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BIM-BASED SIMPLIFIED APPROACH TO AUTOMATICALLY ESTIMATE BUILDING COSTS FOR PROJECTS IN THAILAND

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ABSTRACT: Cost estimating is a significant and critical phase of construction projects. Traditional cost estimating methods count on 2D drawings and human interpretation resulting in time-consuming and prone to errors. Emerging Building Information Modeling (BIM) is a process that can enhance the quantity takeoff and cost estimating with a higher level of accuracy. BIM-based cost estimating approaches can be done by integrating 3D BIM with BIM-based estimating software. These approaches are complicated, expensive, and required skilled-personnel to reap the full benefits from every estimating tools integrating with the external database. This research presents a developed BIM algorithm that is capable of automatically estimating building costs. 3D BIM intelligent objects were integrated with a custom built database with specialized templates, thereby providing ease of use while eliminating the need to manually re-enter cost changes. This algorithm creates a list of the specialized work breakdown structure (WBS) containing construction specifications, and unit costs, based on the Thai standard system. A typical BOQ was generated from the 3D BIM case study and linked to the specialized templates that automatically estimate building cost. Estimating costs of the traditional and BIM-based approaches were compared and showed approximately closed value. This research offers a simplified but essential BIM-based cost estimating algorithm for Small and Medium Enterprises (SMEs) with a simple, fast and accurate process.

Keywords: Building information modeling, Bill of quantity, Quantity takeoff, Cost estimates

1. INTRODUCTION

Construction cost estimating is a complicated, time-consuming and error-prone process. It is one of the significant and critical phases of construction projects. Traditionally applied cost estimating methods are performed that the process relied heavily on 2D drawings and human interpretations for generating the quantity takeoff (QTO): every single building element is measured and counted then inputted onto excel platforms to keep an inventory of all items and produce a bill of quantity (BOQ) [1]. Eastman [2] mentioned that using traditional methods are usually missed interpretations and incorrect inputs because of the hard process and complex relationships between large amounts of building elements.

In Thailand, traditional cost estimating method is still using manually quantity takeoff based on a spreadsheet of BOQ according to Thailand's Comptroller General Department (CGD), Ministry of Commerce's format. The BOQ based on the CGD format is still required for bidders in every government building work.

In the modern information technology, Building Information Modeling (BIM) is a high tech process being used in different construction aspects such as visualization, simulation, cost estimation, facility management, and construction project lifecycle [3]. As a visualized database of building elements, BIM is able to offer an accurate QTO process as well as facilitate to decrease the variation of the cost estimations [4].

This research presents a BIM algorithm that automatically estimates building costs based on BIM 3D models that integrate with custom built databases and specialized templates. This approach will facilitate ease of use without the need for updating unit costs in BIM applications; also it is capable of enhancing BIM-based QTO process and automatically estimating costs. This research offers a BIM-based simplified approach with an essential process based on the CGD format for AEC industry and SMEs use to implement in their building construction projects in order to increase accuracy, minimize time and costs.

The following sections in this paper will present the overview of related researches, custom built database and specialized templates, develop objects properties and model a 3D building in BIM application, link typical BOQ with specialized templates for automatically generating total cost estimation.

2. LITERATURE REVIEW

2.1 Cost Estimation

Cheng [5] defined the cost estimate as an essential task for all projects because it affects

planning, bidding, design, and budget. The accurate cost estimating is a crucial aspect of any organization liable for budget submission, contract negotiation, and financial decision making [6]. The benefit of estimation is that it allows decision makers to select adequate alternatives as well as to decrease misjudged solutions [7]. The significant goal of doing cost estimating is to assist owners and other decision makers to clearly visual the detailing information of the construction projects that based on this, they can consider to continue or alter the process according to the suitable budget and time period requirements for project completion.

2.1.1 Traditional cost estimation

The traditionally applied methods of cost estimating start during clients got preliminary 2D drawings from designers and then offered to contractors for manually calculating a summary QTO and brief cost estimate [8]. The traditional process of QTO is involved the design objects measurement and other related documents such as 2D shop drawings that contain top views, left and right views, and section views of building specifications. These 2D based documents, either hand designed or facilitated by CAD software, are used for extracting the materials quantities by human interpretation to produce BOQ [9]. In the organized BOQ, material and labor unit costs then will be inputted manually by estimators for multiplying with the quantities in order to get the final costs. The traditional estimating process is time-consuming and low level of accuracy.

