual estimation with DProfiler	30
Figure 10. Model-based cost estimate that integrates AutoCAD or Revit models with the Timberline estimating system via the use of Innovaya.	31
Figure 11. Type of organization of collected samples.....	41
Figure 12. Roles of respondents' jobs.....	42
Figure 13. The respondents' years of work experience in the construction business	43
Figure 14. Current QTO and cost estimating techniques in sample data	44
Figure 15. Software in use for Traditional QTO method	45
Figure 16. Software in use for BIM-based QTO method.....	46
Figure 17. Advantages of Traditional method (Group 1's opinions)	47
Figure 18. Disadvantages of Traditional method (Group 1's opinions).....	48
Figure 19. Advantages of Traditional method (Group 2's opinion).....	49
Figure 20. Disadvantages of Traditional method (Group 2's opinion)	51
Figure 21. Ground floor plan of the 3-story residential building	62
Figure 22. Column layout plan for second floor	63

Figure 23. Beam layout plan of second floor	63
Figure 24. Orthographic projections of architectural 3D BIM model	64
Figure 25. Visualization of a finished 3D BIM architecture model	65
Figure 26. A sectional view of the model.....	65
Figure 27. Importing 2D beam layout plan from AutoCAD (a) and beams and slabs for 2 nd floor in Revit (b)	66
Figure 28. Structural 3D BIM model in Revit.....	67
Figure 29. Flow chart showing quality checking and 3D BIM modeling procedure prior to exporting quantities for BOQ and cost estimation	69
Figure 30. Model design error: Placing Steel Belt in the wrong position (in Beam area)	72
Figure 31. Beam having Unequal Length and Cut Length.....	78
Figure 32. Placing Longitudinal Steel in the wrong position (in Beam area)	84



CHAPTER 1 INTRODUCTION



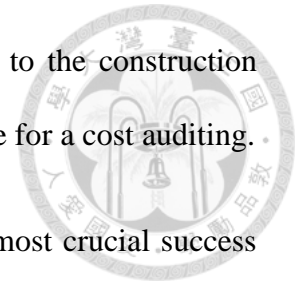
1.1 Research background

The process of cost estimating may be defined as the forecasting of costs assessing the characteristics of the project, such as the needed materials, manpower, and time limitations. For budgeting and planning, cost estimate is a crucial component of other construction industry processes (Sattineni & Bradford II, 2011).

A critical step in the cost-estimating process is quantity surveying. Up until recently, 2D CAD drawings and CAD tools were used to establish quantities. Olsen & Taylor (2017) claim that since there are so many variables involved in the amount take-off process utilizing conventional techniques, it is time-consuming, labor-intensive, and prone to mistakes. The amount take-off procedure utilizing conventional techniques becomes error-prone when many parts are intertwined. For instance, there is a chance of duplicate counting, missing components, and mistakes when transferring data from 2D designs. Due to the estimators' need to closely scrutinize every picture in order to prevent missing or double estimating the components, the procedure is becoming exceedingly time-consuming (Olsen & Taylor, 2017). It is clear that conventional methods take too long when considered in terms of time. For instance, if a design change is made, all the products impacted by the change should be carefully researched, which calls for spending too much time amending Bills of Quantities (BOQs).

A new method known as BIM-based QTO is now a prominent trend in the architectural, engineering, and construction (AEC) industry. Furthermore highlighting the fact that the amount take-off operation is carried out during the course of the project, Monteiro and Martins (2013). It is used early on in the project for a rough cost estimate,

during the bidding process for a cost and schedule estimate prior to the construction stage for the planning of activities, and during the construction phase for a cost auditing.

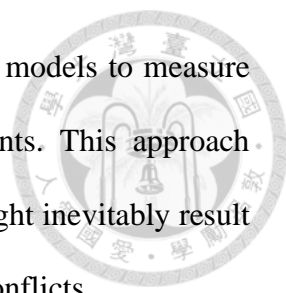


The accuracy of the quantity take-off represents one of the most crucial success factors for the estimate process. Quantity surveying is a crucial step in the cost estimating process. As a result, it is clear that using the QTO approach and using precise numbers are necessary for construction projects, and new techniques are regularly tested to get the greatest results.

1.2 Problem statement

Due to its effects on both funding and schedule, the process of cost estimating plays a crucial role in building projects. The procedure of cost estimating is conducted during the bidding phase; to produce a competitive bid; prior to the construction phase; to verify the quantities and costs for the first budget projection; and during construction phase to monitor the project's budget.

Due to the financial effects of the cost estimating process on the projects or the budget limitations of the projects, organizations in the construction market are continuously striving for more accurate, quicker, and simpler methods of executing the process. The process of estimating costs consists of two main steps: obtaining quantities and determining prices. Without accurate quantities, it is difficult to produce an accurate projected cost, despite the fact that pricing is one of the most important phases in cost estimates. Due to the fact that quantities are typically extracted from drawings, the method demands substantial knowledge, expertise, and dedication in order to provide an accurate result.

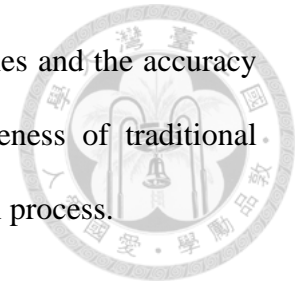


Traditional quantity take-off (QTO) techniques use 2D CAD models to measure distances, heights, areas, and quantities using human measurements. This approach needs more time and effort. On the other hand, manual processes might inevitably result in a lot of problems like incorrect measurements and unintentional conflicts.

Nowadays, BIM is being used more and more in place of conventional quantity take-off techniques. There are several software programs available, including Bentley, Vico, Autodesk Navisworks, Allplan Architecture, Graphisoft ArchiCAD, and Autodesk Revit. Quantity take-off and modeling calculations differ for each application. Programs vary in the problems they generate when used and the advantages they provide since they operate according to various principles. Sattineni and Bradford II (2011) claim that BIM enables construction organizations to receive exact and accurate cost estimations while also minimizing the time and cost associated with the process. The context makes it evident that BIM models have certain drawbacks despite their advantages. Despite the fact that BIM technologies are now frequently used in projects. Olsen and Taylor (2017) claim that models made using BIM software don't always guarantee sufficient quality to extract precise values. There might be significant data gaps in the model about waste, lapping, etc. According to Kulasekara, Jayasena, and Ranadewa (2013), the inconsistency between BIM-obtained quantities and those from traditional approaches causes a lack of faith in the BIM-obtained data. Similar to this, Olatunji, Sher, and Ogunsemi (2010) stated that although while BIM reduces errors and conflicts, its deployment for construction projects still faces challenges, mostly because of the discrepancy between the automated approach of BIM and estimate traditions.

Compared to the BIM-based QTO, the 2D approach is still heavily used by cost specialists in the industry.

In conclusion, in terms of the applicability of these approaches and the accuracy of the take-off findings, it is necessary to evaluate the effectiveness of traditional method and BIM-based QTO method in the Vietnam cost estimation process.



1.3 Research objective

The purpose of this thesis is to compare the effectiveness of conventional method and BIM-based QTO method in cost estimation process, in terms of suitability of these approaches and the accuracy of the take-off results.

Therefore, this study was conducted to find out about the perspective of two group of people: People applying Traditional method (Group 1) and People applying BIM-based QTO method (Group 2), on the suitability of these two methods in Vietnam cost estimation process. At the same time, the study was conducted to compare and evaluate the accuracy of quantity results extracted from the Traditional method and BIM-based QTO method. From these assessments, the author will give recommendations for construction project owners in applying BIM-base in their projects in the future.

1.4 Research method

The approach that was used to attain the goal of this research is shown in the figure to the right. The research will compare the effectiveness between 2D takeoff method and BIM-based QTO method, by using two ways, i.e survey and case study.



Figure 1. Proposed Research Method

The author sent a survey to 70 experienced managers and engineers of construction companies in Vietnam. The survey was conducted for the purpose of collecting opinions of managers and engineers about two takeoff methods, traditional and BIM-based, and their assessments of benefits/barriers in quantity take off and cost estimation process of these two methods.

Besides, in order to get the most specific view of the accuracy level of these two methods, a case study of a residential house will be used for evaluation. Specifically, the author will use the information of a real project has implemented and conduct quantity assessment and measurement by two methods. Thereby, the author will draw conclusions about the similarities and differences, and at the same time give strengths and weaknesses of the two methods above.

CHAPTER 2 LITERATURE REVIEW



2.1 BIM background

2.1.1 Definition of Building Information Modeling (BIM)

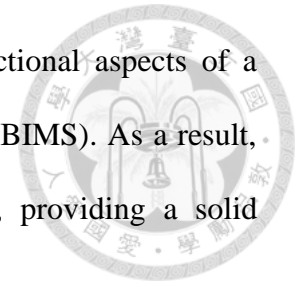
BIM is understood as Building Information Modeling. The term BIM first appeared in the nineties (Tolman, 1992), but only really popularized with Autodesk Software Corporation publications at the beginning of the 21st century. BIM is a new technique that was created using digital technology, is now being implemented, and is extensively used in the construction market of many nations. BIM is regarded as one of the most crucial approaches to the 4.0 technology advancement in Vietnam's building industry (Hong Duyen et al., 2018).

BIM has several distinct definitions. BIM is a process involving the creation and use of innovative 3D models to guide and discuss project decisions, according to Autodesk. The design, visualization, simulation, and collaboration achieved by BIM technologies improve the understanding of the project by all stakeholders throughout its lifetime. BIM facilitates the achievement of project objectives."

BIM is described as "the process of developing and utilizing virtual models for planning, constructing, and/or running of projects" in the 2009 McGraw-Hill Construction book *Getting Building Information Modeling to the Bottom Line*.

In the UK's strategic plan for BIM, BIM is defined as follows: "BIM is a collaborative approach, underpinned by digital technologies, that unlocks efficient methods in design and construction. and operating the project. BIM puts building data into a 3D computer model and uses it to effectively manage information throughout the entire project lifecycle from initial concept to commissioning."

BIM is "the digital representation of the physical and functional aspects of a structure," according to the National BIM Standards Committee (NBIMS). As a result, it acts as a repository for general information about a facility, providing a solid foundation for decisions made throughout its lifespan.



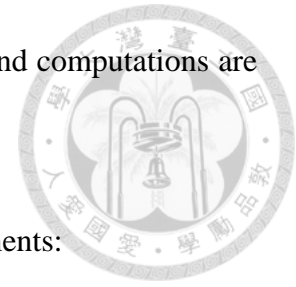
BIM is described as "a collaborative process, powered by digital technology, that unlocks efficient processes in construction and design in the UK's BIM strategy plan. as well as executing the project. BIM puts building data into a 3D computer model and uses it to effectively manage information throughout the entire project lifecycle from initial concept to commissioning."

BIM is further described as follows in the US National BIM Standard: "BIM is the digital representation of physical and functional features of a building. It is used as a source, disseminating information about the project to stakeholders so that choices can be made with confidence at all stages of the project's life cycle, from the development of initial concepts to the conclusion of dismantling the works.

In addition to these explanations, a different perspective on BIM dimensions is required to respond to the question, "What is BIM?" The four dimensions of BIM now include 4D, 5D, 6D, and 7D. The following are the 4D and 5D dimensions:

- In modeling, time is added to the first three dimensions to create the fourth dimension. The model or modeling process becomes 4D when time is introduced to models in order to plan building (BIMe Initiative, 2018).
- The inclusion of cost to the first four modeling dimensions is referred to as the fifth dimension (5D). When cost is included into BIM models and Model Components,

a model (or modeling process) becomes 5D. Target Value Design and computations are done in 5D. (BIMe Initiative, 2018).



In addition, BIM is also defined, including the following elements:

a. Information: divided into 2 types:

Geometric information (Geometry 3D): includes geometric models such as: architectural models, structural models, MEP models which are easily recognizable models. Besides, the model also contains other models such as: analytical model (Analytical Model) representing the force-bearing model of the structure, or energy model (Energy Model) used to simulate and analyze energy quantity. Geometry information will provide full information required by the user such as: length, width, height, position of components in the work such as floor beams, pipes, bathtubs, balls, lamps, tables and chairs, cabinets, etc.

Non-geometric information (Data): includes necessary attributes in construction such as cost information, construction activities, COBie information for operation management or sub information about structure such as manufacturer, maintenance time, cost, supplier, etc.

From the stage of concept design through the building and operation stage, BIM is a single 3D model comprising construction information that is utilized for shared exploitation across disciplines and stakeholders.

With activities like modeling, coordination, information interchange, and information modification, BIM is not simply a source for storing and transmitting plans and specifications from the design, construction, and operation management phases.

Information in BIM includes the following characteristics:

- BIM is a reliable source of information
- BIM is well-structured
- BIM has clear standards of information development
- BIM helps parties exchange information through the rules of close coordination



BIM is seen as a technique. The goal of the process is to produce "Information" that is shared with stakeholders and is trustworthy enough for the parties to make independent choices in the context of a specific project. Making the appropriate choice will help you save money and time.

A shared data environment serves as the storage location for the BIM model, which is considered as the relationship between "geometric information" and "non-geometric information" connected to construction (CDE).

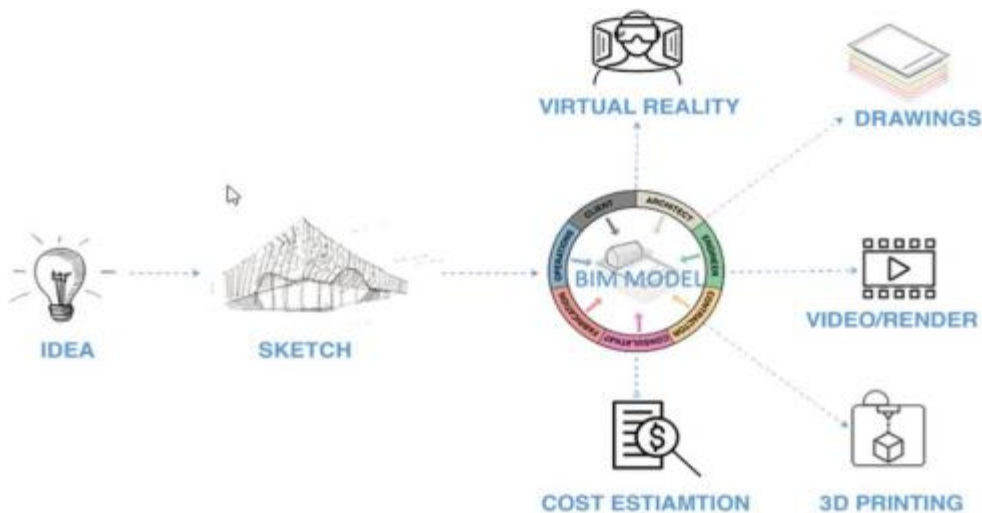


Figure 2. BIM - A single project-wide source of information

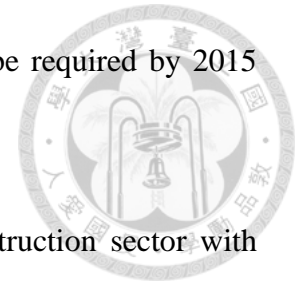
2.1.2 Evolution of BIM in the AEC Industry

Although the BIM idea has been around since the 1970s, its execution has only been extensively used in a few of countries since the early 2000s. BIM has been used in several countries throughout the globe to this point, and certain governments are aware of its significance for building management. Many countries such as UK, USA, Germany, Japan, Australia, Brazil, Canada, France, New Zealand, Korea, Singapore, Russia, China, etc have applied BIM to different extent, thereby improving productivity, competitiveness of the construction market.

Many studies have indicated that BIM adoption in North America increased rapidly between 2007 and 2012 from 28% to 71%. The application of contractors is 74%, surpassing that of architects (accounting for about 70%), this is the object that is leading the process of revolutionizing BIM and helping to clearly define the values of BIM. The number of developers who have requested to use BIM in over 60% of the projects they manage has increased from 18% in 2009 to 44% in 2012.

Singapore has had the best success with BIM because of its national standards and BIM Roadmap (Kaneta, et al., 2016). By 2015, 80 percent of the construction industry should be using BIM, according to the BIM Roadmap, which was developed in 2010 by the Building and Construction Authority (BCA). In order to give the public sector the initiative, BCA worked with GPEs (Government Procurement Entities) to suggest BIM for their projects starting in 2012. The most important construction industry policy in Singapore is this one. In May 2012, The BCA of Singapore and The GPEs collaborated to publish "The Singapore BIM Guide" and "The BIM Particular Conditions" as a crucial need for adopting BIM and laying out the responsibilities and obligations of the parties concerned for the usage of BIM across all project stages.

These regulations mandated that engineering BIM resubmissions be required by 2015 for any new building projects of at least 5,000m².



A completely integrated, technologically sophisticated construction sector with fewer enterprises and a skilled and educated employment market were the goals for the year 2020.

The Bird's Nest Stadium in Beijing, which was finished in 2008, was the country's first BIM project, as according Sawhney et al. (2014). In the same year, the Chinese government launched a BIM digital platform to encourage the use of BIM in the building industry. A number of BIM workshops and conferences were held at this time, and participants included investors, consultants, contractors, academics, and the government. The "BIM Establishment Plan 2011-2015" was made public by the Ministry of Urban, Rural, and Housing Establishment in 2012 in order to assist the creation of national BIM standards and conduct software research. Since 2005, BIM research labs have been created at Tsinghua University, Tongji University, and Central South University. Institutions started to provide BIM software-based courses in 2007. China introduced a master's in BIM in 2012. (Wang X, 2012).

Through its Facility Information Council, the National Institute of Building Sciences (NIBS) in the US began looking into BIM in 1998. In order to promote the expansion of BIM across all industries, geographical areas, and nations as well as to establish the national BIM standards, the National BIM Standard (NBIMS) - US Project Committee was established in 2007. Designers, engineers, contractors, and investors used BIM in 71 percent of their projects, up by 75 percent between 2007 and 2012, according to McGraw-Hill (2012). The majority of BIM users at the time were contractors, with an adoption rate of 74%. 67 percent of engineers used BIM after that.

In contrast to the US, the UK took longer than expected to embrace BIM in the building sector. However, the UK was leading the way in adopting BIM two years later. (2014) Sawhney and associates The UK set a target of 20% cost reduction for federal projects in 2011. 2011 Cabinet Office. In order to do this, the UK government created the BIM implementation strategy and roadmap in June 2011. Before being widely adopted, this plan was evaluated in a few government projects between 2013 and 2015. The United Kingdom has promised that by 2016, BIM would be used at the appropriate stages of all public investment projects costing more than £5 million. One of the main forces behind UK BIM adoption is the BIM maturity model, which shows a systematic movement in BIM maturity levels in the industry (Seen at Figure 3 below).

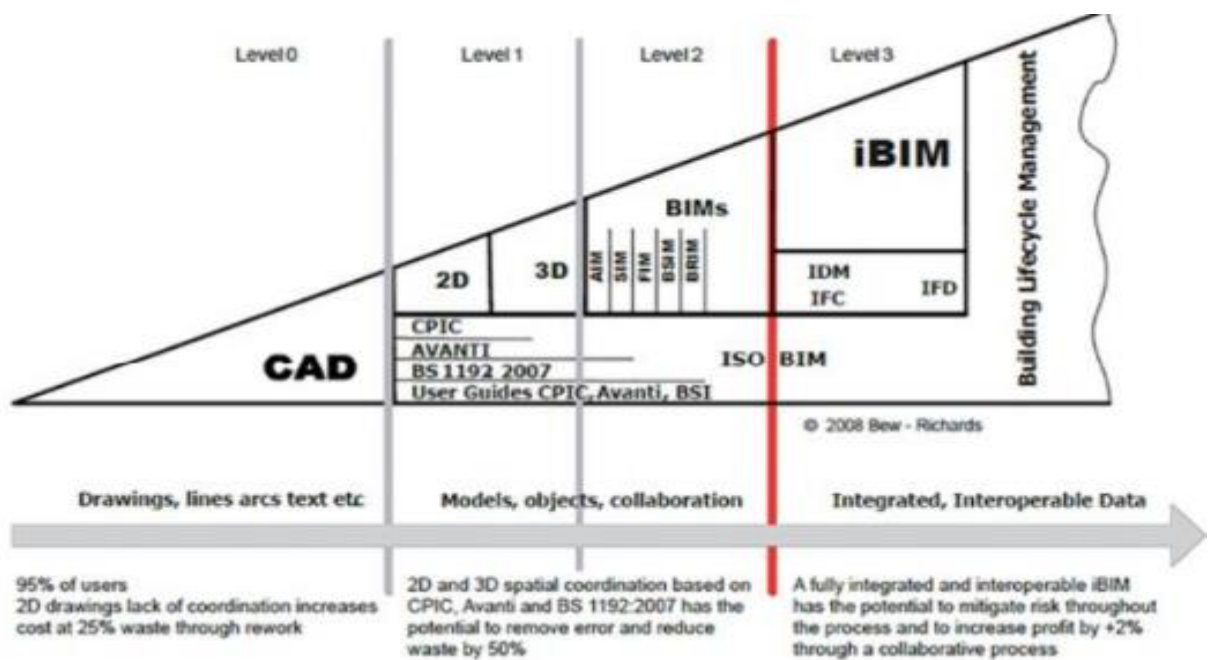


Figure 3. Bew-Richards BIM development model

In addition to the management framework, the United Kingdom government has also embraced the notion of gentle landings (GSL). Through this concept, the British government is encouraging a stronger synchronization of design and building with operation and asset management.

In Europe, outside the United Kingdom, the deployment of BIM in the public construction industry is required in Norway, Finland, the Netherlands, and Denmark. In 2014, nations including France, Australia, and Germany were developing standards and adoption procedures for BIM (Sawhney, et al., 2014). The adoption of BIM around the globe is seen in Figure 4.



