Automatic Quantity Takeoff and Cost Estimation in BIM Design

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Abstract:

Building information modelling (BIM) can benefit architects to consider cost issues in their design process. A possible solution is to integrate quantity takeoff (QTO) and cost estimation into the design environment to allow integrated cost analysis along with modelling designs. Designers can thus gain cost results automatically and consider more suitable designs within their familiar design environment. To realize this possibility, suitable software architecture (SA) is expected to refer to building component measurement methods, map to specific building element types and prices for calculation and obtain cost results effectively and efficiently.

The proposed SA consists of two independent applications of BIM authoring tool and spreadsheet. It adopts Component Object Model (COM) technology, e.g. Microsoft COM, into the BIM design environment. Therefore, it enables data access from the BIM authoring tool to the external spreadsheet. Importantly, text-based building component measurement methods need to be converted into digitized calculation rules in advance. The spreadsheet hence becomes an information repository for the BIM authoring environment to provide relevant values and calculation rules. Simultaneously, the design tool can receive the values and rules, quantify designed building elements and output QTO and cost estimation results as bill of quantity (BOQ) in the spreadsheet. These kinds of data access and output between the BIM authoring tool and spreadsheet can be occurred synchronously when interactive operations trigger related design events, such as add objects, delete objects, modify object attributes, etc.

The synchronous QTO and cost estimation mechanism between design modelling and spreadsheet provided by the SA can conveniently benefit designers to control cost for making design decisions before land investment for property development. Another advantage is that the spreadsheet contents can be flexibly updated without influencing on the BIM tool's usage. It is thus applicable for handling different quantity takeoff criteria stored as spreadsheet contents from diverse countries.

Keywords: automation, building information modelling, cost estimation, design decision, quantity takeoff.

1. INTRODUCTION

Building Information Modelling (BIM) as an innovative approach to transforming the architecture/ engineering/construction (A/E/C) industry has attracted great interests in the world. Governments and organizations in many countries issue policies, standards and guidance to promote its development. The UK government mandates its building industry to fully adopt BIM by 2016. In its report (UK BIM Task Group, 2011), BIM evolution is classified into 4 levels from 0 to 3 that indicates BIM advancement from a technology development perspective. This BIM evolution map is helpful to clarify relevant BIM application features including quantity takeoff (QTO) and cost estimation.

The evolution of QTO and cost estimation development using information communication technology (ICT) keeps consistency with UK BIM level gradient. Relevant applications are accordingly identified to be manual calculation at level 0, CAD-based application at level 1 and BIM-based application at level 2. Being widely accepted, both level 0 and 1 application work is generally labor extensive and less automation available to relief huge workload until the level 2 becomes available. It is because components in BIM models at this level are computer-recognized to perform relevant (semi-) automated calculation for QTO and cost estimation. Hence, BIM-based QTO and cost estimation applications are considered one of most profitable areas in the BIM era (Monteiro et al., 2013).

QTO and cost estimation using BIM models is important for property development before and after potential lands to be invested. Its utilization can be differentiated into macro and micro BIM applications. The former is applicable for rough estimation of cost in the early design stage that 3D massing models contribute to this work. The latter, however, relies on detailed BIM models so that relevant components in a BIM model can be quantified automatically and therefore suitable for accurate and efficient cost estimation. At this micro level, QTO and cost estimation can lead to detailed bill of quantity (BOQ), which is useful for procurement at the tendering phase. In

the property development, it is also useful to make this result available during design process to control cost for the purpose of satisfying business strategies to win profits on the market.

Automating QTO and cost estimation in an integrated BIM authoring environment can benefit building designers. It can help them know whether or not related building designs may be in line with price strategies on certain property markets. Particularly, synchronizing model designs with associated cost estimation may allow designers to beware of cost issues based on every designed building component. Nevertheless, challenges for such a solution involve substantial issues like classification system, building component measurement method, price information, etc. These issues actually vary on the dependence of countries and hence need ad-hoc solutions for specific markets. Additionally, suitable software architecture is vital to realize this desired outcome.

The aim of this paper is to discuss an integrated approach to QTO and cost estimation in BIM design. With this solution, the designers are able to gain cost information in their design processes for better cost control. The structure of this paper consists of an analytical discussion of existing approaches to BIM-based QTO and cost estimation, the proposed approach and features, its software architecture framework, future work and conclusion.