2.1.2 BIM-based cost estimation

Building Information Modeling (BIM) is a high prototype technology and process in architecture, engineering, and construction industry. BIM is capable of enhancing visualization, simulation, cost estimation, and facility management in the construction project lifecycle. BIM visualization and simulation of construction specification analysis offers design alternatives for decision makers communicate with stakeholders to avoid reworks and conflicts when the design is changed [10]. BIM can fulfill a process-related requirement series, non-geometric data, interoperability and automated digital data sharing for a successful facility management [11]. BIM can enhance interoperation between project teams in the AEC industry as well as facilitate the construction performances and decrease project expense [12].

BIM applications allow users to access 3D building models with quickly analyze, select, and apply the material specifications for every building component in order to create the intelligent objects that will support a BIM-based QTO process. The 3D building that is modeled by using smart objects can enhance of extracting quantities that then link to estimating software for pricing [13]. Linking BIM components to the estimating software is capable of mapping BIM objects and matching with external database to produce estimating costs in their systems. Estimating costs using a BIM-based QTO tool is able to extract the data from BIM tools to estimating software by their readable format [14]. BIM-based cost estimating process is capable of providing the accurate QTO with essential effort and time savings.

3. METHODOLOGY

This research developed a BIM-based simplified approach for estimating building costs based on BIM tool that integrates with a custom built database and specialized templates. The whole process of this method is illustrated in Fig.1.

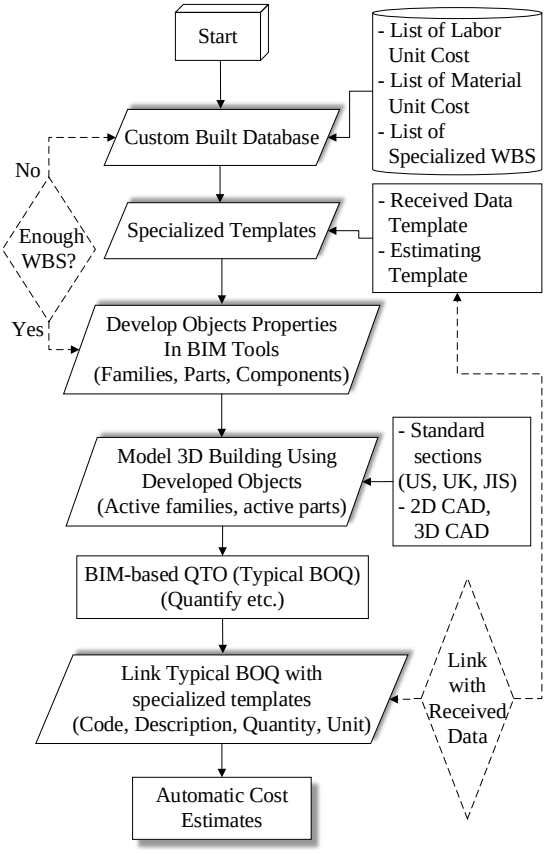
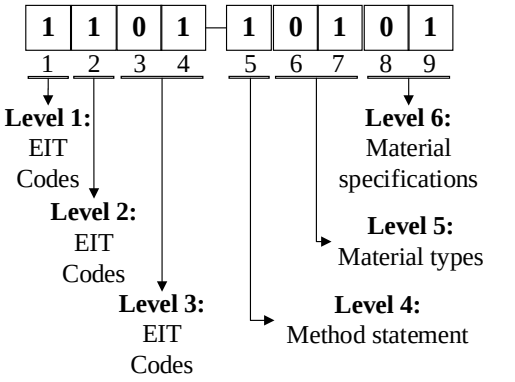


Fig.1 Flowchart of a BIM-based simplified approach to automatically estimate building costs

3.1 Custom Built Database

The custom built database represents an excel list of special work breakdown structure (Specialized WBS) that is created based on the combination of labor and material unit cost lists.

The Practical Guidelines and Details for Calculating Construction Cost, Thai handbook updated in October 2017, contain lists of labor costs/operations for construction cost calculation that used as an original basic data for creating the excel labor unit cost list. The excel list of material unit cost is created based on lists of standard materials price, Bureau of Trade and Economic Indices, produced by Thai Ministry of Commerce. The created list of Specialized WBS contains specifications such as codes, descriptions, units, and unit costs. The codes applied to items of the WBS have six levels, which level 1 to level 3 followed the Engineering Institute of Thailand (EIT) standard cost codes and the level 4 to level 6 are manual codes created based on the Thai Standard System as illustrated in Fig.2.