Figure 4. Global BIM implementation status

In addition, BIM has been created and is widely utilized in the building business in many other countries. Only two Asian countries—South Korea and Hong Kong—require government agencies to utilize BIM in the construction sector. Both countries are now developing a strategy framework and Bim adoption guidelines. For university academics, Malaysia also provides BIM standards and training courses.

71% of designers, technicians, contractors, and investors employed BIM for their projects, up 75% from 2007 to 2012, according to McGraw-Hill. With a 74% rating, contractors were leading the way in the usage of BIM at the time. BIM use among engineers was second, at 67%.

Figures 5 and 6 show the perceived effect of BIM on contractors in a variety of categories, based on study results from a 2015 McGraw-Hill Smart Market Report on the use of BIM in challenging construction projects.

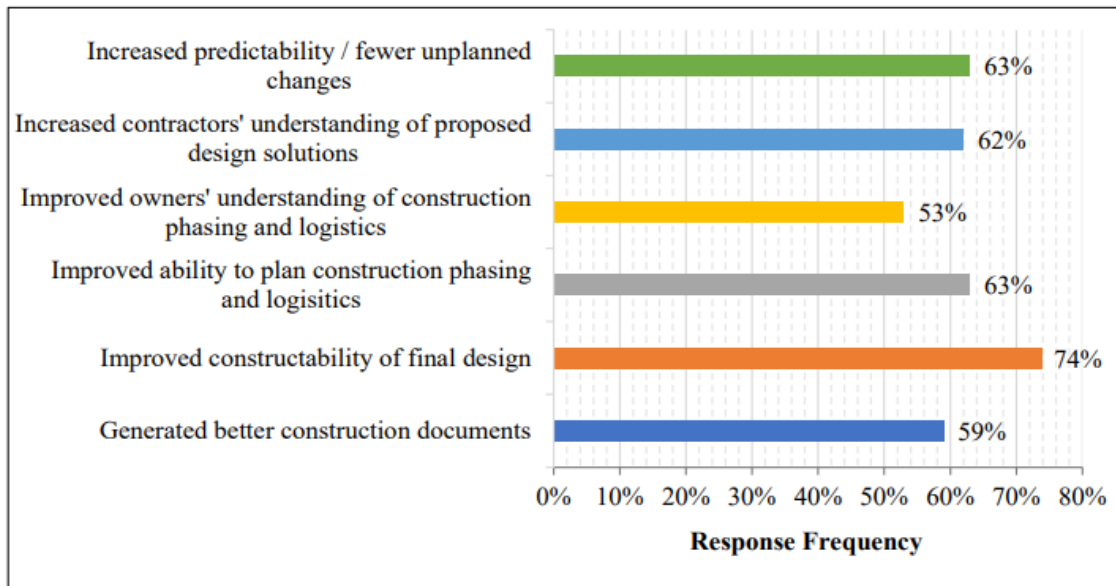


Figure 5. General Contractor Ratings of top BIM Impacts on Industry

Figure 5 shows that, as of 2015, BIM has a significant influence (between 53 and 73% of "high" scores and above) on the general quality of the construction paperwork, its comprehension by participants, and organizational capability (between 53 and 73% of "high" scores and above).

Figure 6 shows that the statistically measurable and on-site advantages of BIM obtained lower "high" and above scores in the poll (between 13 percent and 47 percent). Characteristics such as decreased project budget, accuracy of construction prices and bids, performance, reviewable safety events, and other numeric quantitative aspects have not been rated as highly as BIM's documentation quality and organizational capability.

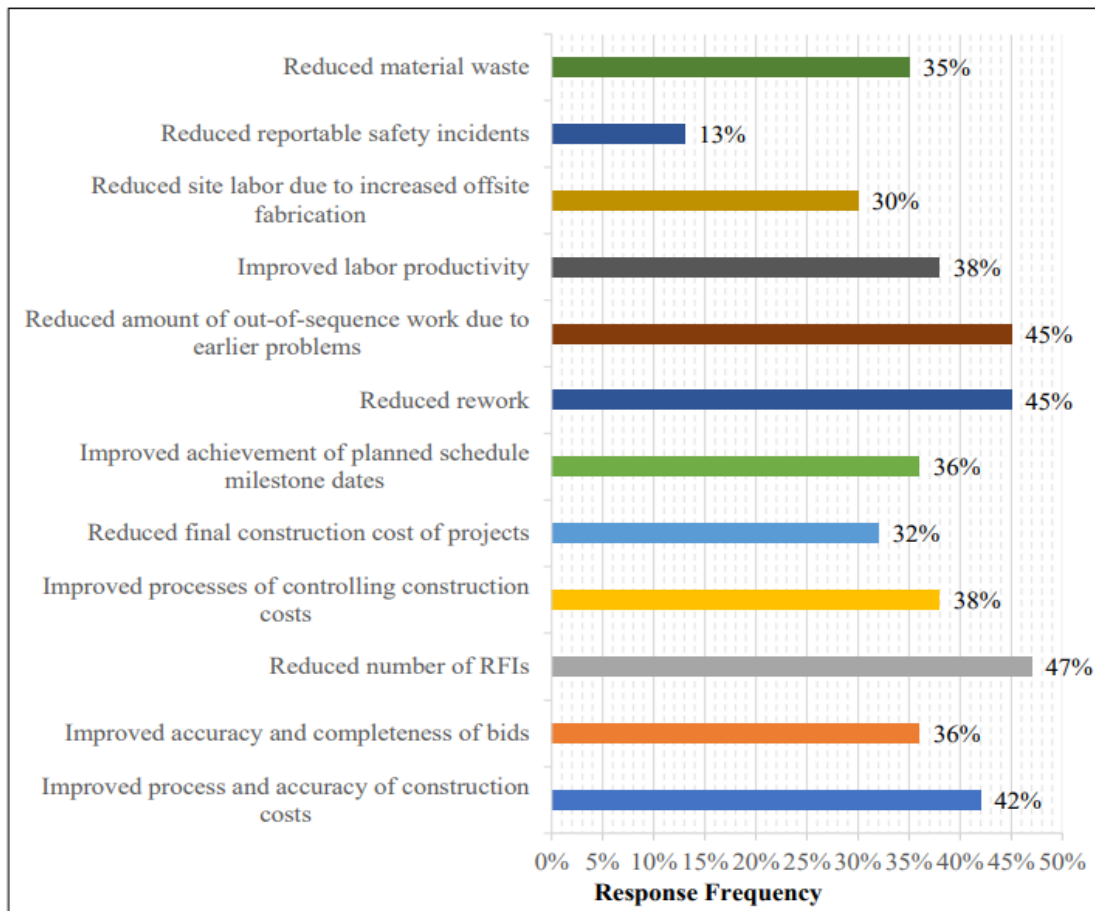
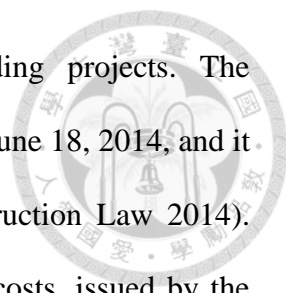


Figure 6. General Contractor Ratings of Lower BIM Impacts on Industry

Importantly, despite the fact that the findings varied based on the scope of work evaluated, they demonstrated a considerable beneficial influence of BIM in different factors of the AEC business. As governments in these nations evaluated the economic positive aspects of adopting this new technology, the transition towards it accelerated drastically (Smith, 2014).

2.1.3 Legal framework about BIM in Vietnam

In recent years, Vietnam has encouraged the use of BIM via a number of projects. The state administration publishes a variety of legal documents for the construction sector, including: The Construction Law addresses a number of BIM-related issues, including the use of new tech, data management on construction works (Item 3, Article

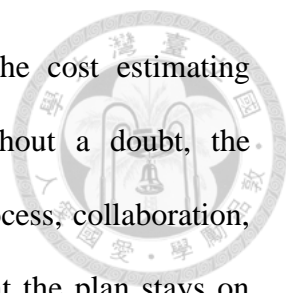


4), and the implementation of information systems for building projects. The Construction Law was approved by the XIII National Assembly on June 18, 2014, and it became effective on January 1, 2015. (Item 1, Article 66, Construction Law 2014). Decree No. 32/2015/ND-CP regarding the control of construction costs, issued by the Construction Ministry on March 25, 2015, specifies the regulation of project management fees for projects that use a certain project management style (Item 2, Article 23, Section 2, Article 25). When BIM is utilized in consulting services, how to compute consultant fees is explained in the Construction Ministry's Decision 79/QD-BXD dated 15-Feb-2017 on "Basic project management and Construction consultancy charges" (Article 2, Section 2). The use of the Information Technology Project (BIM) is one of the scheme's main methods of accomplishing its objectives, according to the Prime Minister's Decision No. 134/QD-TTg dated 26 January 2015 on the restructuring program of the construction projects in accordance with the transition of the development approach (towards improving quality, efficiency, and competitiveness) in the period 2014-2020. In order to meet the demands of long-term growth and global integration, the Government's Resolution No. 26/NQ-CP, dated April 15, 2015, on the issue of "The Implementation of the Government's Operational Plan," encourages the use and advancement of information technology.

2.2 Traditional QTO and Cost Estimation

2.2.1 Definition of QTO and Cost Estimation

A fundamental step in a construction project is quantity takeoff (QTO), which involves measuring and counting the parts of a structure (Monteiro & Pocas Martins, 2013). The QTO process is defined as "the means of determining the amount, type, and installation method of all components in the item" prior to the building stages (Goaszewska & Salaszewak, 2017).

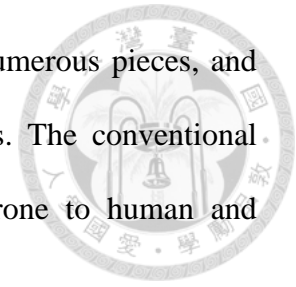


The QTO technique is integral to and intertwined with the cost estimating process. The most crucial component of every project is, without a doubt, the construction estimate. Accurate cost estimation affects planning process, collaboration, and tendering (Moon and colleagues, 2018). In order to ensure that the plan stays on track, the estimator would prefer to keep a close eye on the cost throughout the process of design development. There are many various types of estimations made throughout the design phase of a construction project, ranging from rough estimates in the early stages to more accurate estimates in the detailed planning phase. The volume taken off during the design process is the author's main concern in this study.

2.2.2 Traditional QTO and Cost Estimation method

The conventional or paper-based approach of computing quantity takeoff and estimating has long been used in the AEC industry. The most typical method for creating "bid-tender" or comprehensive cost estimates is this one (Brook 2017). Measurements are taken for this operation using digital design documents, such as building plans, partition plans, roof plans, perspectives, front views, sections, etc. In the CAD-based quantity takeoff process, according to Monteiro and Martins (2013), estimators must comprehend every complicated circumstance, such as the connections of structural sections and the mix of ceilings and walls and execute estimates using reliable incoming data. In order to determine the volumes and produce an estimated cost, the estimator will utilize them to measure all necessary dimensions of all project components. They will then enter those values into a spreadsheet like Microsoft Excel or a supported estimation program. The procedure is manual and depends on the estimator's understanding, which makes it prone to error. In addition, Monteiro and Martins (2013) summarized the major drawbacks of manual amount take-off methods found in the studies. "Difficulties in recognizing conflicts, inconsistencies, or omissions,

portrayal of intricate scenarios, such as junction points between numerous pieces, and identification of cascade problems" are some of these drawbacks. The conventional approach for calculating QTO requires a lot of work and is prone to human and mathematical errors (Yang et al., 2017).



According to common thinking, the typical quantity take-off method takes an excessive amount of time, both for the initial research and for any subsequent revisions. Cost estimate is often only done in the middle and final stages of each project phase, according to Sattineni and Bradford II (2011), since the quantity take-off technique may take up to three weeks and is time-consuming. As a result, it is hard to continuously track how design changes affect price.

Alder (2006) further noted that, especially for large projects, the traditional amount take-off method is very time-consuming, complicated, and mistake. An quantity surveyor must utilize rigorous and well-organized procedures and exercise caution when transferring measured data to other documents in order to avoid errors like double-counting or factual errors. Khosakitchalert, Yabuki, and Fukuda (2018) claim that quantity surveyors need a high level of expertise and knowledge in order to understand a collection of two-dimensional conceptual design and choose the best method for each structural element. Consequently, the process takes a very long time, and the information gathered by different surveyors may differ.

The following procedures are listed as the typical order for measuring QTO in Vietnam in the official letter No. 737/BXD-VP from the Ministry of Construction dated 23 April 2008:

Step 1: Examining the illustration.

Step 2: Gauging the design's dimensions.

Step 3: Calculating the amount for each item and component.

Step 4: Determine the remaining components' volumes.

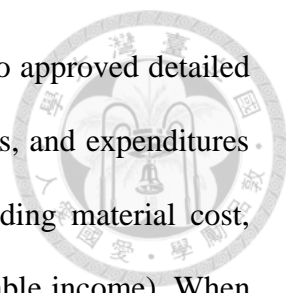
Step 5: Editing and synthesis.



According to this rule, estimators and quantity surveyors often use three methods to determine QTO. The first method is the measurement by work or item type. Second is the estimate based on the sequence of drawings, followed by the calculation based on the order of execution. These strategies are based on basic input data. However, these techniques are very inactive (Ho et al., 2018). In the case of a massive project, for instance, a significant number of drawings must be manually calculated. Thus, might lead to inaccuracies such as overlap quantity, omitting certain pieces or components. In addition, the estimator/quantity surveyor will need to devote a great considerable time and effort to handling the final findings.

Quantities are taken from conceptual design in the event of an approximate calculation. As a result, the quantity surveyor uses the related expenses to calculate the project's budget. The capital cost ratio of constructing a building or data from previous studies that have been built are what determine these expenses, according to the Vietnamese Construction Ministry's 2016 Circular No. 06/2016/TT-BXD (Construction Ministry, 2016).

According to Circular No. 06/2016/TT-BXD from the Vietnamese Construction Ministry from 2016, the estimate is calculated by QTO and building price per unit or by QTO and construction actual cost. The technical designs or shop drawings are used to determine the QTO (Construction Ministry, 2016).



For the constructed unit price (or detailed price), there are two approved detailed prices: the partly unit price (which covers material costs, wage costs, and expenditures for machinery and equipment) and the complete unit price (including material cost, wages, machine and equipment expenses, general expenses and taxable income). When calculating construction unit cost, the following elements must be taken into account:

- The list of construction projects that must be organized in accordance with the Standard Codes And regulations (Work Breakdown Structure - WBS).
- Standardized building costs.
- The price of labor, raw materials, and equipment (with delivery to the building site, but excluding tax).

2.2.3 Traditional QTO and cost estimation process

The cost estimating process can be done in a variety of methods. Eastman et al. (2011) stated a BIM technique's QTO and estimating procedure as an alternative to the conventional paper-based approach (as shown in the following Figure 7). This process was recommended if the surveyor used BIM Quantity takeoff software to do it.

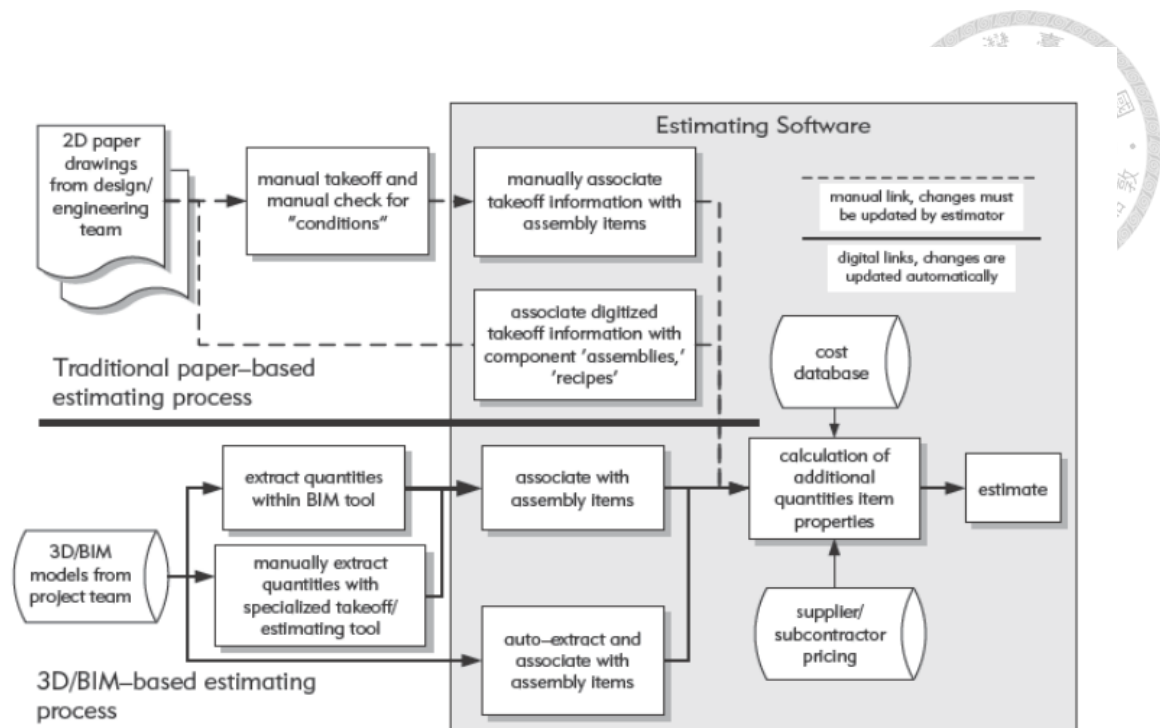


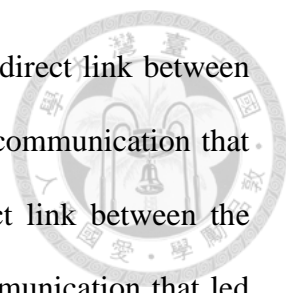
Figure 7. Schematic illustration of the BIM quantity takeoff and estimate process

According to AACE International (Association for the Advancement of Cost Engineering), the typical method of cost estimation consists of the following 3 steps:

Step 1: comprises mostly of external communication that is documented in a foundation of estimation. The needs of the estimate are guided by communication between estimators and designers. Some of this data is missing from the contract paperwork.

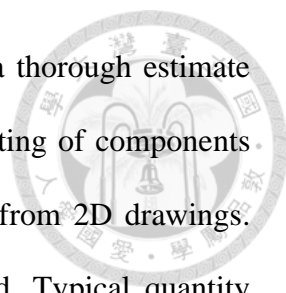
Step 2: is the contractor going over the plans and specifications to determine the whole scope of work (Scope of work). Estimators use this time to visualize project specifications. After each need has been visualized, the estimator may categorize it using the WBS and OBS (Brook, 2017).

Step 3: The estimators estimate quantities subjectively and categorize them in the WBS. Drawing shapes on the 2D drawings is used to measure the lengths, areas, and



volumes of the work-in-progress (Pickett, et al. 2014). There is no direct link between the quantity and the corresponding specification section, detail, or communication that led the estimator to establish this condition, and there is no direct link between the quantity and the corresponding specification section, detail, or communication that led the estimator to establish this condition. This connection would be great for creating an audit trail (Chen, et al., 2015). Estimators who cooperate must manually coordinate scopes using techniques other than the estimate, such as email or face-to-face meetings. After that, the estimators must personally check each other's work to ensure that the whole SOW is recorded once and for all (Brook 2017).

The numbers related to areas and amounts are what are needed to construct an estimate, according to Eastman et al. (2011). For example, the m^2 of feature set are numbers associated with regions. The measurements of areas, such as enclosure, length, height, and width, etc., are quantities related to volumes. These numbers are then used to calculate the beginning price of a structure by connecting them to their corresponding prices after being eliminated from the idea designs. These numbers are based either on the estimator's past experience with constructions of a similar kind or on rates for typical buildings. That is dependent on where the building is located and the regional building codes. (2017) Goaszewska and Salamak Although this early estimate seems to be a "parametric cost estimate," the elements behind its figures are sometimes inaccessible at this stage of design. If the initial estimate does not match the owners' budget requirements, adjustments must be made to fulfill this need. As a consequence, the whole human process of estimating must be repeated until the economic goal and technical solutions are achieved. This procedure is laborious and prone to error as a result of the invisibility of some variables and the fragmentation of price information (Eastman, et al., 2011).



As the design process progresses and the drawing evolves, a thorough estimate and quantity will be created. The list of exact values, such as counting of components and objects, area volumes, and material weights, must be derived from 2D drawings. During this stage, a vast quantity of drawings must be completed. Typical quantity takeoff and estimating methods that require human data entry can result in errors such as volume duplication and the omission of certain items or elements. These errors are the result of worker error and worker perception. Consequently, the necessity for the new technology or new solution to address these deficiencies is essential. BIM using technology advancements in 3D modeling might be seen as an appropriate remedy for these deficiencies. The visualization capability of the 3D model may result in a more precise QTO, and the automation capability of the BIM approach can aid the estimator/quantity surveyor in avoiding human error. In addition, automatically updating data whenever anything is modified may considerably cut the time required for this operation.

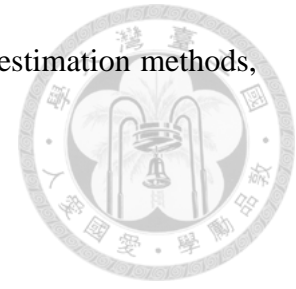
In conventional cost estimation procedures, the degree of precision for each estimate step changes as seen in Figure 8.

Table 1. Error variation among several kinds of estimations

Type of estimate	Construction Development	Expected Percent Error
Conceptual	Programming and schematic design	± 10-20%
Semi-detailed	Design development	± 5-10%
Detailed	Plans and specification	± 2-4%

According to Figure 8, the estimated proportion of inaccuracy in estimates reduces as the quantity surveyor has access to additional design information concurrently with the design's evolution. Since a result, conceptual estimation has a

greater risk of inaccuracy and is more prone to error than standard estimation methods, as the project knowledge is insufficient (Wu, et al., 2014).