2. APPROACHES TO BIM_BASED QTO AND COST ESTIMATION

The use of BIM models for QTO and cost estimations are two connected application areas. However, most BIM authoring tools are able to perform QTO but short of the function for cost estimation, which is usually done by using different software. For instance, the off-the-shelf tools like Autodesk Revit, Graphisoft ArchiCAD, etc. have QTO functions but they need to export BIM models through the neutral data schema of industry foundation classes (IFC) (buildingSMART, 2013) to third party software for cost estimation. Because QTO functions in these BIM authoring tools normally cannot fit needs from diverse countries, they need to be customized to satisfy specific criteria in accordance with provided requirements. Given these problems, the development of QTO and cost estimation applications has several strategies to create relevant solutions.

One of strategy is to adopt fully independent software architecture (SA) into QTO and cost estimation applications' development. Dedicated software of this kind, e.g. CostX, etc. can import the design models using IFC for QTO and cost estimation (Smith, 2014). This conversion process following openBIM strategy is popular in the current BIM applications for QTO and cost estimation. Its advantages are that the QTO and cost estimation SA is independent to BIM authoring tools and be convenient for programmers to focus on the coding work of QTO and cost estimation respectively. Nonetheless, its drawback is obvious because of data loss in the process of data conversion between propriety model data from BIM authoring tools and neutral IFC. It means that created BIM models are not in consistency with these being converted into IFC format after they are exported from BIM modelling environments and then imported into the IFC-based QTO and cost estimation tools. This independent approach is also not beneficial to designers to check cost information conveniently in their design environments.

Another strategy is to create partially integrated software architecture (SA) that QTO and cost estimation applications are integral but needs data transfer from BIM modelling environments. Applying propriety data schema and modelling rules instead of using IFC for specific BIM authoring tools is a feasible approach to the avoidance of data loss for accurate QTO. Building designers need to get familiar with these rules in their practices so that to guarantee the quality of BIM models to be created. For example, RIB iTWO 5D system has its specific modelling guidance for Revit modelers to create compatible Revit models to be inputted as its propriety CPI (construction process integration) format into iTWO 5D for QTO and cost estimation (RIB, 2015). This is certainly helpful to avoid potential inaccurate calculation for QTO at the pre-construction and construction phases. Its SA integrates both QTO and cost estimation functions and be suitable for data transfer seamlessly. Nevertheless, such an application mode usually needs design models to be imported in the system after the design models are completed. It hence prevents building designers from checking cost information conveniently in their practice processes to monitor potential cost of their design considerations.

The 3rd strategy also adopts partially integrated SA that QTO functions are customized within the BIM authoring environments and related results can be transferred to the separate cost estimation applications. In terms of QTO customization in BIM authoring or simulation tools, commercially available toolkits like Autodesk Revit, Navisworks, etc. allow extending QTO functions by using application programming interface (API) for further development without possibility of losing data. The QTO customization in BIM authoring environments can benefit designers to examine their design options. For example, THSWARE (THS WARE, 2015) is a plug-in application of the Autodesk Revit to suit the QTO needs for the Chinese market. Unfortunately, existing software of this kind has no intention to integrate cost estimation functions into the same environment to help designers. The UK AEC industry highlights the value of automating QTO and cost estimation as integration for better cost planning in the 5th dimension of BIM (5D BIM) (RICS, 2010).

To summarize these three application approaches, their techniques, advantages and disadvantages are compared and listed in Table 1. As shown in the table, the identification of these approaches is on the basis of relationship

among BIM authoring tool, QTO and cost estimation applications. Their integration relationship is symbolized by using PLUS (+) whilst the data export/import is marked as ARROW (→). In accordance with the foregoing discussion, the table lists three discussed approaches to BIM-based QTO and cost estimation. These approaches all have their merits and pitfalls that are inconvenience for designers to perform cost estimation in BIM modelling environments. Besides these discussed approaches, a novel approach is listed as the 4th approach that interactively integrates QTO and cost estimation into a BIM modelling environment. Its significant feature lies in the SA to embed a spreadsheet object into a BIM authoring environment, in which created BIM objects can interact with external spreadsheet through the embedded object to exchange data. The spreadsheet functions an integrated data container to synthesize relevant data for QTO and cost estimation. Its application therefore is symbolized BIM←→QTO + Cost Est. where the BI-ARROW (←→) indicates data exchange between BIM objects and spreadsheet.