Level 1 to Level 3 followed the Engineering Institute of Thailand (EIT) codes.
Ex. 1101: Piling work
1102: Earth work
1103: Reinforced concrete

Level 4 to Level 6 are Customized codes created based on the Thai System (method statement, materials, and specifications).
Ex. 1101-10101: Drive prestressed concrete pile, rectangular-shape (0.15x0.15x6.00 m)
1103-10101: Install rounded bar (RB), SR24 (Dia. 6mm)
1204-10601: Install structural steel frame, E60, H-shape (100x100x6x8mm), 103.2kg

Fig.2 Schema of the specialized WBS codes

This research requires the custom built database in order to transfer the labor and material unit costs into the estimating template for automatically generating a total cost. This database is significant and efficient for the BIM-based cost estimating approaches, thereby providing sufficient construction WBS that is easy to observe costing of an original estimate according to cost changes while eliminates re-enter the unit costs multiple times.

3.2 Specialized Templates

The specialized templates (received data and estimating) are created in different excel sheets linking each other by the assigned formulas and functions. The received data template contains the same columns heading with those of the typical BOQ that can facilitate the data exporting process. The estimating template is a special detailing sheet that "if function" and "v-lookup" are assigned into every cell for linking with the received data template and custom built database. Once the received data template got the data such as WBS codes, descriptions, quantities and units from the typical BOQ, that information will be automatically transferred into the estimating template. Especially, based on the WBS codes, this estimating template is capable of automatically searching for unit costs from the custom built database and generating a completed BOQ and total costs.

3.3 Develop Object Properties in a BIM Tool

In this research, AECOsim Building Designer V8i™ is used as the BIM tool for developing the object properties. This BIM application provides "building primary tool" within "dataset explorer" that contains "Parts" and "Components" for users to develop objects geometries depend on their projects' requirements. The process of the objects properties development is shown in Fig.3.

3.3.1 Part (WBS) and components (materials properties)

AECOsim Building Designer V8i™ allows users to create WBS specifications, which the definitions and rendering properties can be applied by "Families" and "Parts." This BIM tool also offers "Components" tool that allows users to create materials specifications by applying the density, unit, unit price and level of accuracy to each of them. By using this BIM tool, users can put either the labor or material unit price to the material specifications that will support the QTO process to produce directly an estimating BOQ with unit cost, but all will need to be re-entered again when the costs are changed. Moreover, some of existing objects properties provided by BIM tools contained the incorrect assigned data information even they are not well-organized that this could be complicated and make users difficult to find the existing objects properties as well as cause to be error for the estimating process. So, this present research is trying to resolve those problems by creating well-organized objects properties based on the Thai standard system that can utilize for construction projects in Thailand. This research creates "Part families" and "Parts" that represent all

construction activities in the list of specialized WBS. “Part families” are referred to all main activities that contain codes level 1 to 5. “Parts” are all of the sub-activities that contain codes level 6. The main activities and sub-activities that are created will be shown in “active families” and “active parts” respectively in the “building primary tool.” This can facilitate users to utilize depend on objects specifications during drawing process.