2.2.4 Disadvantages of Traditional QTO method

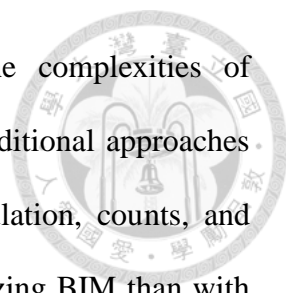
Conventional quantity takeoff and estimating methods that require human data entry can result in errors such as volume overlap and the omission of certain items or parts. Problems with the 2D takeoff approach include the fact that it requires a great deal of time to extract numbers, is less precise, lacks specifics in certain areas, and involves less coordination with other involved parties. According to Kim et al. (2019), potential errors in computing the bill of quantities using 2D-based estimate owing to worker error may delay the making of crucial decisions.

In conclusion, it is evident that conventional quantity takeoff utilizing CAD falls short of meeting the speed and accuracy requirements of the construction market. As a result, a new way for performing QTO and estimating activities is clearly and urgently required.

2.3 BIM-based QTO

2.3.1 BIM-based QTO method

BIM has been used globally in a wide range of construction-related operations, including design (3D), forecasting, planning and progress management (4D), estimating, and cost management (5D). By incorporating intelligent technology, current technical advancements in the building sector have transformed the present construction process. Due of its many dimensions, BIM has quickly gained traction in the building sector. BIM has had a substantial influence on the construction project's design in a number of aspects, along with cost estimation (Akanbi and Zhang, 2017). Using a BIM-based cost estimate might improve its overall effectiveness from the project's conceptual



stage forward (Wasmi and Castro-Lacouture, 2016). Given the complexities of construction activities, BIM provides a number of benefits over traditional approaches for estimating construction costs (Azhar et al., 2012). Item calculation, counts, and several metrics may be altered within the model more quickly utilizing BIM than with conventional CAD files (Gholizadeh et al., 2018). As a result, BIM practice is far better than traditional 2D CAD practice (Eastman et al., 2011).

There are three alternatives available to the estimator/quantity surveyor for customizing their work to specific circumstances (Eastman, et al., 2011). One of the options is to export quantity information to estimate software. Typically, the option to extract quantities is included in all BIM programs (building item quantities). This information could be sent to computer applications like a spreadsheet or an external database. Microsoft Excel is the most popular and suitable tool in this selection for handling BIM quantities for extra essential calculations (Sawyer and Grogan, 2002). Using a quantity takeoff example from Revit (2007) and exporting the results to MS Excel, it can be shown that this tool was simple to use and ideal for the estimation process. The materials takeoff is created in Revit and supplied to the cost estimator in certain businesses. Additionally, this method is how data from 3D BIM models is converted into a format that cost estimator tools can understand (Forgues, et al., 2012). A second alternative is to use the direct connectivity between BIM elements and estimating tools. 2011 (Eastman et al.). Using a plug-in or a third-party application, these BIM technologies may be directly connected to an estimating program. The BIM elements are directly connected to estimating package assemblies, recipes, or objects. Figure 9 demonstrates a relationship between BIM parts and assemblies, formulas, or estimating package elements.

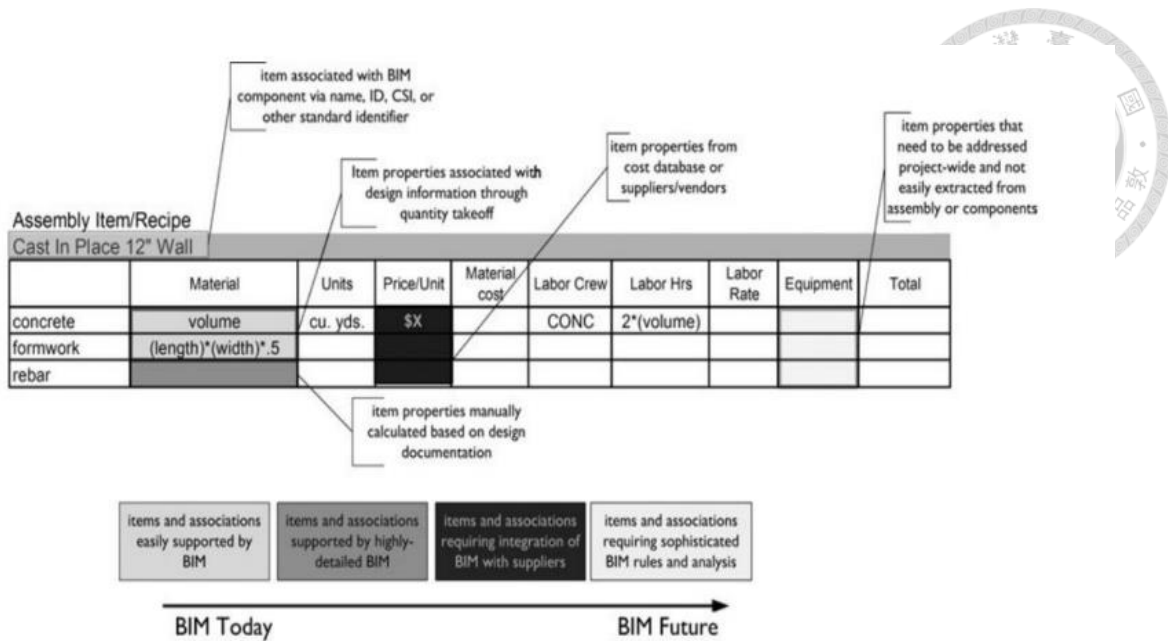
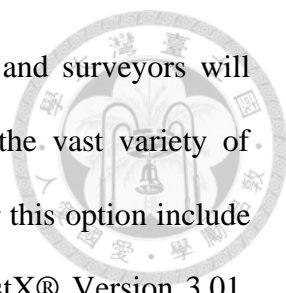


Figure 8. BIM component definitions and estimation of assembly pieces and procedures

Estimators and surveyors may use the calculation procedures to deduct amounts for component operations. On these packages, they may also apply the construction techniques (building processes, sequence of construction steps, etc.), resources (labor, equipment, resources, etc.), duration, and budget expenditures. In this case, surveyors and estimators might make use of Graph iSOFT Estimator, U.S. Costs 2007, and Innovaya 2007. (Vico 2007). For contractors who have specialized in a certain estimate program and BIM technology, this strategy works well. If several BIM systems are used, managing the integration of component information from builders and different trades may be difficult (Eastman, et al., 2011).

Utilizing a automated 3D model quantity takeoff tool is the last option (Eastman, et al., 2011). The estimator was considered while designing this instrument. It is not necessary for estimators and surveyors to comprehend every feature of the BIM tool. These tools often have the ability to link directly to assemblies and objects, modify and provide visual takeoff diagrams. This system provides varying degrees of manual



takeoff assistance and automatic extraction assistance. Estimators and surveyors will need a mixture of conventional and automated tools to support the vast variety of takeoff and quality examinations they will be asked to do. Tools for this option include Vico Takeoff Manager (Vico 2010), Innovaya (2010), Exactal CostX® Version 3.01, and Autodesk QTO (QTO 2010). These QTO tools connect the data (BIM objects) from the BIM model to the cost database in addition to extracting it from the BIM model into a form that can be used by cost estimation software (Forgues, et al., 2012). Wu et al. (2014) also provide BIM-based QTO approaches in this paper. They also highlighted the key elements of each strategy in terms of the conditions surrounding its execution and their combination. These methods are referred to as "automatic takeoff," "derived takeoff," and "manual takeoff." The first approach is used if the model is built in accordance with takeoff requirements. For QTO, maximizing BIM's potential results in the highest level of efficiency (Wu et al., 2014). The quantity information of building components is automatically extracted using QTO tools or a BIM authoring tool; if any pieces are missing from the BIM model, the second approach, derived takeoff, is utilized. These elements may also be derived from other building elements and must be included in the QTO. For instance, columns or beams made of concrete might be used to create concrete formwork. The fourth method, manual takeoff, is utilized when parts are missing from the BIM model. However, they continue to be QTO requirements and cannot be produced by other features. In this case, manual takeoff works well in conjunction with BIM-based QTO (Wu, et al., 2014).

2.3.2 BIM-based QTO process

When changes are made to a project, the BIM mathematical model that is generated within the BIM methodology permits the automatic updating of data obtained in QTO and may be utilized to control the financial element of a building project

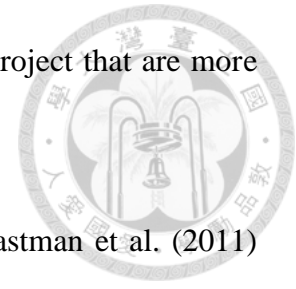
(Forgues, et al., 2012). A parametric three-dimensional (3D) model, from which data may be automatically retrieved, serves as the basis for BIM methods (Parreira, 2013). The models should then be used, enabling the creation and use of a bill of quantities. As a consequence, it will take less time to create tables of supply amounts for a project, lowering costs and project inconsistencies (Shen and Issa, 2010).

Items in a parameterized BIM model include data on numerous aspects, such as shape, material properties, cost, and features relating to maintenance, among others. The linkage of geometrical elements with the BIM 3D model allows for the automated processes of volume extraction. As changes are made to the project, these metrics may be changed using information from the model (Sampaio, 2017).

BIM is a solution that might make surveying more accurate and productive. The Royal Institution of Chartered Surveyors (RICS) (2017) highly advocates the use of technology methods that are integrated, such as BIM, since they may significantly increase clarity, accuracy, and process efficiency in the quantities and cost surveys of a project (Raisbeck and Aibinu 2010). When the design team and surveyors are fully coordinated, information sharing and conflict resolution are simplified, resulting in better and more client-focused advice from the project's early phases (Whang and Park 2016).

Wu et al. (2014) show via an analysis of this BIM-based estimating approach that the intellectual capacity of BIM in conceptual estimations consists in the capacity to link all cost data to the model. It is also simple to accept changes in quantities, measurements, and prices since this connection is consistent with the design across all phases of the project. Because of this, the estimator/quantity surveyor may spend less

time and effort on this process and more time on elements of the project that are more valuable.



As an alternative to the traditional paper-based approach, Eastman et al. (2011) highlighted the QTO and estimation technique of a BIM method (as shown in Figure 7 above). This process was recommended if the estimator used BIM QTO technology to accomplish this task.

Currently, the three processes listed below are essentially how BIM is used to takeoff quantities (Hong Duyen et al., 2018):

Step 1: Create 3D models in Autodesk Revit from 2D blueprints. The design of the 3D model must adhere to fundamental rules like component identification, detail level, etc. in order for the 3D model to automatically generate the quantity results.

Step 2: Customize Autodesk Revit so that the work items and names are appropriate and adhere to the guidelines.

Step 3: Use the Revit API, export data from the Revit 3D model to Microsoft Excel. Users may easily estimate the time and resources needed for each different components from the quantity table they have acquired, which can then be used as a foundation for building progress and cost predictions. All BIM software is capable of supplying item dimensions, area and quantity, and material volume. When used in conjunction with costing software, these programs nevertheless have significant drawbacks. For example, the object dimensions supplied by BIM sometimes fall short of the amount of information needed by the estimating program to apply a unit price to a specific project. At the moment, estimating engineers are required to take part in the design process, work together, and continuously exchange information with architects in

order to construct BIM models that will meet the goal of determining the proper cost estimates for each stage of the project.



2.3.3 BIM-based QTO workflow

Depending on the project type, the enterprise, and the BIM platform being used, the QTO and estimate process BIM workflow will vary (Eastman et al., 2011). It was recommended that each design phase follow the cost estimation type (Choi, et al., 2015). The procedure shown in Figure 10 was created in the case study "Hillwood Commercial Project - BIM for conceptual cost estimate" by Eastman et al. (2011). The process includes the following steps: creation and simulation of a design scenario utilizing parametric structural components and/or project frameworks; evaluation-based cost estimates using cost data related to building components from a cost database, such as RS Means, with guidance from an expert designer and project manager; and presentation and evaluation of the estimated design option including the investor and design-build team. This whole process is transferable to many design situations.

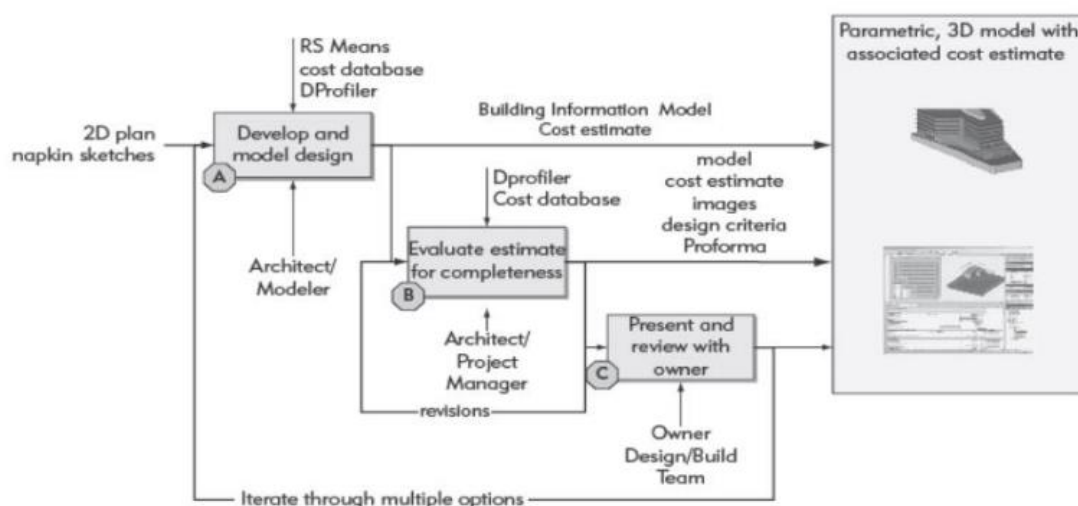


Figure 9. Workflow conceptual estimation with DProfiler

Another proposal for workflow in detailed estimation was undertaken in another case study by Eastman et al., 2011, "Sutter Medical Center, Castro Valley," as illustrated in Figure 11 below. To make model-based estimating a reality, a lot of work was put into determining the ideal element between BIM designs and BIM estimation software, as well as interaction between the design team and builders (Eastman et al., 2011).

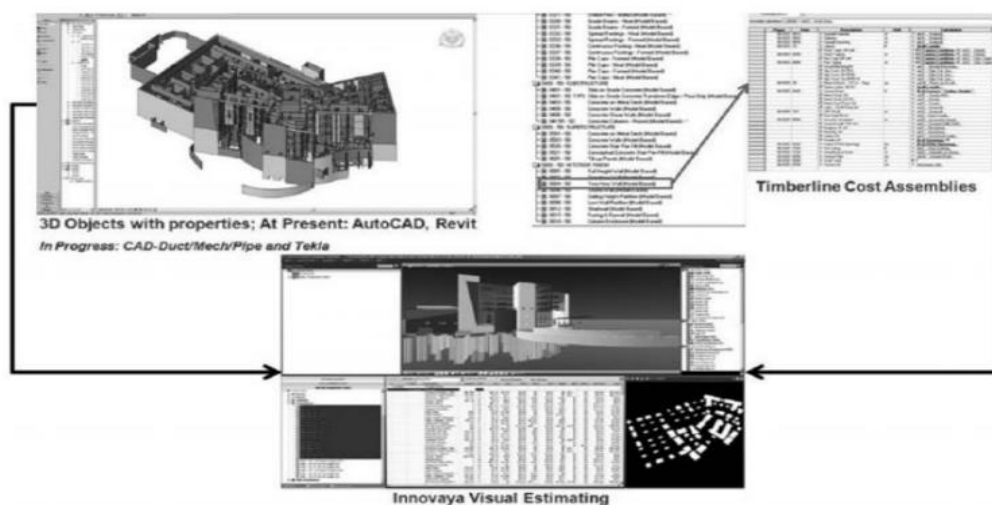


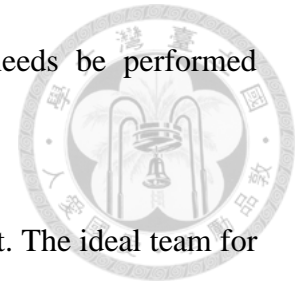
Figure 10. Model-based cost estimate that integrates AutoCAD or Revit models with the Timberline estimating system via the use of Innovaya.

The following lessons on building a BIM workflow for the quantity surveying and estimate process are emphasized in summary from the aforementioned case studies:

- Building a BIM process for QTO and estimates based on each design stage.
- Determining the project's design elements and budgetary requirements.
- Specify the BIM design tool and BIM-based cost estimating software interoperability system.

- Determining if a portion of the total amount takeoff needs be performed manually.

- Establish a collaborative team at the beginning of the project. The ideal team for this procedure should consist of three specialists: an architect, an estimator, and a BIM engineer.



2.3.4 Advantages and Disadvantages of BIM-based QTO

2.3.4.1 Advantages of BIM-based QTO method

This technical advancement increases the data's accuracy. BIM reduces project design faults, improving the accuracy of the estimation process over the 2D takeoff approach (Aibinu and Venkatesh, 2014). By removing the possibility of duplicate quantities, the BIM implementation step not only greatly reduces time but also improves the accuracy of the whole process (Hwang et al., 2019). Furthermore, Kim et al. (2019) found that throughout the design phase of cost estimation, design alterations, recalculations, and partial calculations may be easily accepted utilizing BIM-based QTO. The BIM QTO technique may significantly reduce incorrect cost estimations, especially for internal components where fine details are often hidden in 2D views. To get exact cost estimates, various geometric characteristics in the structural elements may be easily obtained from the BIM model.

Along with this benefit, Kim et al. (2019) emphasized the relevance of estimating precise numbers utilizing BIM, which may significantly reduce the time needed to produce an estimate. According to Olsen and Taylor (2017), the BIM-based QTO process is around 80% faster than the traditional method. Reducing the time and effort needed to put up an estimate is one of the specified advantages of adopting BIM, according to the case study "Hillwood Commercial Project" provided in the book by

Eastman et al. (2011). One of the most notable features of BIM is that it significantly reduces the time and expense of the estimating process, according to study by Ramaji et al. (2018).

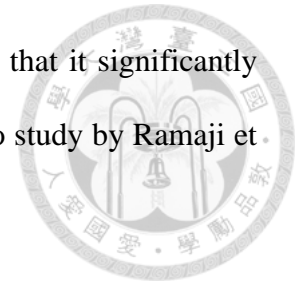


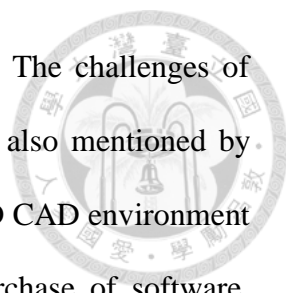
Table 2. Time saved by utilizing the BIM for quantity take-off

Category	Contents	time [minutes]	
		Manual	Revit
Table of rooms	Floor and ceiling composition	40	20
Foundations	Pads, belts, slabs	125	20
Construction phase	Walls, pillars, girders	420	10
Vertical constructions	Masonry, isolation	450	30
Wall surface	Plasters, paints	330	20
Ceiling composition	Ceiling composition	20	15
Floor composition	Floor composition	40	15
Wall composition	Wall composition	100	20
Facade	Facade	240	20
Roof composition	Roof composition	20	5
Balcony composition	Balcony composition	50	15
Groundwork	Excavations, embankments, removal	120	-
Staircases	Staircases	60	-
Other construction and work	Cleaning, shining, covering	70	20
Tables for take-offs		-	130
Total		2085	340

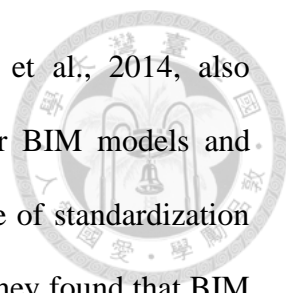
2.3.4.2 Disadvantages of BIM-based QTO method

Although few publications have specifically addressed the BIM QTO's advantages, there are a number of downsides.

Both Yan and Damian (2008) and Kiviniemi (2007) agree that BIM has flaws. They believe that despite BIM's ability to quickly complete the bulk of physical work, not all quantification issues can be resolved. What issues could arise when implementing BIM to a project or organization, and specifically to the QTO and estimating process? Using BIM wisely would reduce the frequency and severity of problems related to traditional approaches, claim Eastman et al. (2011). It will also provide significant challenges, such as changing the connections between construction stakeholders and their contractual responsibilities. It specifically relates to challenges with collaboration and teamwork, regulatory adjustments to ownership and production



of documentation, and changes in the use and use of information. The challenges of implementing the BIM process when it relates to a business were also mentioned by Eastman et al. in 2011. They contend that switching from a 2D or 3D CAD environment to a building model system necessarily requires not only the purchase of software, training of staff, and upgrading of hardware, but also the alteration of nearly every factor of a firm's operations (rather than simply carrying out the same tasks in a different manner) (Eastman et al., 2011). Despite its sophisticated technology, BIM-based estimating presents the following hurdles for the application of BIM on QTO and estimation processes. These obstacles might be seen as characteristics of working with BIM tools from the standpoints of selecting software and team interaction. (Gołaszewska & Salamak, 2017). The first problem was caused by the cost estimation software's restricted access to functional data. The information offered by software suppliers or on their websites is often limited and does not demonstrate the full capabilities of the application. They prefer to emphasize the advantages of utilizing application of BIM more than the software's features. The same applies to the instructional videos. As a consequence, this misinformation influences how designers choose cost estimating tools. Collaboration is a problem throughout the whole model development and cost estimates process, which is the second challenge. One of the most crucial facets of project management in this Digital environment is the group's members' communication with one another. Having good communication will lead to a better model (Goaszewska and Salatak, 2017). According to Wu et al., 2014 's research, "How might BIM aid the New Rules of Measurement (NRM1)?" the issues include the current industry's misconceptions and ignorance about BIM. Quantity surveyors are hence hesitant to use BIM because of this. Gaining understanding about the characteristics of materials, construction techniques, and construction processes while



maximizing the return on investment is a further obstacle. Wu et al., 2014, also mentioned three more obstacles in BIM-based estimation: inferior BIM models and insufficient information; data interchange concerns; and the absence of standardization and incorrect price format in reality. In relation to the first subject, they found that BIM models fall short of the informational and quality standards set by quantity surveyors. Two factors that are included in the model—the caliber of the information and the details of the construction technique—affect the accuracy and quality of a BIM-based estimate. The accuracy of BIM-based cost calculations depends on the degree of development of assemblies and objects in the model. This makes it difficult for quantity surveyors to locate and organize the crucial data within the model in order to provide cost estimates. The majority of software only permits quantities within the model to be continually shared and adjusted during design alterations, not cost information, and many BIM estimating solutions do not provide bidirectional data communication. Due to the lack of an industry standard for the relationship between model and cost estimate, the last barrier—a lack of standardization and an inappropriate pricing format in practice—arises. They learned that the quantity surveyor/estimator may get a thorough analysis of costs via the BIM application. But they are seldom presented in a manner that is acceptable for the price (Wu et al., 2014).