Table 1. Comparison of BIM-based QTO and cost estimation approaches

Approach	Technique	Advantage	Disadvantage	Example
BIM→QTO → Cost Est.	IFC export & import	Benefit dedicated cost estimation	Data loss & not for designers	CostX
BIM→QTO + Cost Est.	Propriety data & modelling guidance	No data loss	Inconvenient for designers	iTWO 5D
BIM + QTO → Cost Est.	API for functional enhancement	No data loss	Inconvenient for designers	thsware
BIM ←→ QTO + Cost Est.	COM & spreadsheet	Convenient for designers	Needs automation	N/A

3. BIM-BASED AUTOMATIC QTO AND COST ESTIMATION

To avoid the pitfalls in the existing application approaches, an automated QTO and cost estimation application is expected to be integral within BIM authoring environment. As such, the system is able to remain all design information without any loss. Simultaneously, it is expected to be flexible in system configuration to combine QTO measurement methods with price information. Therefore, the application may encompass two independent but communicated environments: a BIM authoring tool to contain all design objects and a spreadsheet to host QTO measurement methods and price information. The former plays an active role in interacting the latter for retrieving related information and performing calculations. The latter, meanwhile, acts as a passive information repository to host required data and receive upcoming calculation results from the former.

Adopting mature technologies, e.g. Component Object Model (COM) (Microsoft, 2015), can connect the BIM authoring tool and the spreadsheet for interaction and communication without adapting their existing software architecture. Its interactive working mechanism follows four procedures for data exchange. Firstly, the BIM authoring tool calls the object of spreadsheet so that to enquire relevant the measurement methods for QTO for a specific designed BIM object. Secondly, the spreadsheet object retrieves right rules and return to the BIM environment. Thirdly, the QTO is performed within the BIM tool. Lastly, the result is sent to the spreadsheet so that it can be stored and dispatched for possible tendering usages through the spreadsheet object.

In order to achieve these automated features in the foregoing discussion, three conditions need to be satisfied in advance. Setup BIM modelling regulations is above all important as this is identified to be crucial to handle complex spatial relationship for correctly quantifying every building objects (Monteiro et al., 2013). Digitizing the measurement methods as second condition is necessary for providing relevant data to the external BIM tools since most of these methods are currently text descriptions only and hence be unsuitable for automatic computing. Besides these two conditions, suitable software architecture is critical to underpin the computing performance. It can be helpful to clarify data exchange protocol between two standalone applications and involved modules to provide relevant functionalities.

4. PROPOSED SOFTWARE ARCHITACTURE

To realize foregoing discussed features, it needs the support from the rule checking technique (Eastman et al., 2009) for automatically retrieving building component measure methods and resource price information. The principle and usage of this technique can be illustrated by dedicated SA (Figure 1), which consists of BIM authoring tool, spreadsheet and their contained modules and items within an operating system like Windows, Mac OS, etc. This section discusses these modules' interaction and dataflow for the application.

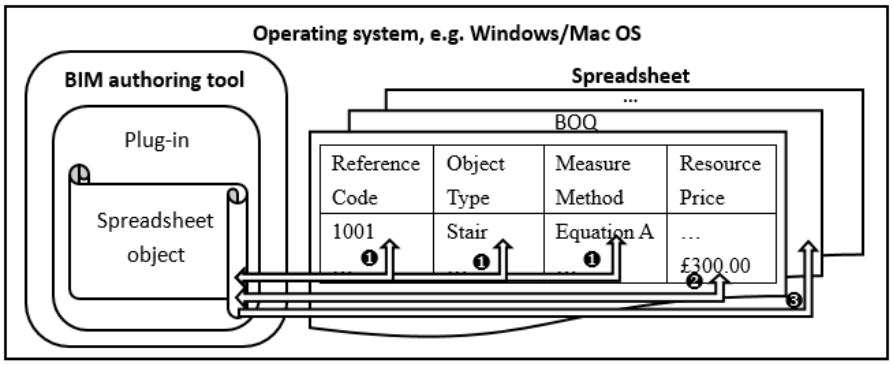

Figure 1. Software architecture

Indicated by the SA, a plug-in module has a spreadsheet object to be adopted into the BIM authoring tool. The module plays a key role in connecting BIM objects with external spreadsheet instance in the authoring tool. Created BIM objects by the authoring tool hence can access the spreadsheet's contents with the spreadsheet object for QTO and cost estimation. On the other hand, the spreadsheet as partner can response to the BIM authoring tool's requests to provide required information.

The structure of the spreadsheet is composed of two fundamental table pages. One is to host synthesized measurement methods and resource pricing information so that to provide the plug-in module in the BIM authoring tool with information for QTO and cost estimation. Another is for hosting BOQ after the result of cost estimation is available. Therefore, the first table can be designed to have some items like reference code, object type, measurement methods, resource price information, etc. to satisfy integrated QTO and cost estimation using BIM objects. The structure of the second table page for BOQ is on the dependence of business needs from different organizations.

The dataflow between the plug-in module and the spreadsheet instance is identified to be three types, which keep consistency with the foregoing discussed interactive working mechanism for data exchange. The first type is from the spreadsheet object to query a right BIM object type, which is applicable for a BIM object to be measured. The queried information record including reference number, object type and measure methods needs to be returned to the plug-in module for QTO. The second is to find out and retrieve the right resource price information for cost estimation according to the BIM object attributes like building material, labor, machine usage, etc. The last is to generate the BOQ as a summary to be stored into the BOQ table.