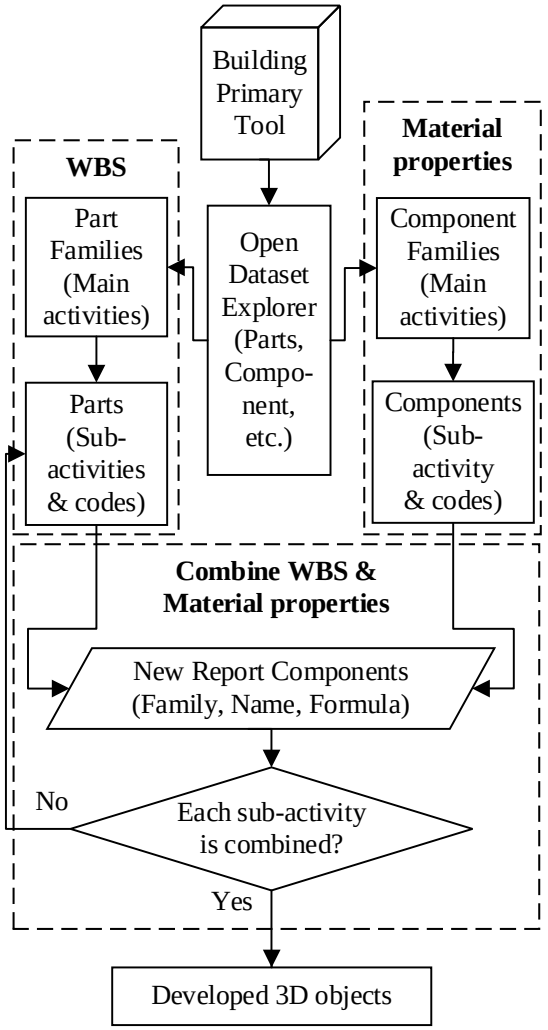


Fig.3 The system of developing objects properties in a BIM application

3.3.2 Combine WBS with materials properties

This is an important part of the objects' properties development in order to create the completed smart elements that can affect to the quantity takeoff process. The WBS represent objects definitions and the material properties represent objects specifications, If both are not combined the software will not recognize the materials to be taken off as well as error will happen during the takeoff process. According to the existing objects properties provided by BIM tool are not sufficient for construction projects in Thailand as well as the formulas assigned are not suitable for Thai material specifications. The present mechanism creates the building WBS with material properties based on the Thai standard system and combines them with the data information and formulas assigned are correct as well as adequate due to the Thai construction requirements. The mechanism to combine is to select for “Report component” at “Part view” then open property for one of sub-activity at “Parts groups” that need to be combined. Next, click on “New report component” to show columns of Family, Name, and Formula that users can select respectively for “Component families” and “Components” then assign formula based on the object specifications.

This research creates a schematic database in BIM tool in order to support the 3D building models as well as quantity takeoff process with higher accuracy, thereby providing the adequate intelligent objects based on the Thai material specification. This database is a necessary requirement and sufficient for SME utilizing to estimate their building projects in Thailand.

3.4 Model a 3D building Using Developed Objects

This present research developed the intelligent objects based on the Thai standard system that is a necessary requirement for users utilize for modeling 3D building in BIM tool in order to produce an accurate BOQ. The way to place a 3D object in AECOsim Building Designer V8i™ is by entering data points using “AccuDraw” or by selecting object types from which the shapes are generated. In this case, users can consider placing the 3D intelligent objects developed by the author in two ways; 1) Select for the developed objects at “Active families” and then “Active parts” respectively during the process of objects placement; 2) Place all the 3D objects to complete the 3D model then modify all of them after the process completion by using either “Apply parts” or “Building element info” tools. Moreover, the shape of every object can be modified by connecting, applying cutbacks or modifying ends.

3.5 BIM-based QTO (Typical BOQ)

BIM tool is capable of extracting material takeoffs from the 3D models and export that data information in the form of spreadsheets, databases, or word processing files. The reported BOQ is based on settings completed using the “Quantify” tool and component definitions defined by the “Families” and “Parts” in the “Dataset explorer” that the level of accurate results is highly affected by the intelligent 3D objects. This present approach

modeled a completed 3D building by using the intelligent objects, which contains specific codes that can associate with the Thai material specifications. This completed 3D model is then extracted due to a BIM-based QTO process in order to produce the typical BOQ, which have only building WBS specifications and quantities. So, this algorithm requires linking the typical BOQ with specialized templates that is capable of deriving labor and material unit price and generating a completed BOQ.

3.6 Link Typical BOQ with Specialized Templates

The typical BOQ is a summary of data information in an excel sheet, which is extracted from the completed BIM-based intelligent 3D models. Specialized templates are also the excel sheets that created for linking with the typical BOQ. The received data template contained the same columns heading to those of the typical BOQ in order to facilitate the linking process. All data information in the received data template will be automatically reflected to the estimating template that is capable of deriving unit costs from the custom built database due to the WBS codes then automatically generates for the completed BOQ as well as total costs. Linking between two excel workbooks is a simple process and it is sufficient for the estimators implement in their building construction project in order to get the accurate results and time saving.

4. RESULTS AND DISCUSSIONS

As a result, this research offers a BIM-based simplified approach that automatically estimates building costs based on BIM 3D models that integrate with custom built database and specialized templates. This approach is compared to the traditional and BIM-based estimating software methods as below discussion consecutively.