CHAPTER 3 RESEARCH METHODOLOGY



3.1 Hypotheses to test

Case studies and questionnaire surveys will be used in the thesis as a combination of quantitative and qualitative research methods. The study compares the effectiveness of the conventional QTO technique with the BIM-based QTO approach in the Vietnam cost estimate process, focusing on the method's suitability and the precision of the quantity outputs.

The following sub-objectives were created to carry out the main objective:

1. Sub-objective 1 (SOB1): To compare the perspective of people using Traditional QTO method (Group 1) and people using BIM-based QTO method (Group 2), on the suitability of these two QTO methods for adoption in Vietnam cost estimation process.

2. Sub-objective 2 (SOB2): To compare and evaluate the accuracy of quantity results extracted from traditional QTO method and BIM-based QTO method.

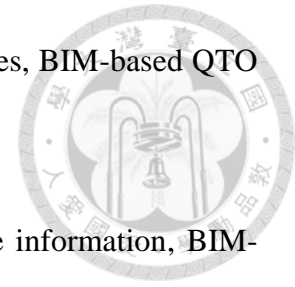
Apart from identifying the opportunities/barriers of two QTO methods in cost estimation process, the study also tested the following hypotheses:

Hypothesis 1: In terms of Visualization, BIM-based QTO method is different from Traditional method.

Hypothesis 2: In terms of Compatibility with Vietnam construction norm, BIM-based QTO method is different from Traditional method.

Hypothesis 3: In terms of Suitability for quantities appraisal, BIM-based QTO method is different from Traditional method.

Hypothesis 4: In terms of Reduction in measurement mistakes, BIM-based QTO method is different from Traditional method.



Hypothesis 5: In terms of Ability to update and summarize information, BIM-based QTO method is different from Traditional method.

In this sector for the survey, using the Likert Scale, respondents in two groups (engineers utilizing usual technique and engineers utilizing BIM-based QTO method) ranked their level of agreement or disagreement with approximately twenty statements regarding the benefits and drawbacks of these two methods in the quantity takeoff and cost estimation process. Respondents were instructed to score each element on a 5-point Likert scale: 5 = Strongly Agree; 4 = Agree; 3 = Neutral; 2 = Disagree; and 1 = Strongly Disagree. Following this, the findings will be rated to determine the top benefits and drawbacks of adopting BIM-based QTO and traditional approach in the QTO and estimating process in Vietnam. To gather more data, one "open-ended" question was included, which encouraged respondents to offer their thoughts on the possibility of using BIM to quantity take-off and to provide other remarks.

3.2 Methodology of survey

The author's survey was conducted mostly using a quantitative technique. Initially, a quantitative technique using a structured questionnaires was used to collect data from a broad population sample.

Using the Google Forms program, a web-based questionnaire was developed and sent to the specified recipients. Posting of the URL link to the poll on Facebook groups such as the Vietnam BIM network and the BIM community in Vietnam network was a second strategy for reaching this target audience.

The questions were created for all construction workers in Vietnam, regardless of their BIM expertise. The owners, contractors/subcontractors, site managers/engineers, consultants, and quantity surveyors were consulted to get a wider perspective on the studied topics. The questionnaire was divided into four pieces as mentioned below:

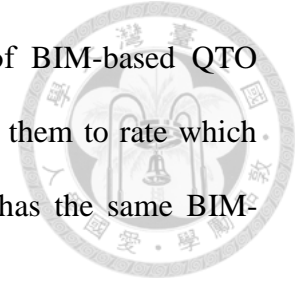
Section 1: Introduction. The general information of survey questions, the objective of the survey, and the researcher's commitments to the respondents' privacy were established. No question appeared in this section.

Section 2: Fundamental information respondents' backgrounds were gathered in order to obtain information on survey participants and their organizations, such as their years of work experience, firm type, and position. Here, information on the current QTO process and estimate has been compiled. This part further separated responders into two groups: those who used the classic QTO approach and those who utilized the BIM-based method.

Section 3: Opinions of respondents applying traditional QTO method. This section was constructed for people using traditional QTO method to collect respondents' opinions about the advantages and disadvantages of Traditional QTO method, some statements about BIM-based QTO method, also ask them to rate which method is stronger based on those specific criteria. An "open-ended" question was also introduced to collect additional data, which invited respondents to share opinions on the potential of applying BIM-based QTO method in the future, and to give comments on why/why not applying this method.

Section 4: Opinions of respondents applying BIM-based QTO method. This section was constructed for people using BIM-based QTO method to collect

respondents' opinions about the advantages and disadvantages of BIM-based QTO method, some statements about BIM-based QTO method, also ask them to rate which method is stronger based on those specific criteria. This section has the same BIM-based QTO method statements as section 3.



CHAPTER 4 SURVEY IMPLEMENTATION



Three sections comprise the findings of the quantitative research conducted utilizing the survey:

1. Section 1: Analysis of the raw data. It concentrates on the business and respondent characteristics as well as the QTO and estimate techniques currently being employed in the Vietnamese construction industry.

2. Section 2: The perspective of people in Group 1 (applying Traditional method) on the advantages and disadvantages of traditional QTO method and BIM-based QTO method.

3. Section 3: The perspective of people in Group 2 (applying BIM-based method) on the advantages and disadvantages of traditional QTO method and BIM-based QTO method.

4.1 Survey data description

In total 68 responses were received in Vietnamese AEC industry. 68 answers were analyzed.

There were 15 respondents working for the construction investment organizations, clients; 33 people came from contractors/sub-contractors. There were 17 respondents from design consultant companies; 1 person from the state construction management unit; 1 person from a research company and 1 person working in the educational field. The distribution of the sample that was collected is shown in the following table:

Table 3. Type of organization of collected samples

No	Type of organization	Total	Percent
1	Owners/Clients	15	22.06%
2	Contractors/Sub-contractors	33	48.53%
3	Construction consultant company	17	25.00%
4	State construction management unit	1	1.47%
5	Research company	1	1.47%
6	Educational institutes in construction field	1	1.47%
	Total	68	100.00%

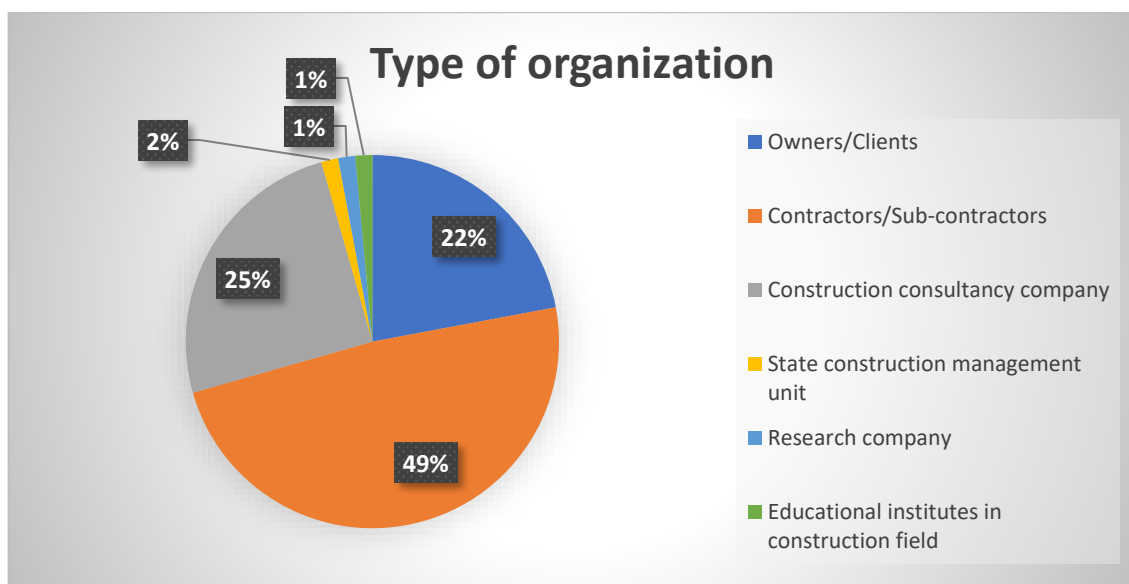


Figure 11. Type of organization of collected samples

According to Table 4 and Figure 11, there were 24 respondents working as Quantity Surveyors/Estimators, 24 respondents working as Project Manager. There were 10 people working as Site Managers/Site Supervisors; 6 people came from design field; 1 respondent who are QA/QC; and 2 people from research field.

Profile of respondents from collected samples:

Table 4. Roles of respondents' jobs

No	Job roles of the respondents	Total	Percent
1	Quantity surveyor/estimators	24	35,29%
2	Project Manager	24	35,29%
3	Site Manager/Site Supervisor	10	14,71%
4	Civil Engineer	1	1,47%
5	Architect	6	8,82%
6	QA/QC	1	1,47%
7	Researcher	2	2,94%
	Total	68	100.00%

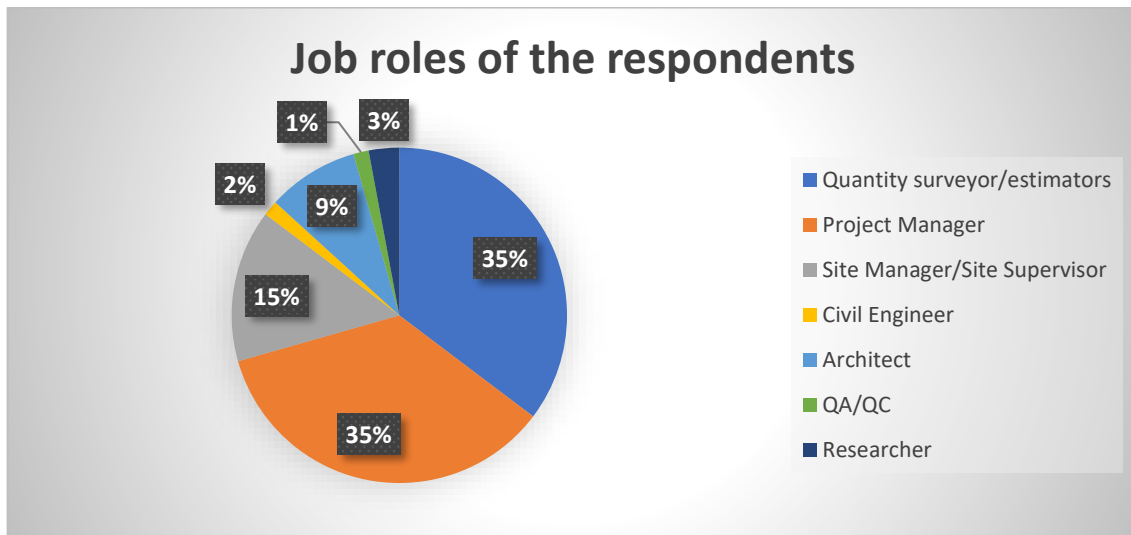


Figure 12. Roles of respondents' jobs

In addition, based on the data shown in Table 5 and Figure 13, these respondents had a rather considerable amount of construction business experience. Specifically, 19.12 % of consultants have more than ten years of experience, while 23.53 % have between five and ten years of experience. 33.82 % have 0 to 2 years of experience, while 23.53 % have 2 to 5 years of experience. Based on this study, there is a balance of

group experience. However, the percentage of responders with 0 to 2 years of work experience is the most at 33.82 %.

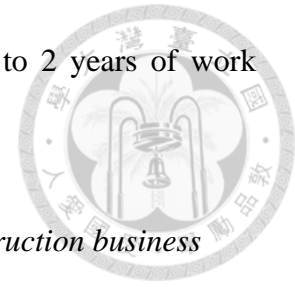


Table 5. The respondents' years of work experience in the construction business

No	Years of working experience	Total	Percent
1	From 0 to 02 years	23	33.82%
2	From 02 to 05 years	16	23.53%
3	From 05 to 10 years	16	23.53%
4	More than 10 years	13	19.12%
	Total	68	100.00%

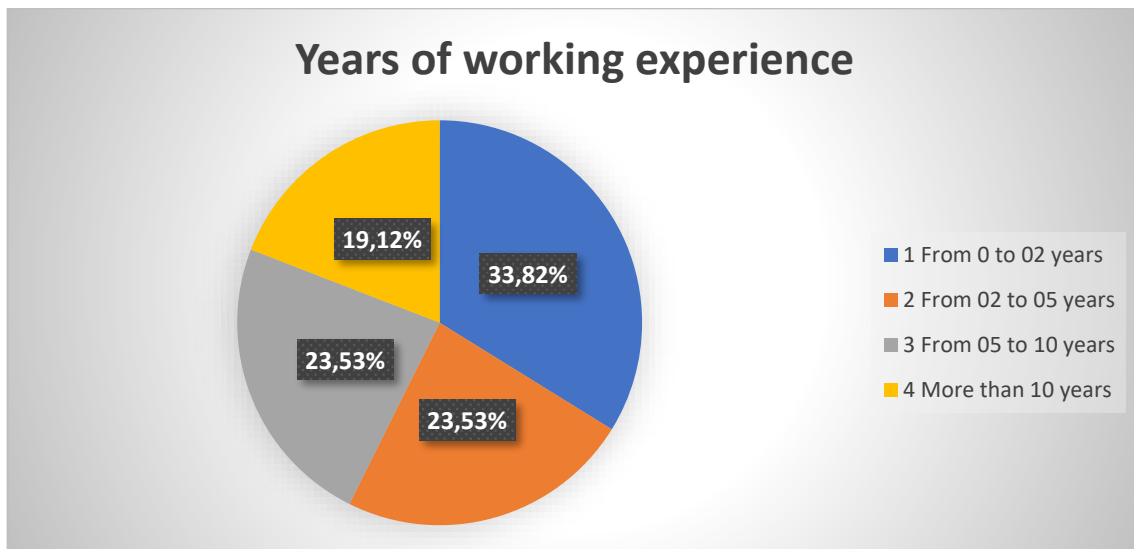


Figure 13. The respondents' years of work experience in the construction business

4.2 Findings of Quantity takeoff method in use

As shown in Table 6 and Figure 14, the most popular approach (paper-based method) was used by 58.82 % of survey respondents who provided verified answers. The remaining 41.18 % of replies used the BIM approach.

Table 6. Current QTO and cost estimating techniques in sample data

No	Current method of QTO and cost estimation	Total	Percent
1	Traditional method	40	58.82%
2	Combination of traditional and BIM-based QTO method	28	41.18%
	Total	68	100.00%

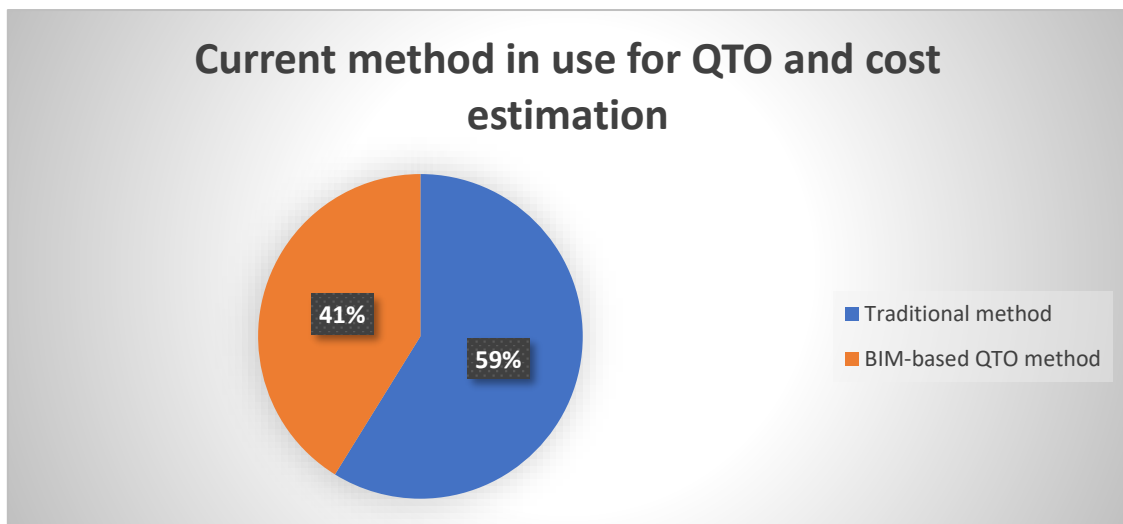


Figure 14. Current QTO and cost estimating techniques in sample data

MS Excel and common cost estimation tools such as GXD, G8, and F1 were the most often used software packages within the conventional technique.

Table 7. Current method of QTO and cost estimation in collected samples

No	Type of software	Frequency	Percent
1	Excel	22	55,00%
2	G8	8	20,00%
3	F1	4	10,00%
4	Manual	3	7,50%

5	Other	3	7,50%
	Total	40	100,00%

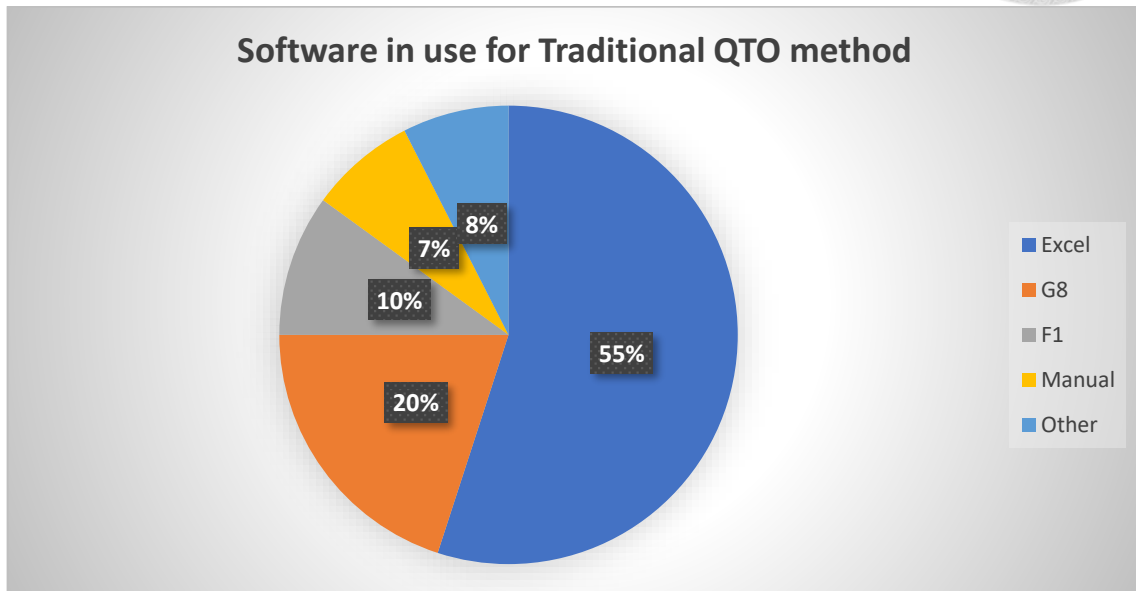
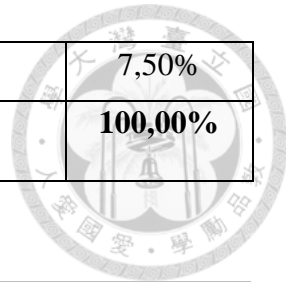


Figure 15. Software in use for Traditional QTO method

Regarding the BIM-based QTO method, Revit is the most popular software for this approach, accounting for 53% of the total. Cubicost and Naviswork are the two software that follow up, with the total of users are 5 and 3, respectively.