The dataflow can be driven by a series of interactive events occurred within the BIM authoring environment. During the design process, BIM designers can conduct related operations like add, delete, modify objects, which may trigger the BIM authoring tool to send relevant events. These allow an internal signification between operated BIM objects in the BIM tool and spreadsheet object in the plug-in module. In accordance with the difference of events, the spreadsheet object can decide to perform relevant operations for accessing related data or export calculation results in the external spreadsheet.

5. FUTURE WORK

Creating a referencing system in the synthesized table page for QTO and cost estimation is worth a careful consideration. Practically it can be realized to apply a classification system. However, not every country like UK or US has a classification system for the AEC industry. Designing and allocating proper reference code or number for each quantifiable BIM object type and specific object is essential. As such, relevant calculation items can be correctly referred to. A possible approach to solving this matter is to adapt the existing classification systems like Uniclass (NBS BIM Toolkit, 2015) etc. to fit the reference needs.

Another issue for the synthesized table page is to formulate right calculation formula and value types in terms of volume, area, length, etc. for related BIM objects' measuring. For instance, an onsite casting stair component is quantified as its projection area instead of volume to calculate related materials according to Chinese measurement methods for building components. Therefore, the object type of onsite casting stair needs its projection area value for QTO. Such a correspondence between BIM object type and calculation principles ought to be established in the synthesized table page.

The resource pricing information is critical to be integrated with the measurement methods according to each of specific building component. This integration could be efficient if the classification system is available and applicable for different resources with variable prices. Normally building component measurement methods and

the price book is separated and their correlation needs to be established through the classification system. However, digitizing both measurement methods and connecting pricing information needs to handle enormous information. A suitable automation approach is thus appreciated to accelerate the connection of both sides so that to relief significant manual workload.

6. CONCLUSION

Automatic QTO and cost estimation in the BIM environment is a valuable approach to cost control in the design stage before land investment or property development starts. Its challenge lies in the synthesized table page creation to establish a referred structure to associate both building component measurement methods with resource pricing information for QTO and cost estimation. Ideally adopting and adapting an existing classification system is a convenient approach to solving their connection problem. Once achieving this desired outcome, building designers could undertake duties to consider cost control issues within their familiar design environment without relying on third party tools and avoiding any data lost risks. Further research efforts will be put in the automation the connection of building measurement methods with resource pricing information by using a classification system like Uniclass in the next step.

REFERENCES

buildingSMART. (2013). *IFC2x3*. Retrieved from buildingSMART website: http://www.buildingsmart-tech.org/ifc/IFC2x3/TC1/html/index.htm, accessed on September 24, 2015.

Eastman, C., Lee, J., Jeong, Y., Lee, J. (2009). Automatic rule-based checking of building designs, *Automation in Construction*, 18(8), 1011-1033

Microsoft. (2015). *COM: Component Object Model Technologies*. Retrieved from Microsoft website: https://www.microsoft.com/com/default.mspx, accessed on September 24, 2015.

Monteiro, A. and Martins, J.P. (2013). A survey on modeling guidelines for quantity takeoff-oriented BIM-based design, *Automation in Construction*, 35 (2013) 238–253

NBS BIM Toolkit. (2015). *Classification*. Retrieved from the NBS BIM toolkit website: https://toolkit.thenbs.com/articles/classification/, accessed on September 24, 2015.

RIB. (2015). *RIB iTWO combines traditional construction planning and trail-blazing 5D planning*. Retrieved from RIB website: http://www.rib-software.com/en/landingpage/rib-itwo.html, accessed on September 24, 2015.

Smith, P. (2014). BIM & the 5D Project Cost Manager, *Procedia - Social and Behavioral Sciences*, 119, 475-484.

THS WARE. (2015). *BIM—3D QTO for Revit User Manual V1.0 (Chinese Version)*. Retrieved from THS WARE website: http://www.thsware.com/Revit.html/UploadFiles/20150618/24c3ebce-288e-4e5e-b1f1-4373c02f04aa/1EB28924-BDDB-4454-96B5-98C17ADFE0C7.pdf, accessed on September 24, 2015.

UK BIM Task Group. (2011). *Strategy Paper for the Government Construction Client Group from the BIM Industry Working Group – March 2011*. Retrieved from UK BIM Task Group website: http://www.bimtaskgroup.org/wp-content/uploads/2012/03/BIS-BIM-strategy-Report.pdf, accessed on September 24, 2015.