Traditional cost estimating methods are time-consuming and error-prone because they rely heavily on 2D drawings and human interpretation to generate the BOQ. Zhao [15] mentioned that cost control-based traditional method requires much time, 23% of training time and 77% for implementing cost control process.

Emerging BIM technology provides users with the capability of modeling 3D smart elements and produces a BOQ with unit costs, but that information needs to be inputted manually into the BIM tools or by linking via plug-in/third-party with the estimating software that derives cost data from the iCloud database. To grasp the benefits from BIM based estimating software approaches, the experienced on software using, habitual modeling, and high level of users training are necessary requirements [16]. This method is also time-consuming, 65% for software training and 23% on 3D modeling, and have the causes for inaccuracies; an inadequate classification system of BIM compatibilities; insufficient of construction material definition; incomplete BIM compatible calculating rules properties; and lack effort in a way of operability for data exchange requirements [17].

A case study, Start-Up and Innovation Building, was estimated for its construction costs by two different methods. The building is located in Faculty of Engineering, Naresuan University, Thailand. It is a mixed of reinforced concrete and steel structure, which has total floor area is 1469.54 m^2. The estimating cost results using the Thai Manual Method, produced by an estimator of the design team in Faculty of Engineering, Naresuan University, and those results estimated by the author using BIM-based simplified approach were compared that is shown the approximately close values as illustrated in Table 1.

Table 1 The results of estimating costs produced by Thai manual method and BIM-based approach

Building WBS	Thai Manual Method (Dollars)	BIM Simple Approach (Dollars)	Different Values (%)
Sub-Structure	$14,922.43	$14,740.38	1.22%
Super-Structure	$115,117.34	$116,326.08	-1.05%
Floor	$26,355.36	$26,010.11	1.31%
Wall	$30,323.71	$30,008.35	1.04%
Ceiling	$7,753.57	$7,850.50	-1.25%
Door	$33,197.41	$32,948.43	0.75%
Window	$22,131.61	$21,965.62	0.75%
Stair	$6,851.72	$6,753.73	1.43%
Toilet	$14,140.56	$14,006.24	0.95%
Roof	$53,012.20	$52,572.19	0.83%
Total	$323,805.92	$323,181.60	0.19%

This research presents a BIM algorithm that the process of QTO is to export the building component quantities from BIM application to Microsoft Excel for producing the typical BOQ. This BOQ does not contain unit prices, so it requires the custom built database and specialized templates to fulfill this gaps. Custom built database is a well-organized list of WBS based on the required CGD's format, which contains construction activities codes, labor and material unit costs. These data then will be transferred to the estimating template that automatically generates a completed BOQ and total costs. The created mechanism provides a simplified, fast and accurate process because it

needs only a BIM application and Microsoft Excel, not requires for interoperating with estimating software and iCloud database. This BIM algorithm is capable of facilitating SMEs to implement their building construction projects in order to minimize time and increase the accuracy.

This proposed method will limit to estimate only a structural and an architectural parts of a building construction project. Users also need to know well BIM software, custom build database, and the Thai cost estimated system.

5. CONCLUSION

The research provides a BIM-based simplified approach for automatically estimating building costs based on BIM 3D intelligent objects that integrates with custom built database and specialized templates based on the CGD's requirement. This algorithm is capable of enhancing the BIM-based quantity takeoff process and automatic cost estimations. This method created a custom built database on that contains WBS specifications and unit costs. This is a significant list with well-organized information that allows users to update either WBS or unit costs due to their construction projects' requirements in Thailand. The developed objects that are created in a BIM tool is the schematic database, which will support the 3D building models in order to produce a typical BOQ with a higher accuracy. The process is completed by creating the specialized templates to link with the typical BOQ and search for the labor and material unit cost from the custom built database that automatically generates the completed estimating BOQ as well as total costs. This BIM algorithm is capable of contributing the estimators and decision makers to reduce the time and increase accuracy for the process of cost estimation. Resulting from this research, a simplified but essential cost estimating algorithm was created for SME to implement and prepare estimating costs on their governmental building construction projects based on the Thailand CGD's requirements with a fast, simple, and accurate process in term of time and cost savings. This method is a necessary requirement for the AEC industry that installs their building projects in Thailand. Especially, the industry that interoperated with the Thai government construction sectors, which the projects will need to be estimated with the monthly updated material costs produced by the Ministry of Commerce and the labor unit cost updated by the Comptroller General's Department (CGD).

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