Table 8. Software in use for Traditional QTO method

No	Type of software	Frequency	Percent
1	Revit	15	53,57%
2	Naviswork	3	10,71%
3	Cubicost	5	17,86%
4	CostX	1	3,57%
5	Tekla	1	3,57%
6	Other	3	10,71%
	Total	28	1

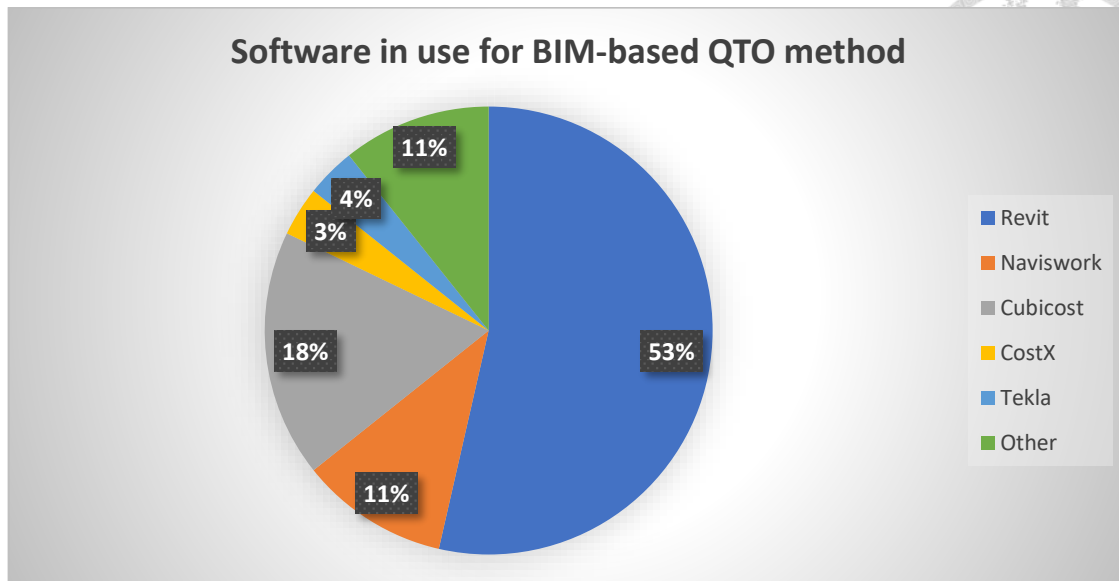


Figure 16. Software in use for BIM-based QTO method

4.3 Findings of perspectives of two groups on Traditional method and BIM-based QTO method

4.3.1 Group 1: People applying Traditional QTO method

Regarding the advantages of 2D QTO method, in Group 1, the factors "Suitable for explanation, verification, and appraisal of quantities" (Mean=3.8, SD=0.82) and "In compliance with Vietnam building norm system" (Mean=3.775, SD=0.86) were the two most notable benefits of the Traditional approach. Placed at number 3 and 4 are the factors "Simple Operation" and "Easy to handle the input data", correspondingly.

Table 9. Results regarding advantages of Traditional method in Group 1

No	Factor	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Total	Average	SD	Rank
1	Suitable for explanation, verification, and appraisal of quantities	1	1	9	23	6	40	3,8	0,822753	1
2	In accordance with Vietnam construction	1	3	6	24	6	40	3,775	0,863802	2

	norm system									
3	Simple Operation	2	1	10	21	6	40	3,7	0,939176	3
4	Easy to handle the input data	2	3	11	19	5	40	3,55	0,985797	4

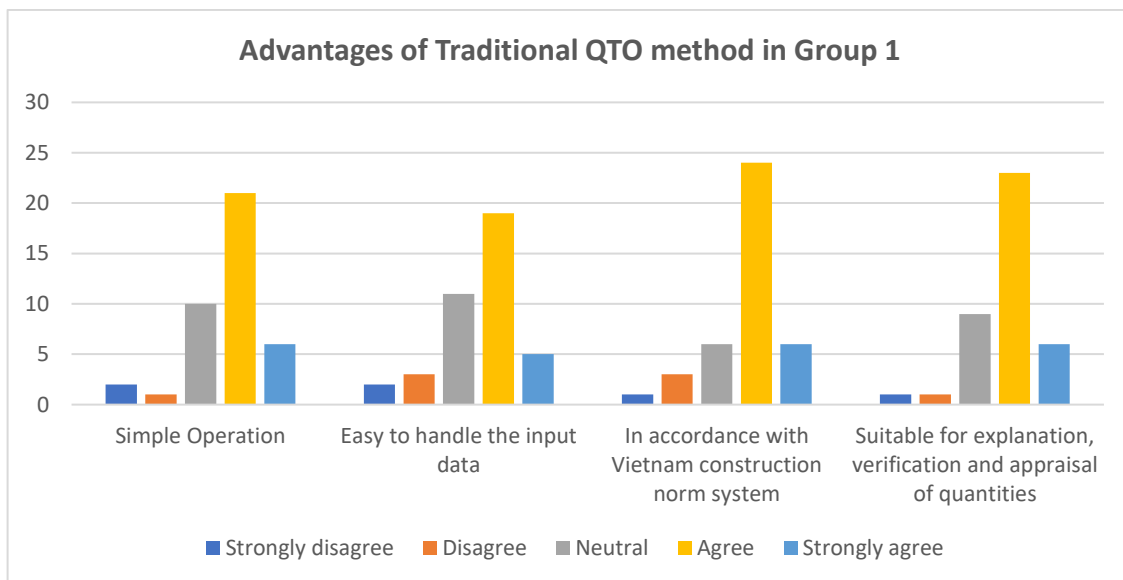


Figure 17. Advantages of Traditional method (Group 1's opinions)

Regarding the disadvantages of Traditional method in Group 1, the major drawbacks agreed upon by Group 1 were factor “Making mistakes, measuring less or extra quantities every time the design changes” (Mean=3.975, SD=0.83), and factor “Difficulty updating and synthesizing information” (Mean=3.775, SD=0.89). Placed at number 3 and 4 are the factors “Waste of time and effort” and “Poor Visualization”, respectively.

Table 10. Results regarding disadvantages of Traditional method in Group 1

No	Factor	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Total	Average	SD	Rank
1	Making mistakes, measuring	1	1	5	24	9	40	3,975	0,83166	1

	less or extra quantities every time the design changes									
2	Difficulty updating and synthesizing information	1	0	8	25	6	40	3,875	0,89119	2
3	Waste of time and effort	1	0	10	22	7	40	3,850	0,80224	3
4	Poor Visualization	2	2	11	22	3	40	3,550	0,90440	4

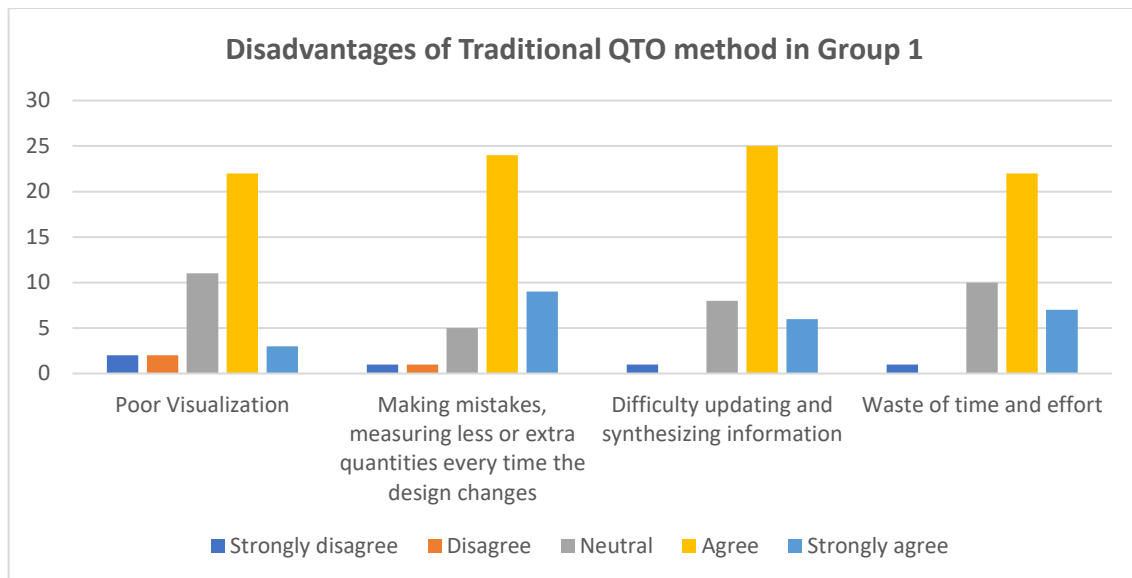


Figure 18. Disadvantages of Traditional method (Group 1's opinions)

4.3.2 Group 2: People applying BIM-based QTO method

In Group 2, regarding the advantages of BIM-based QTO method, the factors “Easily updating and synthesizing information” (Mean=4.286, SD=0.86) and “Good Visualization” (Mean=4.071, SD=0.72) were the two most notable benefits of the BIM-based approach. Placed at number 3 and 4 are the factors “Reducing mistakes, measure

less or excess quantities every time the design changes” and “Good control of construction cost and cashflow of the project”, correspondingly.



Table 11. Results regarding advantages of BIM-based QTO method in Group 2

No	Factor	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Total	Average	SD	Rank
1	Easily updating and synthesizing information	0	0	0	20	8	28	4,286	0,46	1
2	Good visualization	0	0	6	14	8	28	4,071	0,71	2
3	Reducing mistakes, measure less or excess quantities every time the design changes	0	0	4	19	5	28	4,036	0,57	3
4	Good control of construction cost and cashflow of the project	0	1	8	16	3	28	3,750	0,70	4

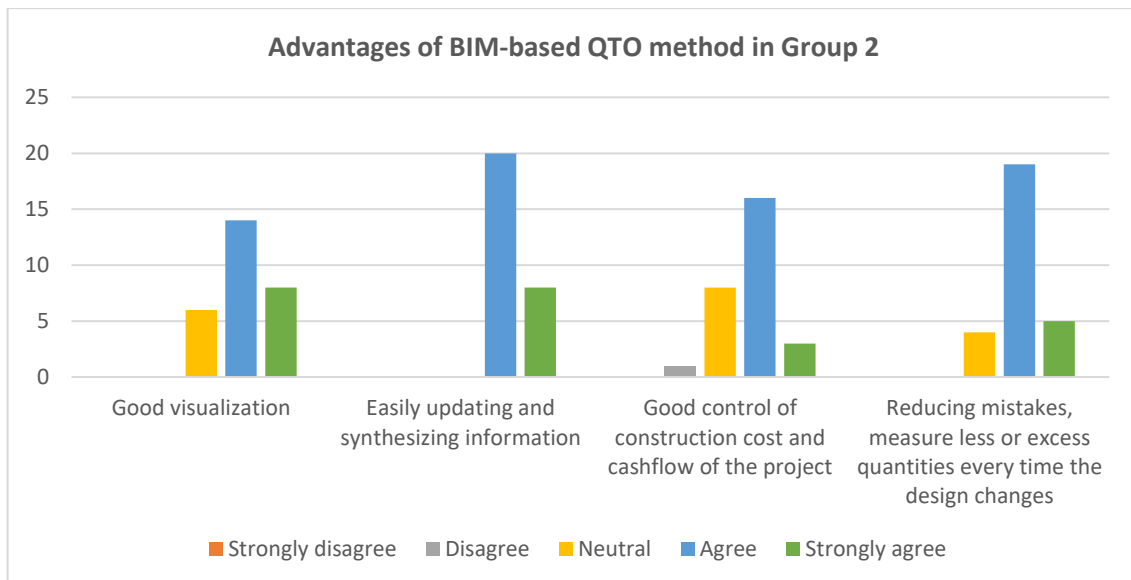


Figure 19. Advantages of Traditional method (Group 2’s opinion)

Regarding the disadvantages of Automated BIM-based QTO method in Group 2, the major drawbacks agreed upon by Group 2 were factor “Quantities from BIM do not

match the State's construction norm system" (Mean=3.857, SD=0.89), and factor "No specific procedure/standard for testing the reliability of the model before exporting quantities" (Mean=3.68, SD=0.9). Placed at number 3 and 4 are the factors "Information from the model is not enough for QTO, cost estimation work" and "Waste of time and effort" and "Unable to meet the demand for explanation, verification and appraisal of quantities", respectively.

Table 12. Results regarding disadvantages of BIM-based QTO method in Group 2

No	Factor	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Total	Average	SD	Rank
1	Quantities from BIM do not match the State's construction norm system	0	1	10	9	8	28	3,857	0,89	1
2	No specific procedure/standard for testing the reliability of a model before exporting quantities	0	3	8	12	5	28	3,679	0,90	2
3	Information from the model is not enough for QTO, cost estimation work	0	4	8	12	4	28	3,571	0,92	3
4	Unable to meet the demand for explanation, verification, and appraisal of quantities	1	7	6	9	5	28	3,357	1,16	4

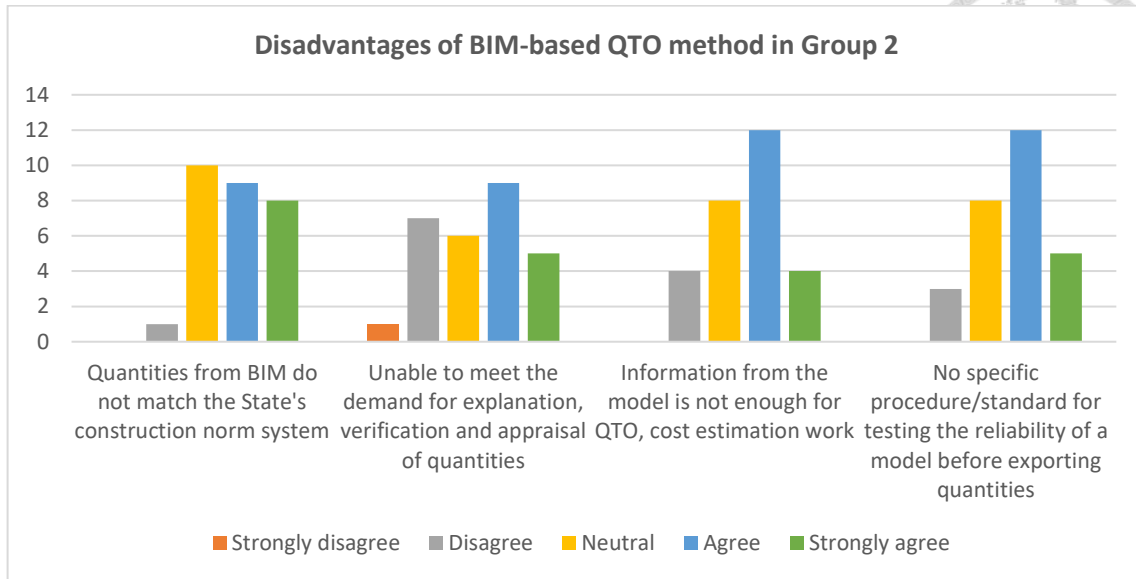


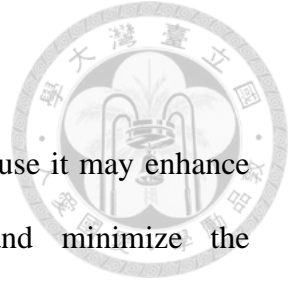
Figure 20. Disadvantages of Traditional method (Group 2's opinion)

4.4 Survey Analysis

68 respondents' survey answers were used to compute the means and standard deviations. The author chose 05 functionalities to obtain and compare in each group, as described in Table 13.

Table 13. Functionality to compare between BIM-based QTO method and Traditional method in both groups

No	Functionalities
1	Visualization
2	Compatibility with Vietnam construction norm
3	Suitability for quantities appraisal
4	Reduction in measurement mistakes
5	Ability to update and summarize information



1. Visualization:

It was determined that visualization was helpful to QSs because it may enhance decision-making, decrease incorrect drawing interpretation, and minimize the predictions the QS must make. Sabol (2008) said that the BIM model offers a better knowledge of construction components, lowering the possibility of overlooking or misinterpreting crucial structural components.

2. Compatibility with Vietnam construction norm:

The cost estimation standards approach used in Vietnam and the BIM methods now in use are vastly different (Nguyen & Nguyen, 2021). It is crucial to give a set of estimates with functional codes in line with the estimated standards established by the Ministry of Construction when creating estimates for state-funded projects (Phng & Quân, 2020).

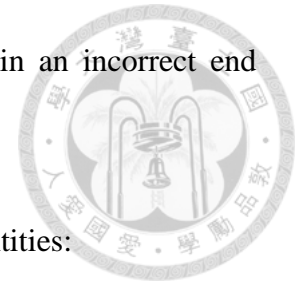
3. Ability to update and summarize information:

Every modification to a project's components or design has an effect on the total cost. All linked paperwork, schedules, and other measures utilized by an estimator should be updated to reflect the modifications made to quantity takeoffs. "The capacity to update and adjust quantities rapidly may be a big advantage for QSs in regards to cost modelling," Stanley and Thurnell (2014) claim.

4. Reduction in measurement mistakes:

During the calculation process, if the design drawing changes, the input data must be re-entered, which easily causes risks such as duplication, omission of measurement and measurement volume. A poor output error may also have negative effects on cost,

time, and productivity. An input error will almost always result in an incorrect end result.



5. Suitable for explanation, verification, and appraisal of quantities:

In Vietnam, quantities and cost estimation of construction projects need to be appraised by State agencies specialized in construction i.e. Department of Construction, etc in every regions in Vietnam before the construction phase starts. For the project to be accepted and the construction phase to start, the quantity should be evaluated and the time for this activity should be done as soon as possible.

In order to perform the appropriate statistical test, the data were judged to have a normal distribution since they had an asymmetrical distribution and no obvious outliers. Once the means and standard deviations of two QTO approaches for both groups have been calculated, a simple linear regression was performed to test all five functionalities, with QTO method as a single dummy variable. This dummy variable is defined as D=0 for Traditional method and D=1 for BIM-based QTO method.

For Hypothesis 1, considering the regression model is:

$$Y (\text{Visualization}) = \beta_0 + \beta_1 \times D (\text{QTO method}) + u$$

The null hypothesis for the simple regression model was that there is no difference between BIM-based method and conventional takeoff approach in terms of Visualization (H0: $\beta_1=0$). In contrast to the alternative hypothesis, which stated that in terms of Visualization, BIM-based QTO method is different from the Traditional QTO method (H1: $\beta_1 \neq 0$). The null hypothesis was either rejected or failed to be rejected based on a comparison of the p-value for β_1 obtained from the regression model. This

hypothesis is rejected when the p-value for β_1 is less than 0.05. Table 14 displays the coefficient, standard error, t Stat and the p-value form regression analysis.

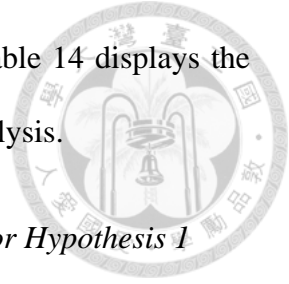


Table 14. Regression Statistic for the simple regression model for Hypothesis 1

	Coefficients	Standard Error	t Stat	P-value	Lower 95.0%	Upper 95.0%
Intercept	2.45	0.131652008	18.60967	5.88E-28	2.187148286	2.712851714
QTO method	1.621428571	0.205164836	7.903053	3.95E-11	1.211803761	2.031053382

a. Dependent Variable: Visualization

The equation of the simple regression model for the independent variable is:

$$\text{Visualization} = 2.45 + 1.621 \times \text{QTO method}$$

Calculations for this Hypothesis 1 yielded a p-value is 0,000, which is less than the alpha of 0,05, signifying that this has sufficient evidence to say that the mean weight between the two QTO method are different. This means the null hypothesis 1 is rejected.

Regression can be broken into two separate regressions as:

$$Y = \begin{cases} 2.45 & \text{when } D = 0 \text{ (Traditional QTO method)} \\ 2.45 + 1.621 & \text{when } D = 1 \text{ (BIM-based QTO method)} \end{cases}$$

There is a non-zero (positive) association between Traditional QTO method and BIM-based QTO method. Based on Traditional QTO approach, the Visualization of BIM-based QTO method increased by 1.62.

For Hypothesis 2, considering the regression model is:

$$Y (\text{Compatibility with Vietnam construction norm}) = \beta_0 + \beta_1 x D (\text{QTO method}) + u$$

The null hypothesis for the simple regression model was that there is no difference between BIM-based method and conventional takeoff approach in terms of Compatibility with Vietnam construction norm (H0: $\beta_1=0$). This hypothesis is rejected when the p-value for β_1 is less than 0.05. Table 15 displays the coefficient, standard error, t Stat and the p-value form regression analysis.

Table 15. Regression Statistic for the simple regression model for Hypothesis 2

	Coefficients	Standard Error	t Stat	P-value	Lower 95.0%	Upper 95.0%
Intercept	3.775	0.1408894	26.79406	3.49E-37	3.4937051	4.0562948
QTO method	-1.6321428	0.219560	-7.43369	2.73E-10	-2.070509	-1.1937764

a. Dependent Variable: Compatibility with Vietnam construction norm.

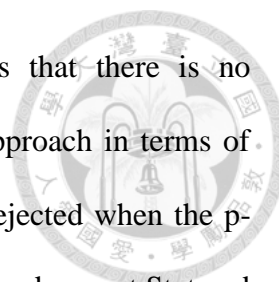
The equation of the simple regression model for the independent variable is:

$$\text{Compatibility with Vietnam construction norm} = 3.775 - 1.632 x \text{QTO method}$$

Calculations for this Hypothesis 2 yielded a p-value is 0,000, which is less than the alpha of 0,05, signifying the null hypothesis 2 is rejected. There is a non-zero (negative) association between Traditional QTO method and BIM-based QTO method. Based on Traditional QTO approach, the Compatibility of BIM-based QTO method decreased by 1.63.

For Hypothesis 3, considering the regression model is:

$$Y (\text{Suitability for quantities appraisal}) = \beta_0 + \beta_1 x D (\text{QTO method}) + u$$



The null hypothesis for the simple regression model was that there is no difference between BIM-based method and conventional takeoff approach in terms of Suitability for quantities appraisal ($H_0: \beta_1=0$). This hypothesis is rejected when the p-value for β_1 is less than 0.05. Table 16 displays the coefficient, standard error, t Stat and the p-value form regression analysis.

