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Building Information Modeling (BIM) for Project Value: Quantity Take-Off of Building Frame Approach

Seoung-Wook Whang[1], **Park, Sang Min** [2,*]

[1] *Ph.D. Research Student, School of Construction Management and Engineering, University of Reading, Whiteknights, PO Box 219, Reading, Berkshire, RG6 6AW, United Kingdom,*

[2] *Ph.D., Associate Professor, School of Architecture, Yeungnam University, 280 Daehak-ro, Gyeongsan-si, Gyeongbuk 712-749, Republic of Korea.*

**Corresponding author*

Abstract

Purpose-Under today's increasingly complex and large-scale construction environment, building information modeling (BIM) is being recognized as an effective and dominant project management tool. To demonstrate the practical benefits of BIM application, we focused on the quantity take-off (QTO) of a building frame by BIM modeling because accurate cost management is now seen as a critical factor for project value.

Design/methodology/approach-QTO is the systematic breakdown of a project into units of work in order to evaluate the cost and time needed to complete a project. We analyze the traditional manual-based approach and the BIM-based approach to find the most practical method, and then examine comparative data from actual case projects. Particularly, a direct comparison of the QTO of building frames between two approaches reveals the accuracy and availableness of the both approaches respectively.

Findings-As a result, the BIM-based approach shows higher QTO accuracy (95%) than the manual-based approach (less than 89%). BIM also has other advantages such as allowing partial calculation, re-calculation, and design changes during production stage. Moreover, because design changes are calculated automatically by the BIM operation, drawing omissions and cost estimation errors can be reduced significantly.

Originality/value-Thus, project value can be improved by the application of BIM for cases in which all the available cost management information is handled and reproduced by different project participants.

Keywords: Building frame, BIM, cost estimates, cost management, modeling, quantity take-off

Paper type: Case study

INTRODUCTION

Building information modeling (BIM) is an integration of different project elements including processes, information, and technologies in order to manage essential building design and project data throughout a project's life cycle (Bryde *et al.*, 2013; Succar, 2009). Within a short period of time since its advent, the proliferation of BIM has been recognized as a natural phenomenon in the architecture, engineering, and construction (AEC) industry. Numerous academic articles and project cases support the idea that the use of BIM makes a project more effective and efficient. From the project management perspective, different project benefits (scheduling information, cost estimation, streamlined supply chain, and facility management) are expected as a result of BIM application (Bryde*et al.*, 2013). However, negative views that project value by BIM is not completely proven and justified still exist. Thus, an appropriate evaluation of BIM effectiveness has been requested. Through the evaluation of accumulative partial benefits, BIM's influence on practical and overall project value can be recognized. We used the quantity take-off (QTO) of building frames as a partial element of BIM in order to evaluate project value.

Cost control is now recognized as one of the most critical elements in construction projects. As projects become larger and more complex, the accurate and timely prediction of project costs has become a key success factor (Lee *et al.*, 2012). Cost estimation is one of the most critical tasks for project management in the architecture, engineering, construction, and facilities management (AEC/FM) industries throughout the lifecycle of a project (Ma*et al.*, 2010; Rundell, 2006). Cost estimation traditionally begins with quantification: a time-intensive QTO process of tallying components from printed drawing sets or, more recently, computer-aided design (CAD) drawings. QTO is the systematic breakdown of a project into units of work in order to evaluate the cost and time needed to complete a project. Later, these quantities are linked to unit costs for materials, labor, and time constraints to predict the cost of the entire project (Monteiro and Martins, 2013; O'Brien, 1994). QTO can also be used to establish the execution plan to pre-construction activities, enabling better economic management throughout the project.

However, each level of QTO can be very time consuming and costly. Existing methods of performing a QTO include measuring and counting all of the elements of a building using a scale, and keeping an inventory of all items (Toenjes, 2000). This approach is very error prone because it is based on human interpretation (JadidandIdrees, 2007). Two-dimensional (2D)-based documents, even those generated by computer-aided design (CAD) tools, are also error prone

(Eastman *et al*., 2011). Incorrect inputs and interpretations are common because it is hard to process the complex relationships between enormous building elements.

To avoid spending unnecessary resources on every project phase, a project manager needs innovative tools that can quickly adjust the estimated costs whenever the original design is changed. One such tool is BIM. BIM increases the speed of estimation and eases the burden on the estimator, enabling a project to stay within the planned budget and duration. BIM offers the capability to generate take-offs, counts, and measurements directly from a model. Thus, information stays consistent through all the phases of a project, and design changes can be readily accommodated. BIM supports the full project life cycle and can ensure integrated costing efforts throughout all project phases. The information in modeling and the type of cost estimate needed depends on the phase of the project, ranging from high-level schematic models during the preliminary phases to detailed estimates as projects enter construction (Ma *et al*., 2013).