Table 16. Regression Statistic for the simple regression model for Hypothesis 3

	Coefficients	Standard Error	t Stat	P-value	Lower 95.0%	Upper 95.0%
Intercept	3.8	0.154268277	24.63241	5.47E-35	3.491993447	4.108006553
QTO method	-1.1571428	0.240409746	-4.81321	9.01E-06	-1.6371364	-0.6771493

a. Dependent Variable: Suitability for quantities appraisal.

The equation of the simple regression model for the independent variable is:

$$\text{Suitability for quantities appraisal} = 3.8 - 1.157 \times \text{QTO method}$$

Calculations for this Hypothesis 3 yielded a p-value is 0,000, which is less than the alpha of 0,05, signifying the null hypothesis 3 is rejected. Based on Traditional QTO approach, the Compatibility of BIM-based QTO method decreased by 1.157.

For Hypothesis 4, considering the regression model is:

$$Y (\text{Reduction in measurement mistakes}) = \beta_0 + \beta_1 \times D (\text{QTO method}) + u$$

The null hypothesis for the simple regression model was that there is no difference between BIM-based method and conventional takeoff approach in terms of Reduction in measurement mistakes ($H_0: \beta_1=0$). This hypothesis is rejected when the p-value for β_1 is less than 0.05. Table 17 displays the coefficient, standard error, t Stat and the p-value form regression analysis.

Table 17. Regression Statistic for the simple regression model for Hypothesis 3

	Coefficients	Standard Error	t Stat	P-value	Lower 95.0%	Upper 95.0%
Intercept	2.025	0.116676329	17.35571	2.72E-26	1.792048193	2.257951807
QTO method	2.010714286	0.181826927	11.0584	1.14E-16	1.647685114	2.373743458

a. Dependent Variable: Reduction in measurement mistakes.

The equation of the simple regression model for the independent variable is:

$$\text{Reduction in measurement mistakes} = 2.025 + 2.011 \times \text{QTO method}$$

Calculations for this Hypothesis 4 yielded a p-value is 0,000, which is less than the alpha of 0,05, signifying the null hypothesis 4 is rejected. Based on Traditional QTO approach, the Compatibility of BIM-based QTO method increased by 2.025.

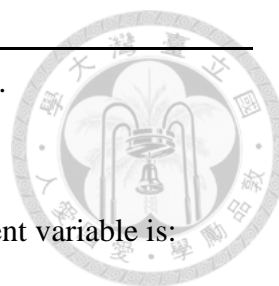
For Hypothesis 5, considering the regression model is:

$$Y (\text{Ability to update and summarize information}) = \beta_0 + \beta_1 \times D (\text{QTO method}) + u$$

The null hypothesis for the simple regression model was that there is no difference between BIM-based method and conventional takeoff approach in terms of Reduction in measurement mistakes ($H_0: \beta_1=0$). This hypothesis is rejected when the p-value for β_1 is less than 0.05. Table 18 displays the coefficient, standard error, t Stat and the p-value form regression analysis.

Table 18. Regression Statistic for the simple regression model for Hypothesis 3

	Coefficients	Standard Error	t Stat	P-value	Lower 95.0%	Upper 95.0%
Intercept	2.125	0.103149799	20.60111	1.89E-30	1.9190547	2.3309452
QTO method	2.160714286	0.160747351	13.44168	1.45E-20	1.8397718	2.4816567



a. Dependent Variable: Ability to update and summarize information.

The equation of the simple regression model for the independent variable is:

$$\text{Ability to update and summarize information} = 2.125 + 2.161 \times \text{QTO method}$$

Calculations for this Hypothesis 5 yielded a p-value is 0,000, which is less than the alpha of 0,05, signifying the null hypothesis 5 is rejected. Based on Traditional QTO approach, the Compatibility of BIM-based QTO method increased by 2.025.

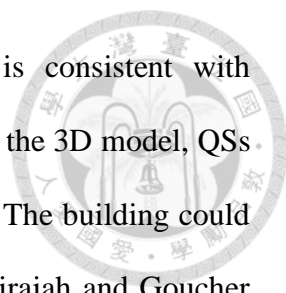
To conclude, all the hypotheses is rejected, which means that BIM-based QTO method is different from Traditional method, in terms of Visualization, Compatibility with Vietnam construction norm, Suitability for quantities appraisal, Reduction in measurement mistakes, and Ability to update and summarize information.

Table 19. Hypotheses testing's results

No	Hypotheses	Coefficients	P-value	Reject/ Fail to Reject
1	Hypothesis 1	1.621429	0.0000	Reject
2	Hypothesis 2	-1.632143	0.0000	Reject
3	Hypothesis 3	-1.157143	0.0000	Reject
4	Hypothesis 4	2.010714	0.0000	Reject
5	Hypothesis 5	2.160714	0.0000	Reject

According to the statistical analysis, the collected data from the survey showed that BIM-based QTO still outperforms 2D QTO approach in some specific sides.

1. Visualization:



The benefits of visualization for QSs were noted; this is consistent with Samphaongen's (2010) assertion that by seeing and interacting with the 3D model, QSs are better able to understand the project in which they are involved. The building could also be analyzed in 3D from every perspective, according to Thurairajah and Goucher (2013), which would help QSs make fewer design assumptions.

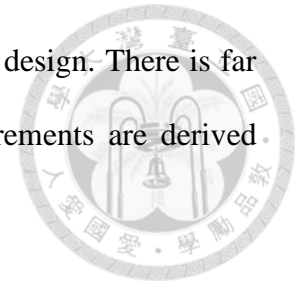
2. Ability to update and summarize information:

Every modification to a project's components or design has an effect on the total cost. Cost adjustments are immediately included into the BIM model via the BIM technique. The information is continuous throughout the course of the project since the takeoffs and measurements are produced straight from the BIM model. Furthermore, the changes made to volume takeoffs are reflected in the associated documentation, timetables, and other metrics used by an estimate. BIM models provide the capacity to distribute data to stakeholders quickly and automatically update modifications. Using conventional approaches, the QS would have had to go through updated documents to find changes.

3. Reduction in measurement mistakes:

During the calculation process, if the design drawing changes, the input data must be re-entered, which easily causes risks such as duplication, omission of measurement and measurement volume. A skilled operator will detect problems that the program misses, including measurement inaccuracies, while entering the data manually. Therefore, even a digital quantity takeoff requires direct interaction, but it may be more quicker, more precise, and contain far more information than a person doing conventional takeoffs on paper or Excel. The application of the BIM 3D model allows

the BIM model to automatically update to represent changes in the design. There is far less danger of measuring too little or too much since the measurements are derived straight from the BIM digital model.



Meanwhile, despite BIM's outstanding benefits, BIM-based QTO method is inferior to traditional methods in some specific aspects. This can explain the reason why traditional QTO method is the most common choice in Vietnam QTO and cost estimation process, instead of BIM method. These criteria below describe the aspects of traditional method that outperforms BIM-based method, which are:

1. In accordance with Vietnam construction norm system:

The cost planning standards system in Vietnam differs significantly from the BIM methods that are currently in use. It is necessary to offer a set of estimations with functional norms in line with the estimated standards issued by the Ministry of Construction when creating estimates for state-funded projects. The Vietnamese estimation guidelines do not follow these standards, and the data in the BIM model is identified in accordance with international standards. Typically, design flaws and the lack of crucial information in BIM models lead to incorrect estimated costs. Meanwhile, in the traditional method, QS engineers can edit, merge or separate the quantities, combined with the technical characteristics of that object to create work codes in accordance with the state's construction norms system. This makes the 2D QTO method is compatible with Industry Standard Cost Planning Formats.

2. Suitable for explanation, verification, and appraisal of quantities:

In Vietnam, quantities and cost estimation of construction projects need to be appraised by State agencies specialized in construction i.e. Department of Construction,

etc in every regions in Vietnam before the construction phase starts. Most of the agencies appraise volumes of the projects by checking and calculating quantities again by using 2D QTO method. Therefore, using BIM-based QTO method to extract volume, will make the process of verification and appraisal difficult, due to different methods. The traditional method would be more suitable for the process to explain, verify and appraise volume in Vietnam.

CHAPTER 5 CASE STUDY



5.1 2D model development

The case study's building structure is a three-story residential construction comprising structural and architectural components. The overall built-up area of the structure is 121.5 m², and the outside measurements of each story are 24.3 meters in length and 5.0 meters in width. There are nine rooms in all, including living areas, kitchens, bedrooms, and bathrooms.

The initial phase in the BIM model development process is the creation of 2D floor layouts for the three-story structure using AutoCAD. The second-floor layout is shown in Fig.21. The remaining floor plans will have a similar layout, however their perspectives will vary slightly. These 2D floor plans were converted to Revit so that architectural 3D BIM models could be created based on them.

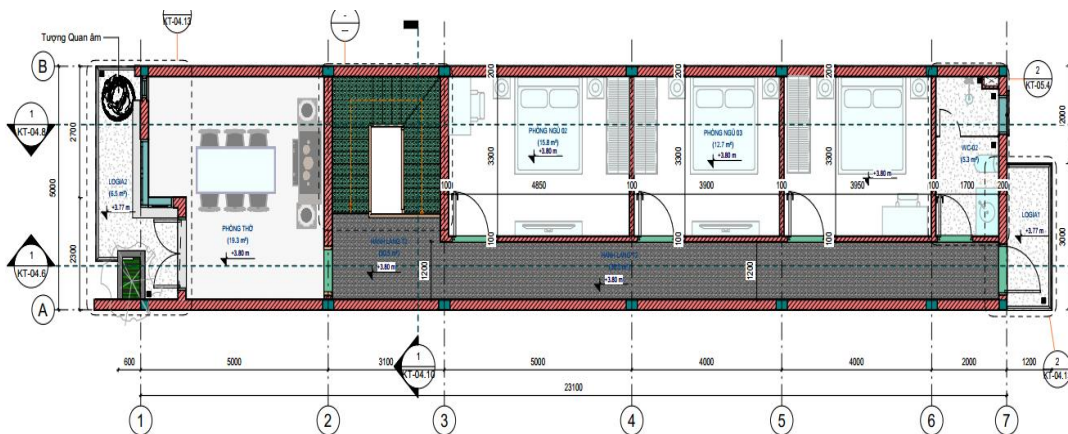


Figure 21. Ground floor plan of the 3-story residential building

In accordance with the 2D floor designs, the column and beam design plans represented in Figures 22 and 23 were also created. This layout design served as the foundation for constructing a 3D BIM model of the structure in Revit Structures.

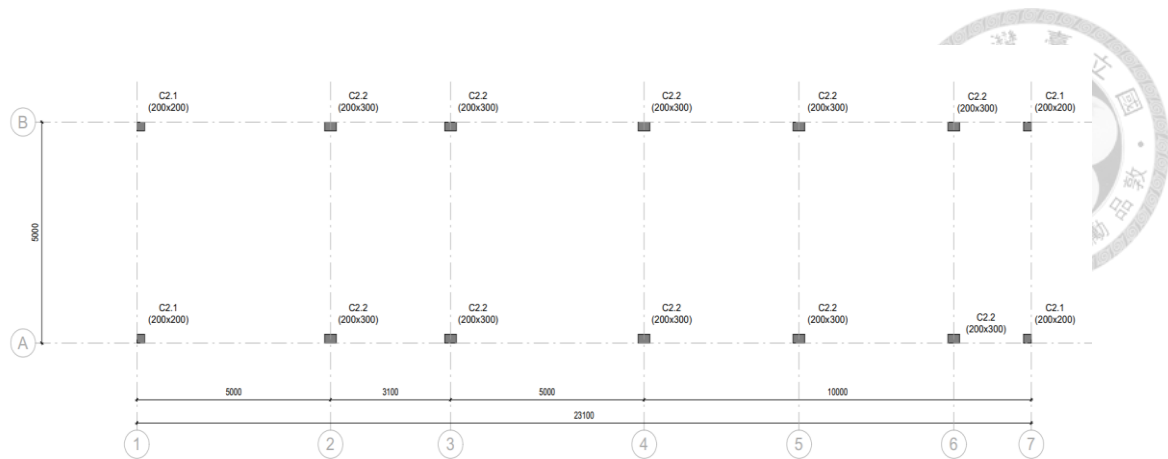


Figure 22. Column layout plan for second floor

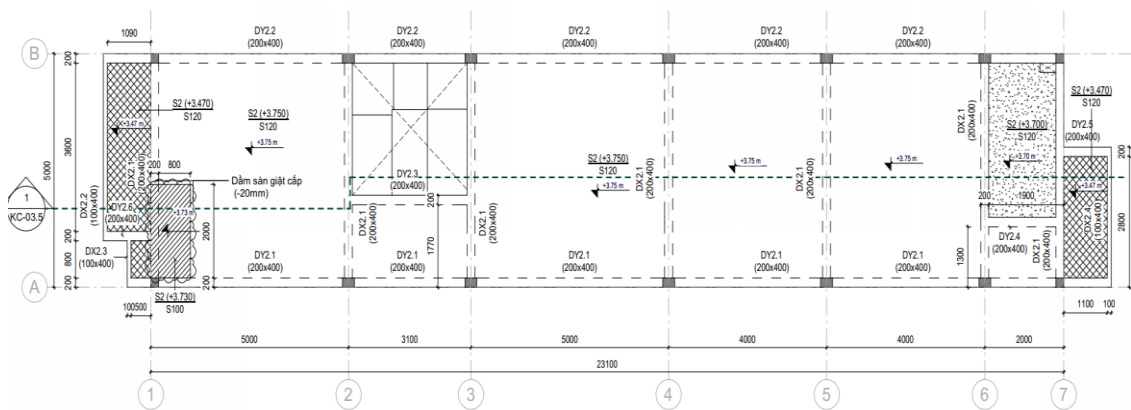


Figure 23. Beam layout plan of second floor

5.2 3D BIM Model Development

Separate architectural and structural 3D models were created.

5.2.1 Architectural 3D BIM Model

The 2D floor plans from AutoCAD were imported into the appropriate levels of Revit to create the 3D architectural model. Using the 2D plans as guidelines, the previous step's essentially graphical plans were transformed into 3D BIM models with both geometrical and nongeometrical features.

Fig.24 depicts the finalized Revit 3D BIM architecture model and its orthographic projections displaying the different viewpoints.

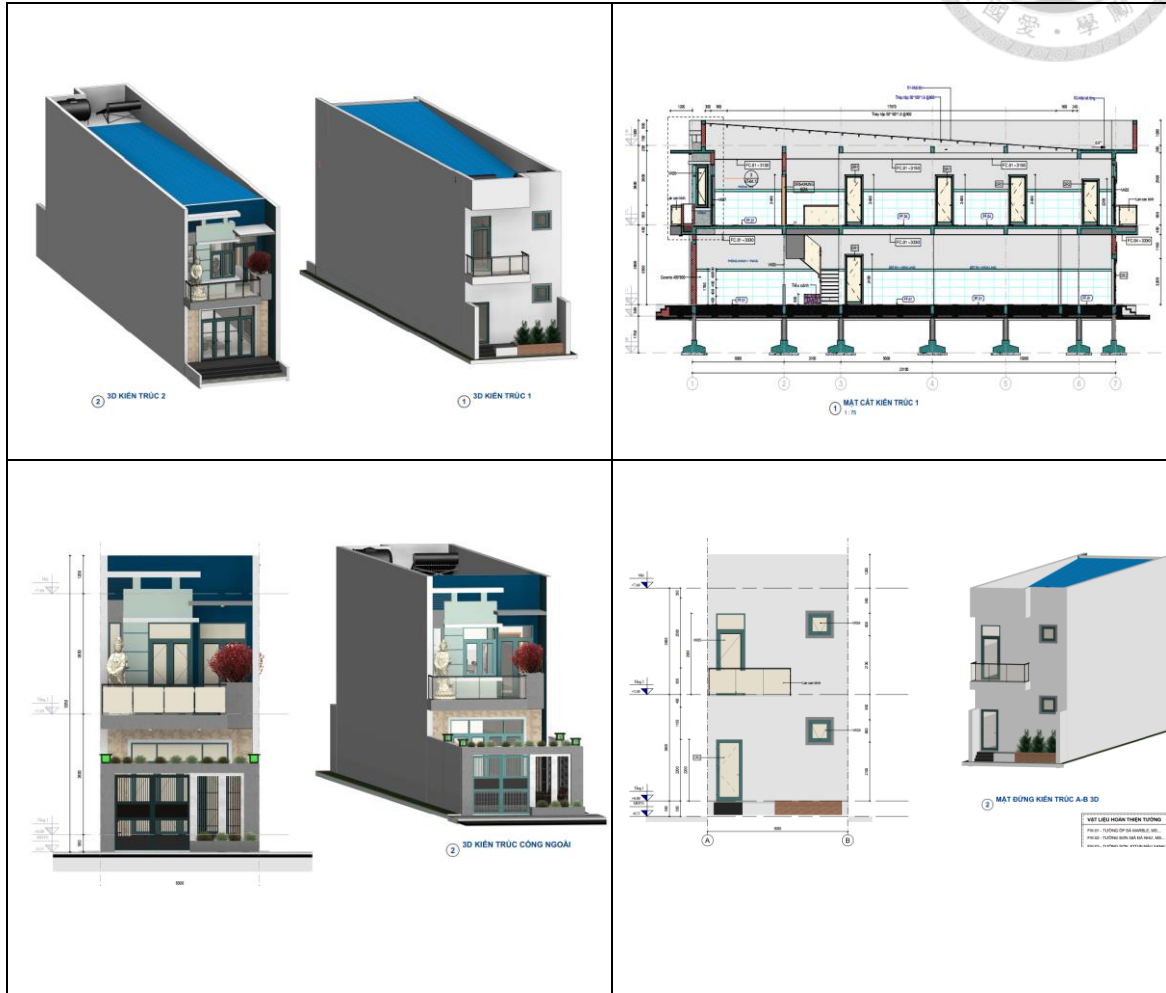
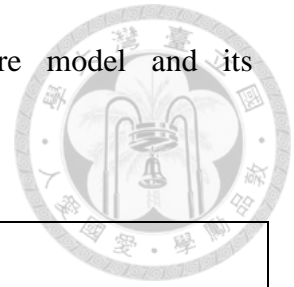


Figure 24. Orthographic projections of architectural 3D BIM model

Using Sketchup and Revit, the 3D model was then produced and displayed to create a realistic architectural 3D model. The completed architectural 3D BIM model is seen in Fig.25.



Figure 25. Visualization of a finished 3D BIM architecture model

A sectional view of the 3D model was produced by adding cutting planes from its three sides, enabling the viewing of interior and other parts that were not visible from the exterior 3D model viewpoint. Figure 26 depicts this.

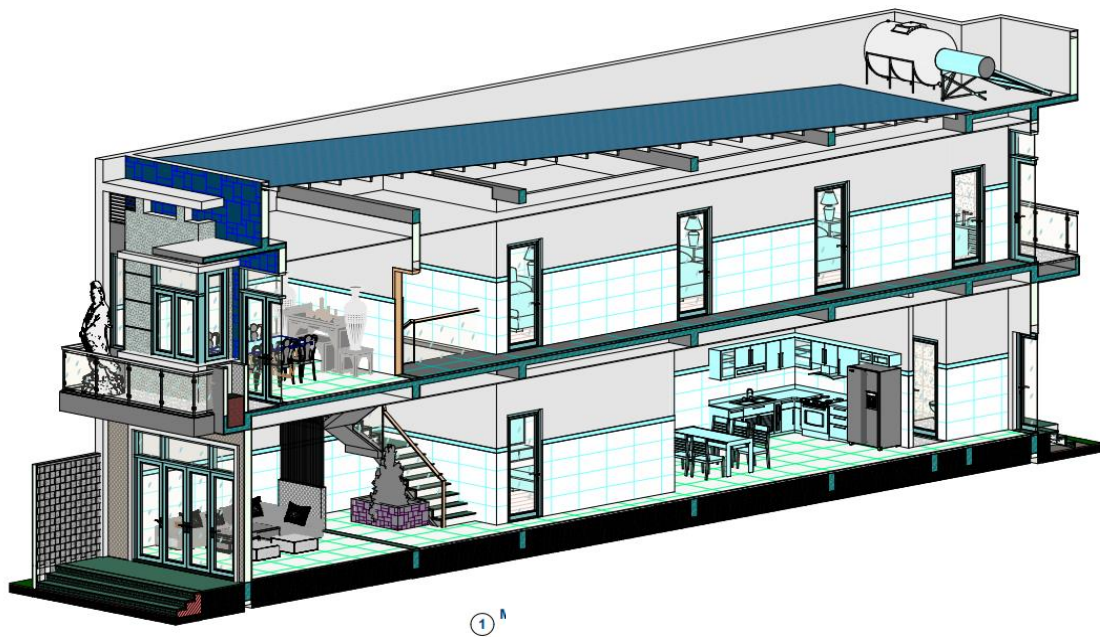
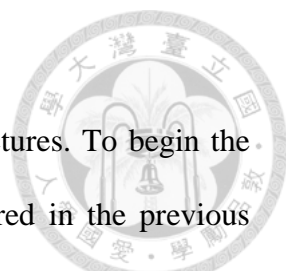


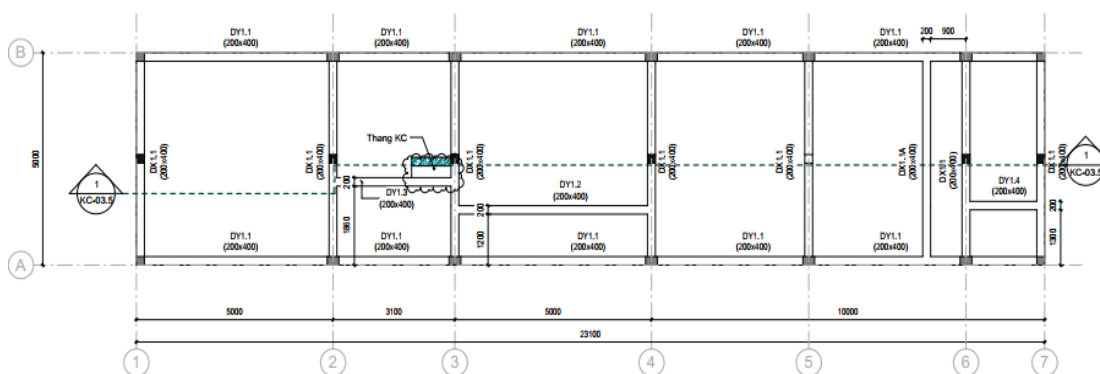
Figure 26. A sectional view of the model



5.2.2 Structural 3D BIM Model

A 3D BIM model of a structure was made using Revit Structures. To begin the 3D modeling, the AutoCAD column layout design that was covered in the previous section is imported into Revit. First defined in Revit were the element sizes and material specifications (foundations, columns, beams, and floors). The 3D BIM components for columns, beams, and foundations were then placed after the imported column layout design. In the image below, this stage is shown.

(a)



(b)

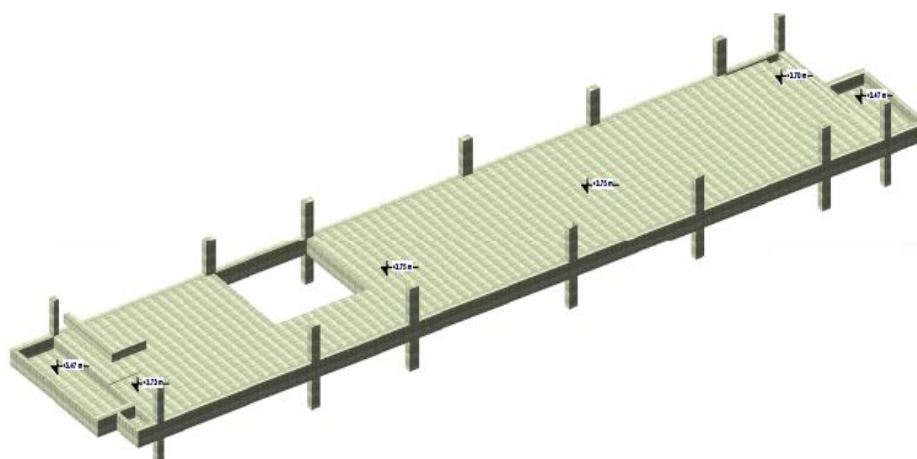


Figure 27. Importing 2D beam layout plan from AutoCAD (a) and beams and slabs for 2nd floor in Revit (b)

After correctly modeling the foundations and columns, beams were inserted between them, and slabs were then placed on top. Figure 28 below shows the finished 3D model.

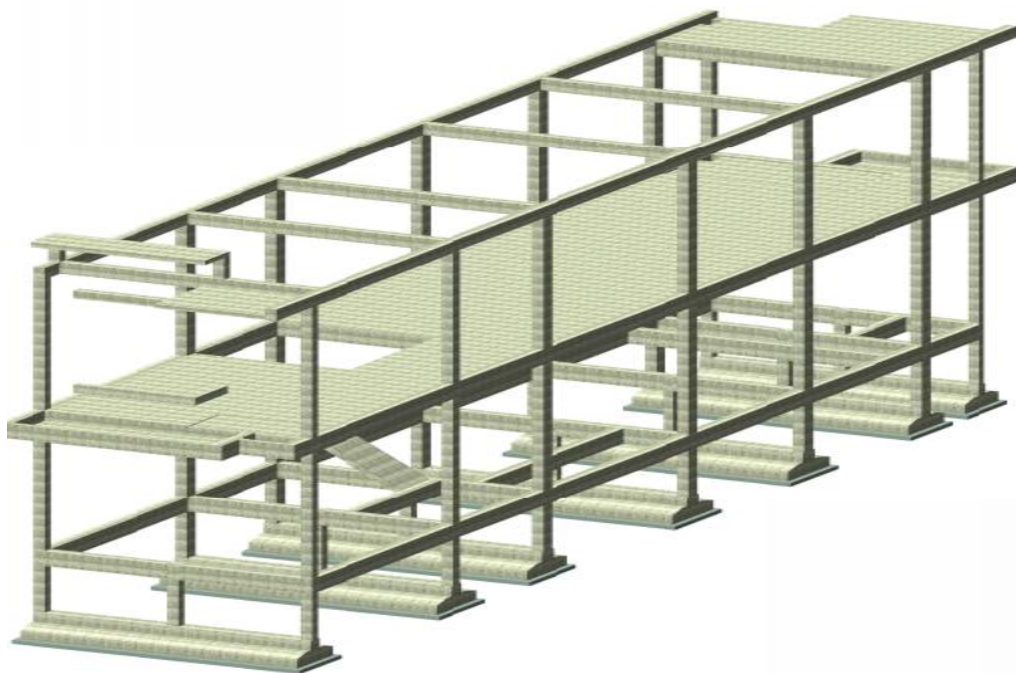
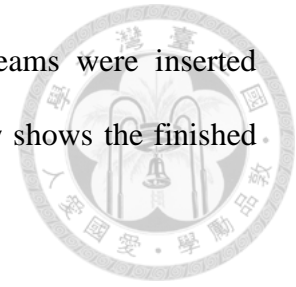
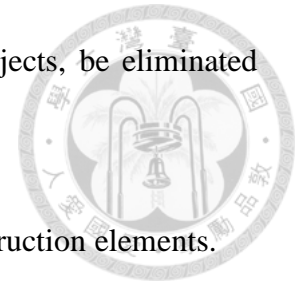


Figure 28. Structural 3D BIM model in Revit

5.2.3 Quality Check of 3D BIM Models

Quality check was performed on 3D BIM models before exporting quantities for BOQ and cost estimation. The 3D BIM model inspection is performed after quantities are obtained from the BIM model by the BIM design/consultant. 3D BIM model is the basis for carrying out the measurement of BIM application, the modeling must comply with certain requirements, in accordance with the objectives of the model. The 3D BIM model needs to meet the following requirements (Construction Economics Magazine, 2020):

- The model must be designed with full necessary BIM objects, be eliminated redundant objects.



- BIM objects must represent the correct function of the construction elements.

- Models (if there is more than one model) must have one co-ordinate.

- The detailed level of BIM objects must ensure to be in accordance with the technical design phase, construction drawing design.

- The model must be designed with enough necessary information of each BIM object, including geometric information (dimensions) and non-geometric information (if any).

The quality evaluation also involves identifying accidents between model components and safety issues (for example, if a safety barrier on a balcony is missing from the 3D model). Solibri Model Checker was used to carry out these quality tests on 3D models (SMC). Fig.6.10 depicts the selected approach for 3D model quality assurance. Following these procedures, further revisions were made to 3D models to address both identified collisions and safety concerns.

As stated previously, quality control was a repetitive process, and the models were modified multiple times until collisions between model components were eliminated and there were no major safety problems.

5.3 Results and Discussion

5.3.1 Preparation of BIM-based Automated QTO

In the chapter on methodology, it was noted that the building model used in the case study of this research does not include MEP works; only structural works are evaluated.

The concrete components take-off procedure is based on the generation of tables of quantities. The tables are flexible, so when any changes are made to the model, the numbers given in the table are updated automatically. The tables may be categorized by type of objects, material, level, or construction industry. Therefore, it is required to pick the information extraction fields. Afterwards, the tables may be exported to Excel, where the user can alter and arrange the information as required.

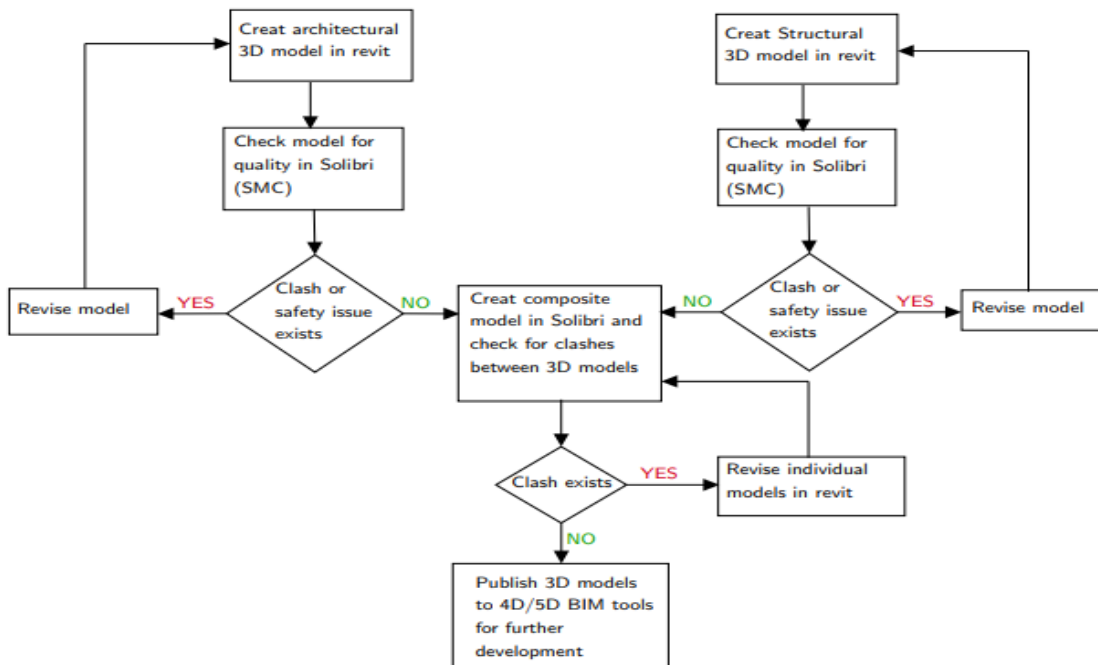
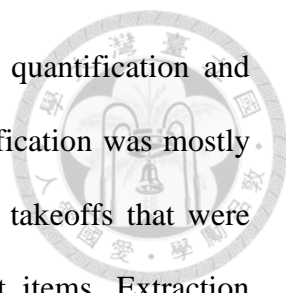


Figure 29. Flow chart showing quality checking and 3D BIM modeling procedure prior to exporting quantities for BOQ and cost estimation



The cost estimate was based mostly on two processes: the quantification and pricing of used resources on project tasks. The procedure of quantification was mostly based on model-based takeoffs; however, non-model-based digital takeoffs that were deemed relevant for the estimate were also performed for select items. Extraction numbers for foundations, for example, were not model based since they were not included in the 3D BIM model.

5.3.2 Comparison of QTO Results

This research only discussed and compared the quantity in the design phase, not the construction phase, hence this study could not compare the QTO results with the actual quantity. In this section of the thesis, the quantities of the modeled components in the scope of the case study derived using Revit and the quantities obtained from 2D drawings (traditional approach) are compared, and the variations in the findings are examined.

5.3.2.1 Comparison of Column Quantity Take-off

The concrete quantity and reinforcing steel of columns are derived using the Revit model and the conventional approach. Additionally, a comparison table displaying the amounts and their discrepancies is produced. According to the numbers recorded on the project's blueprints, the columns were already labeled. Therefore, comparisons may be conducted independently for each column. Tables 20 and 21 include information on column levels, column names, amounts, the difference between quantities, and the ratio of total variations. The comparison table only displays columns with differing concrete volume and reinforcing steel numbers. There are a total of 14 columns on the second level, and only the columns with differing values are manually inspected and verified.

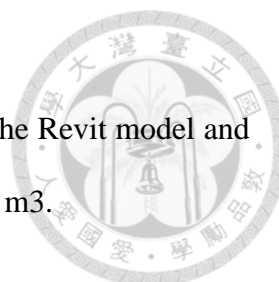


Table 20. Comparison of column concrete volumes volume between Revit model before revised and Traditional method (m3)

Level	Column Name	Concrete Volume (m3) Revit before revised	Concrete Volume (m3) Traditional method	Difference of Concrete Volumes (m3) Revit before revised - Traditional method
2nd Floor	C2.1	0,56	0,56	0,00
2nd Floor	C2.2	2,10	2,10	0,00
Total		2,66	2,66	0,00
Ratio of difference (%)		0,0%		

Table 21. Comparison of column reinforcement weight volume between Revit model before revised and Traditional method (kg)

Level	Column Name	Steel Weight (kg) Revit before revised	Steel Weight (kg) Traditional method	Difference of Steel Weight (kg) Revit before revised - Traditional method
2nd Floor	C2.1	110,81	110,26	0,55
2nd Floor	C2.2	326,11	405,81	-79,7
Total		436,92	516,06	-79,14
Ratio of difference (%)		-18,1%		



The discrepancy between the concrete volume of columns in the Revit model and the amount retrieved using the traditional approach is 0.00%, or 0.00 m³.

The comparative table shows that there are variations in the steel weight of 14 columns. Examining the causes of the reinforcement discrepancies reveals that all 14 of them result from errors in the Revit modeling process. Figure 30 is an example of a modeling error in a Revit model that involves the placement of steel in the incorrect location. Normally, the range of placing and spreading Steel Belt for columns is only placed from the base of the column to the bottom of the upper beam. Meanwhile in this model, some of the column Steel Belts are placed within the beam area, which this error causes the extra quantity on reinforcement volume.

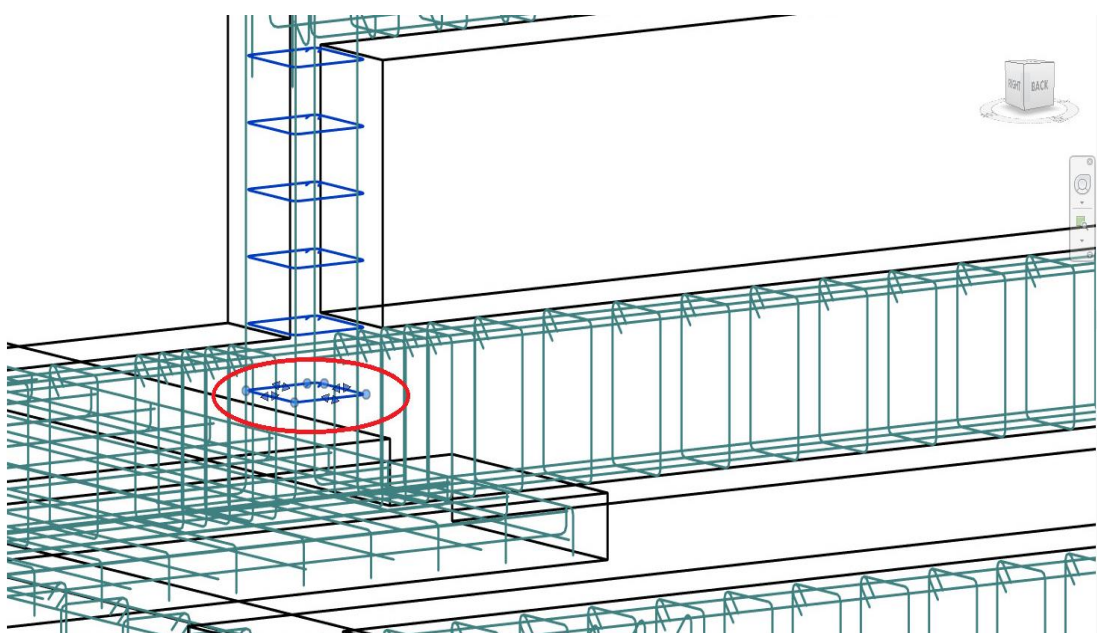


Figure 30. Model design error: Placing Steel Belt in the wrong position (in Beam area)

After correcting this modeling mistake, the overall reinforcement weight of columns in the Revit model is 2.39kg more than the manual technique, with a difference ratio of 0.5%. All disparities may be attributed to human mistake, and if these faults are

removed, there is no difference in volumes. Accordingly, it can be concluded that the concrete volume and reinforcing volume numbers produced from the Revit model for the columns are as precise as the old technique and can be relied upon throughout project execution.

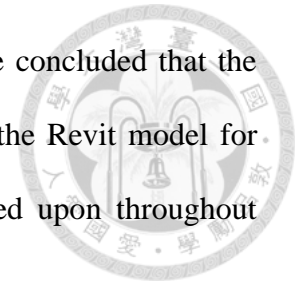


Table 22. Comparison of column concrete volumes between Revit model after revised and Traditional method (m3)

Level	Column Name	Concrete Volume (m3) Revit after revised	Concrete Volume (m3) Traditional method	Difference of Concrete Volumes (m3) Revit after revised - Traditional method
2nd Floor	C2.1	0,56	0,56	0,00
2nd Floor	C2.2	2,10	2,10	0,00
Total		2,66	2,66	0,00
Ratio of difference (%)		0,0%		

Table 23. Comparison of column reinforcement weight between Revit model after revised and Traditional method (kg)

Level	Column Name	Steel Weight (kg) Revit after revised	Steel Weight (kg) Traditional method	Difference of Steel Weight (kg) Revit after revised - Traditional method
2nd Floor	C2.1	110,81	110,26	0,55
2nd Floor	C2.2	407,64	405,81	1,83
Total		518,45	516,06	2,39
Ratio of difference (%)		0,5%		

5.3.2.2 Comparison of Beam Quantity Take-off

From the Revit model, the concrete volume and reinforcing steel of beams are retrieved, and a comparison table displaying the values and their differences is created. By naming the beams according to the numbers inscribed on the project, it was possible to compare each beam individually. Tables 24 and 25 provide information on beam level, beam name, quantity, quantity difference, and ratio of total difference. The table is sorted such that only beams with distinct amounts are shown. There are a total of 16 beams in the structure, and only beams with varied amounts are manually evaluated and verified. As may be observed in the comparative table, the concrete volumes of 02 beams varied. The variations in concrete volume are investigated, and it is determined that two of the variances are due to modeling errors in the Revit model.

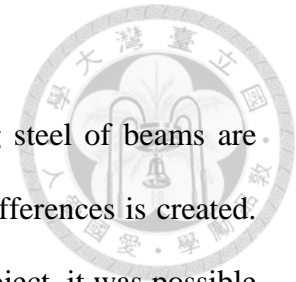
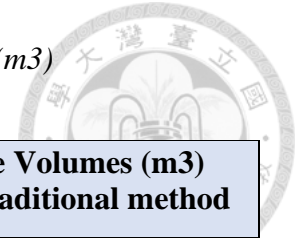


Table 24. Comparison of beam concrete volume between Revit model before revised and Traditional method (m3)

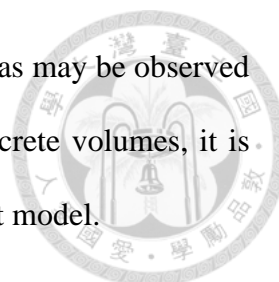


Level	Beam Name	Concrete Volume (m3) Revit before revised	Concrete Volume (m3) Traditional method	Difference of Concrete Volumes (m3) Revit before revised- Traditional method
2nd Floor	DX2.1	2,11	2,58	0,00
2nd Floor	DX2.2	0,14	0,14	0,00
2nd Floor	DX2.3	0,03	0,03	0,00
2nd Floor	DX2.4	0,10	0,10	0,00
2nd Floor	DY2.1	1,98	1,99	0,00
2nd Floor	DY2.2	1,90	1,94	-0,01
2nd Floor	DY2.3	0,16	0,23	0,00
2nd Floor	DY2.4	0,09	0,14	-0,05
2nd Floor	DY2.5	0,10	0,10	0,00
2nd Floor	DY2.6	0,08	0,10	0,00
Total		6,70	7,35	-0,65
Ratio of difference (%)		-9,7%		

Table 25. Comparison of beam reinforcement weight between Revit model before revised and Traditional method (kg)



Level	Beam Name	Steel Weight (kg) Revit before revised	Steel Weight (kg) Traditional method	Difference of Steel Weight (kg) Revit before revised - Traditional method
2nd Floor	DX2.1	511,08	507,54	3,54
2nd Floor	DX2.2	31,01	30,78	-0,27
2nd Floor	DX2.3	10,86	11,23	-0,37
2nd Floor	DX2.4	23,4	23,78	-0,37
2nd Floor	DY2.1	250,68	254,44	-3,76
2nd Floor	DY2.2	243,12	229,27	13,86
2nd Floor	DY2.3	34,19	28,61	5,58
2nd Floor	DY2.4	18,59	19,09	-0,5
2nd Floor	DY2.5	13,19	13,94	-0,75
2nd Floor	DY2.6	13,21	13,94	-0,73
Total		1148,73	1132,63	16,07
Ratio of difference (%)		1,40%		



There are discrepancies in the concrete volumes of 02 beams, as may be observed in the comparison table. Examining the causes of variations in concrete volumes, it is found that two of the variations are from modeling errors in the Revit model.

There are two kinds of beam lengths computed by Revit. One is full length, while the other is cut length. The distance between the points used while modeling a beam determines its length, which varies based on the modeling approach. The length is calculated from column centre point to column centre point if points are chosen from the centers of the columns. The sites chosen during modeling have no bearing on cut length, which is the actual length of the beam. A beam with an unequal length and cut length is shown in Figure 31. During comparison, the cut length of beams is taken into consideration.

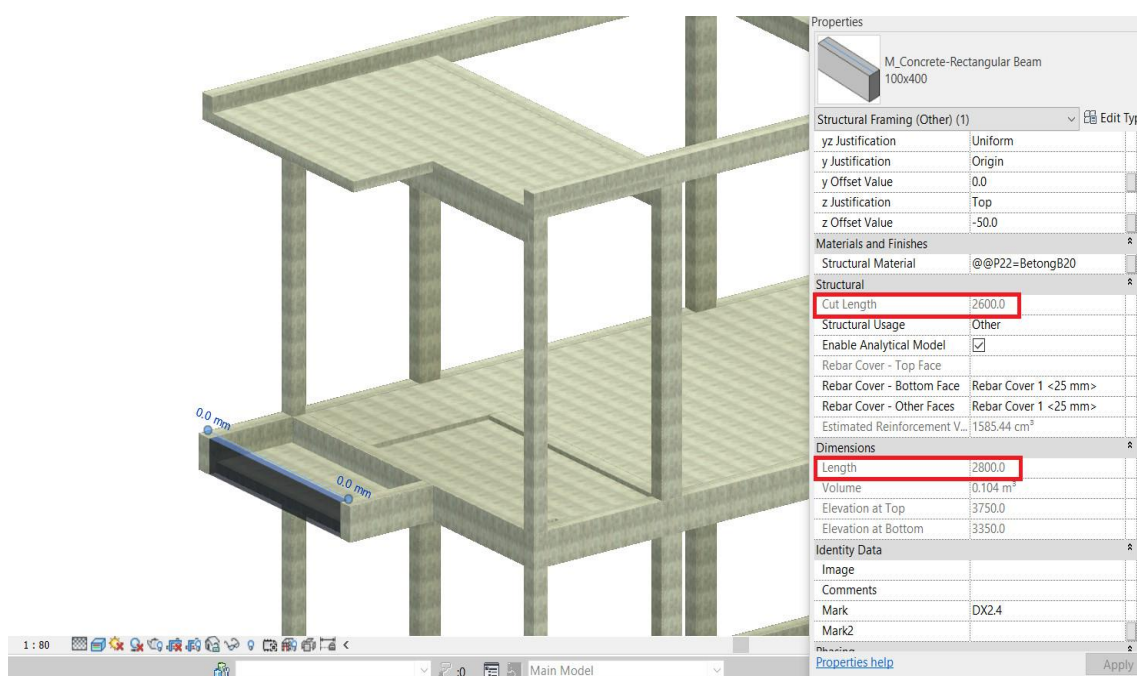


Figure 31. Beam having Unequal Length and Cut Length

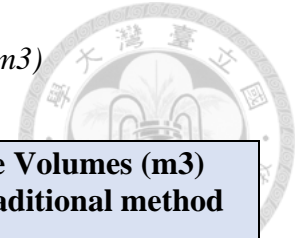
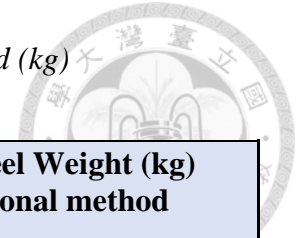


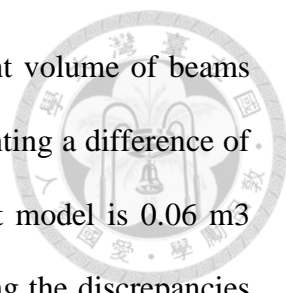
Table 26. Comparison of beam concrete volume between Revit model after revised and Traditional method (m3)

Level	Beam Name	Concrete Volume (m3) Revit after revised	Concrete Volume (m3) Traditional method	Difference of Concrete Volumes (m3) Revit after revised - Traditional method
2nd Floor	DX2.1	2,58	2,58	0,00
2nd Floor	DX2.2	0,14	0,14	0,00
2nd Floor	DX2.3	0,03	0,03	0,00
2nd Floor	DX2.4	0,10	0,10	0,00
2nd Floor	DY2.1	1,99	1,99	0,00
2nd Floor	DY2.2	1,93	1,94	-0,01
2nd Floor	DY2.3	0,23	0,23	0,00
2nd Floor	DY2.4	0,09	0,14	-0,05
2nd Floor	DY2.5	0,10	0,10	0,00
2nd Floor	DY2.6	0,10	0,10	0,00
Total		7,29	7,35	-0,06
Ratio of difference (%)		-0,85%		

Table 27. Comparison of beam reinforcement weight between Revit model after revised and Traditional method (kg)



Level	Beam Name	Steel Weight (kg) Revit	Steel Weight (kg) Traditional method	Difference of Steel Weight (kg) Revit - Traditional method
2nd Floor	DX2.1	511,08	507,54	3,54
2nd Floor	DX2.2	30,39	30,78	-0,39
2nd Floor	DX2.3	10,85	11,23	-0,38
2nd Floor	DX2.4	23,40	23,78	-0,38
2nd Floor	DY2.1	250,68	254,44	-3,76
2nd Floor	DY2.2	243,12	229,27	13,85
2nd Floor	DY2.3	34,19	28,61	5,58
2nd Floor	DY2.4	18,59	19,09	-0,50
2nd Floor	DY2.5	13,19	13,94	-0,75
2nd Floor	DY2.6	13,21	13,94	-0,73
Total		1148,70	1132,63	16,07
Ratio of difference (%)		1,40%		

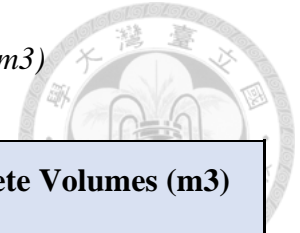


After modeling mistakes correction, the overall reinforcement volume of beams in the Revit model is 16,70 kg more than the old technique, representing a difference of 1.40%. In addition, the concrete volume of the beams in the Revit model is 0.06 m³ smaller than the manual technique, with a ratio of -1.85%. Analyzing the discrepancies reveals that the largest variance in concrete and reinforcing amounts comes from Revit model errors. After modeling errors are corrected, the ratio between the difference in concrete and steel volumes is almost same. Eventually, concrete volumes derived from a BIM model and reinforcement volumes derived from a BIM model are correct and may be utilized effectively, however steel reinforcement volumes derived from a Revit model must be validated and confirmed throughout project execution.

5.3.2.3 Comparison of Floor Quantity Take-off

The concrete volume and reinforcing steel of floor slabs are obtained from the Revit model and conventional technique, and a comparison table is then prepared to demonstrate the numbers and their discrepancies. Floors are labeled according to the numbers listed on the project's designs, allowing for individual comparisons of each level. Tables 28 and 29 provide information on floor levels, floor names, elevation, slab thickness, amounts, quantity discrepancies, and ratio of total quantity differences.

Table 28. Comparison of slab concrete volume between Revit model before revised and Traditional method (m3)



Level	Slab Name	Upper Elevation	Slab Thick (mm)	Concrete Volume (m3)		Difference of Concrete Volumes (m3)
				Revit before revised	Traditional method	Revit before revised - Traditional method
2nd Floor	S2	3.470	120	0,54	0,52	0,01
2nd Floor	S2	3.470	120	0,34	0,37	-0,03
2nd Floor	S2	3.700	120	0,68	0,67	0,01
2nd Floor	S2	3.750	120	10,60	10,02	0,58
2nd Floor	S2	3.750	100	0,20	0,16	0,04
Total				11,75	11,74	0,62
Ratio of difference (%)				5,0%		

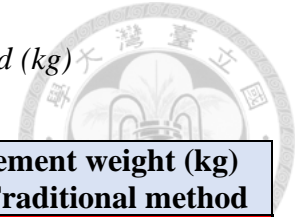
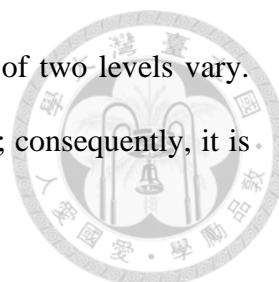


Table 29. Comparison of slab reinforcement weight between Revit model before revised and Traditional method (kg)

Bar mark	Diameter (mm)	Reinforcement Weight (kg) Revit before revised	Reinforcement Weight (kg) Traditional method	Difference of Reinforcement weight (kg) Revit before revised - Traditional method
1	8	56,44	66,84	-10,40
2	10	69,88	81,57	-11,69
3	10	16,87	11,22	5,65
4	10	14,23	10,73	3,50
5	8	13,11	20,17	-7,06
6	8	10,10	7,84	2,26
7	10	329,87	296,06	33,81
8	10	20,98	17,29	3,69
9	10	151,84	151,91	-0,07
10	10	144,20	114,92	29,28
11	8	274,81	246,36	28,45
12	8	17,00	14,28	2,72
13	8	126,72	124,63	2,09
14	8	119,38	99,57	19,81
15	10	23,29	16,40	6,89
16	10	3,70	2,47	1,23
17	10	8,13	14,43	-6,30
18	8	18,77	13,22	5,55
19	8	3,04	1,75	1,29
20	8	8,48	12,12	-3,64
Total		1430,84	1430,84	107,06
Ratio of difference (%)				7,5%



According to the table of comparison, the concrete volumes of two levels vary. The difference between the volumes of concrete is less than 0.05 %; consequently, it is insignificant.

Regarding Table 29, the reinforcing volume of the majority of rebar flooring varies. The variations in rebar volume amounts are analyzed, and it is determined that they are all the result of modeling errors in the Revit model. All variances are the consequence of improper placement of steels. Figure 32 shows an example of incorrect position of steel. Focusing on the Longitudinal reinforcement for slab, the placing range of these steels are only in small floor cells (limited by the surrounding beams). Means that, its position is only the x (m) segment. However, the Revit modeler placed the steel within the range of the beam, which is in the y (m) segment.

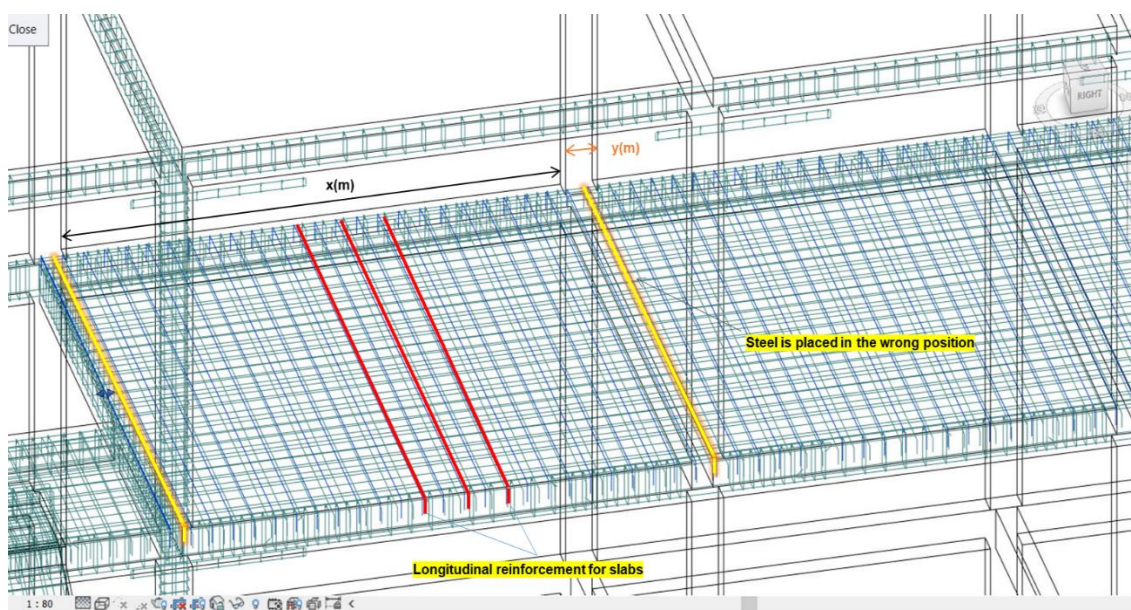


Figure 32. Placing Longitudinal Steel in the wrong position (in Beam area)

Consequently, the total concrete volume of floors in the Revit model is only 0.01 m³ less than the quantities obtained by hand, with a ratio of difference of 0.05 percent, and the reinforcement volume of floors in the Revit model is 98.76 kg more than

traditional method, with a ratio of difference of 6.94 percent. Calculation mistakes of the formwork area tool account for the majority of the variance in quantity of formwork area. The difference in reinforcement amounts is more than %; hence, it is significant. Modeling inaccuracies may result in higher variations across structures. Eventually, concrete volumes and steel numbers derived from a BIM model are as precise as the old technique and can be relied upon, however reinforcement values derived from a Revit model must be verified before to their usage during the project's execution.

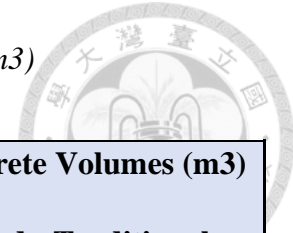
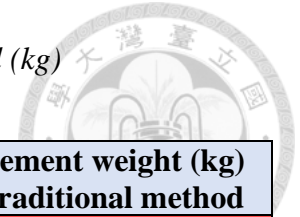


Table 30. Comparison of slab concrete volume between Revit model after revised and Traditional method (m3)

Level	Slab Name	Upper Elevation	Slab thick (mm)	Concrete Volume (m3)		Difference of Concrete Volumes (m3)
				Revit after revised	Traditional method	Revit after revised - Traditional method
2nd Floor	S2	3.470	120	0,52	0,52	0,00
2nd Floor	S2	3.470	120	0,34	0,37	-0,03
2nd Floor	S2	3.700	120	0,67	0,67	0,00
2nd Floor	S2	3.750	120	10.06	10,02	0,04
2nd Floor	S2	3.750	100	0,16	0,16	0,00
Total				11,75	11,74	0,01
Ratio of difference (%)				0,05%		

Table 31. Comparison of slab reinforcement weight between Revit model after revised and Traditional method (kg)



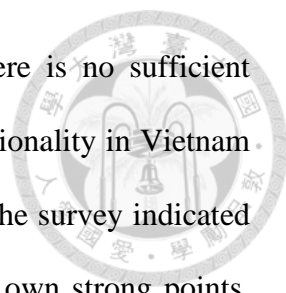
Bar mark	Diameter (mm)	Reinforcement Weight (kg) Revit after revised	Reinforcement Weight (kg) Traditional method	Difference of Reinforcement weight (kg) Revit after revised - Traditional method
1	8	56,20	66,84	-10,64
2	10	69,53	81,57	-12,03
3	10	16,58	11,22	5,36
4	10	14,11	10,73	3,38
5	8	12,91	20,17	-7,26
6	8	11,28	7,84	3,43
7	10	337,95	296,06	41,89
8	10	22,10	17,29	4,81
9	10	151,63	151,91	-0,29
10	10	129,68	114,92	14,76
11	8	277,73	246,36	31,37
12	8	17,65	14,28	3,37
13	8	126,57	124,63	1,95
14	8	110,14	99,57	10,57
15	10	22,92	16,40	6,52
16	10	3,61	2,47	1,14
17	10	10,78	14,43	-3,65
18	8	18,51	13,22	5,29
19	8	2,55	1,75	0,79
20	8	10,12	12,12	-2,00
Total		1422,56177	1323,79	98,76
Ratio of difference (%)				6,9%

CHAPTER 6 CONCLUSION



The estimation of construction costs is a crucial part of the project lifecycle. Quantity takeoff is one of the largest and most significant components involved in the process of cost estimating. As time passes, building projects become more complicated and harder to manage, and the construction industry seeks to improve procedures such as quantity take-off. Typically, numbers are determined manually with 2D CAD drawings and CAD software. This conventional procedure needs an excessive amount of time and effort, and it is also prone to mistake since the majority of its steps are reliant on human intervention. Today, BIM is beginning to be extensively utilized to suit industrial needs, such as enhancing procedures like quantity take-off. However, research indicates that the adoption of BIM for building projects still faces obstacles owing to the gap between the automated BIM process and estimating traditions. In addition, the building sector has the challenge of obtaining precise amounts in a quicker and simpler manner. Consequently, the purpose of this research is to evaluate the efficacy of the traditional technique and the BIM-based QTO method in the cost estimating process, based on the applicability of both methods and the precision of the take-off outcomes.

To conduct a comparison in terms of the method's suitability, the five functionalities were identified and regarded as the main reasons to compare between BIM-based takeoff and Traditional method, which are Good Visualization, In accordance with the Vietnam construction norm system, Suitable for explanation, verification, and appraisal of quantities, Reduction of measurement mistakes, Easy to update and synthesize information. The survey was distributed in two groups to find out their perspective of each group: Group 1 applying Traditional method, Group 2

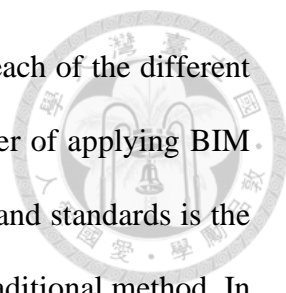


applying BIM-based takeoff method. The survey showed that there is no sufficient evidence to determine that Traditional QTO method has better functionality in Vietnam cost estimation process, over than BIM-based approach. However, the survey indicated that BIM-based method and Manual QTO method both have their own strong points. BIM-based takeoff technique surpasses manual takeoff measurement in terms of Visualization, Reduction of measurement mistakes, and Easy to update and synthesize information. Meanwhile, these functions “In accordance with Vietnam construction norm system” and “Suitable for explanation, verification, and appraisal of quantities” are the aspects that made Conventional takeoff method defeats the BIM-based method. This can be explained why the manual method using 2D drawings is currently the most popular method in use, instead of Automated BIM-based method.

To conduct a comparison regarding the accuracy of extracted quantities, a case study was conducted by designing selected construction items of a building with Autodesk Revit 2017 and comparing the obtained quantities with the quantities extracted from the Traditional method, which is created by a Quantity Surveyor. The needed procedures for obtaining precise quantities for each building component are studied, and the QTO results of several BIM software packages are evaluated in depth. This case study's outcomes are the results of a comparison between the produced quantities from the Revit model and the manual technique (2D drawings):

Concrete volume of these structural elements (columns, beams, and slabs) obtained from Revit model are accurate after rectifying modeling mistakes.

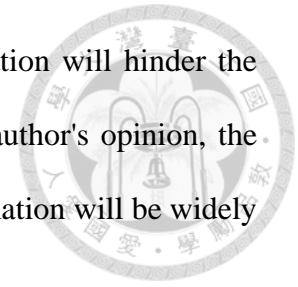
Reinforcement quantities of the structural elements (columns, beams, and slabs) extracted from Revit model are accurate after model design errors are resolved.



Hence, a definite conclusion was drawn from this study that each of the different QTO methods has its own advantages and disadvantages. The barrier of applying BIM in accordance with the current Vietnam legal system, norm system, and standards is the most major disadvantages, which this barrier can be overcome by Traditional method. In addition, it also does not meet the needs of explanation, verification and appraisal of the project's volume (especially for projects using state budget capital). However, BIM will be an effective tool for the task of taking off the volume more quickly and accurately when it can eliminate the subjective errors of the measurer, increase the 3D visualization of the project, easily control and update project information. Moreover, the quantities derived from the BIM model are, in the majority of circumstances, as accurate as conventional methods and are unaffected by human mistake in the QTO process, assuming the modeling process was conducted properly. If the modeling process was completed properly, the results returned from the BIM model are, in most situations, as accurate as conventional methods and are unaffected by human mistake in the QTO process. This research only discussed and compared the quantity in the design phase, not the construction phase, hence this study could not compare the QTO results with the actual quantity. However, applying BIM in the design phase can be suggested as it can significantly improve the accuracy of the quantity. In order to develop a clear and optimum plan before the actual construction, this detail-oriented model may provide improved visualization of design models, cost data during the planning stage, and the ability to prevent expensive errors during the construction phase. It provides "what-if" scenarios to aid in better planning by letting the team see the effects of any timetable adjustments and better allocating resources.

BIM is the development trend of the construction industry, the process of implementing construction projects is the cooperation and participation of many

stakeholders, then the process of manual measurement and estimation will hinder the process of BIM coordination and development. According to the author's opinion, the application of BIM in general and BIM in quantity takeoff and estimation will be widely applied in Vietnam when its benefits are increasingly recognized.



CHAPTER 7 LIMITATION AND RECOMMENDATION FOR FUTURE WORK



The study's limitations are outlined as follows:

- Regarding samples, the sample size of 68 respondents is insufficient for statistical analysis to provide meaningful findings.

- This study only discussed the quantity in the design phase, not the construction phase, so the quantity from Revit and manual method could not be compared to the actual quantity.

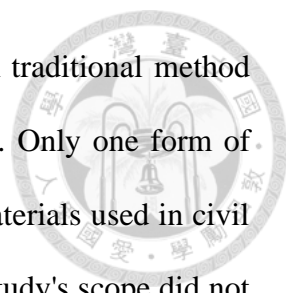
- The accuracy of quantities from Traditional takeoff method depends on the experience of the Quantity Surveyors.

- Concerning the nature of study technique, it should be emphasized that the questionnaire survey may have acquired biased data due to the respondents' own biases or lack of information. No interviews are conducted, which therefore limits the survey findings.

- Quantities are considered as accurate if there is no difference between quantities derived from Revit model and Traditional 2D technique.

- Designers of the project develop the Revit model and submit the quantities. Therefore, it is believed that the model was developed using the appropriate modeling techniques for QTO and estimates regulatory.

Finally, the continuation of the study of BIM-based QTO method's suitability for adoption in Vietnam cost estimation process can be deeply investigated about standardization and appropriate testing procedure for BIM model before extracting quantities.

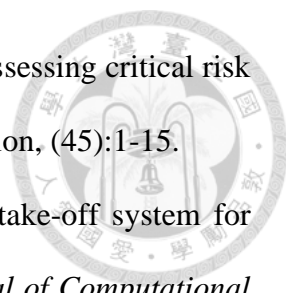


This research focuses on comparing quantities obtained from traditional method and BIM-based QTO method to assess the reliability of the results. Only one form of building (the RC building) and a small subset of the construction materials used in civil work are chosen to be compared for this purpose. For instance, the study's scope did not address SRC or SC structures, or some components like formwork elements, exterior and interior finishing work items.

For the future work, the future work can choose a case study with full information with completed quantity from design phase to the construction phase, to make the case study more objective and accurate. Additionally, amounts of these building types and other objects that were beyond the study's scope may be compared and evaluated. As a result, the building's structure and its components would be compared more often.

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