It is rare to find QTO studies based on actual BIM projects, even if QTO is recognized as one of the most profitable reasons for using BIM. The necessary practical project data used by BIM are not easily accessible to researchers. Even when a researcher manages to access the data, identifying cost elements using BIM is laborious and time consuming. Some experts such as project managers complain that experienced quantity surveyors can conduct cost estimates without using BIM support. They may also argue that certain gaps in estimation are meaningless in the early phases of a project, and that BIM has very little practical impact on the overall project due to repeated design changes and construction delays.

We identified the practical project value of BIM-based QTO using a real project case in South Korea. For a more objective comparison, even if the QTO of this project was conducted with the BIM approach, man-based QTO is also calculated as additional. Actual differences between manual-based QTO, BIM-based QTO, and real input QTO were analyzed after project completion.

LITERATURE REVIEW

Manual-based QTO

The traditional flow of estimating begins when a designer submits preliminary drawings to a client for conceptual cost estimation. And then, preliminary drawings are taken to a contractor again in order to calculate a brief QTO. In particular, design-build and construction management procurement systems rely strongly on conceptual estimates (Ashworth, 2015; Doğan *et al*., 2006). These two procurement systems include the contractor at an earlier phase in the project in an attempt to help expedite the project and smooth out possible problems.

Schuette and Liska (1994) suggest that if the conceptual estimate is not reliable at the time that actual construction begins, there may not be enough capital to complete the job. In the manual-based method, reliable cost estimation is difficult during preliminary project phases. Studies have revealed several drawbacks in relation to 2-D-based design documents (Arayici *et al*., 2011; Howell and Batcheler, 2005; Lee *et al*., 2006). Because 2-D-based QTO is conducted manually, it is inherently prone to errors and omissions.

Any manual process is subject to human error. Even when the measurements are revised, there is no guarantee that they are correct. According to Grabowski (2010), despite cross-checking after estimation, it is quite difficult to perceive whether or not any revised parts are correct. In addition, these manual measurements also depend on human interpretation, increasing the possibility of less detailed QTO specifications. Lea's study (2011) also supports Grabowski's assertion that even when this is not the case, it will ultimately be up to the quantity surveyor to interpret and determine what aspects of the project correspond to the criteria defined in the specifications.

There is often a gap in the vision of project between the designer and the contractor's quantity surveyor. Each can arrive at a different QTO, even though they may both follow the same design documents and specifications. Moreover, according to Arayici *et al*. (2011), quantity surveyors are often less qualified than project architects or engineers. This means that surveyors can be less sensitive to the eventual gap between the predicted QTO and the real input quantity. Erroneous quantities can ultimately lead to incorrect cost estimations with undesirable consequences for budgeting.

BIM-based approach

In contrast to the traditional design and construction approach, the BIM-based approach lays particular emphasis on the integration of individual knowledge in the form of a single data repository that develops through all phases of a project. BIM is a parametric modeling program that uses different individual objects with predefined properties to model a construction project, as shown in Figure 1. To quantify the scope of a project, BIM contains and links predefined properties, or user-defined properties, that can track material quantities and any additional building information (Khemlani, 2006).

Thus, BIM project value is considered beneficial to the AEC industries. It has been used in many different fields including visualization, coordination, analysis, supply chain, material integration, and building construction and maintenance (Gaoand Fischer, 2008; Taylor and Bernstein, 2009).

Eastman *et al*. (2011) researched BIM as a tool for the integration of all project elements. According to their study, BIM improves production efficiency, and streamlines design and construction processes, through integrated information and collaborative work among project participants. Mahalingam *et al*. (2010) focused on the various BIM applications that it has started to fully utilize 3-D graphic data first, and later expands this usage into a 4-D or 5-D environment. This expansion emphasizes various construction business functions, and offers evidence of the extent to which BIM influences the overall project value (Jung and Joo, 2011). BIM is now spreading to areas including building structure, sustainable building, energy consumption, disaster prevention, construction planning, scheduling, project control, and health and safety (Eadie *et al*., 2013).

McGraw-Hill Ltd. (2009) indicates that there has been strong growth in the BIM adoption rate in the US AEC industry, from 28% in 2007 to 48% in 2009. The American Institute of

Architects (AIA) (2007) states that in recent large scale and complex projects, the application of BIM has been increasing in different project stages. A 2008 McGraw-Hill report (2008), which surveyed roughly 300 BIM practitioners, describes various BIM functions and actual applications. The report revealed that BIM is most frequently used for QTO (57%), scheduling (45%), estimating (44%), energy analysis (38%), project management (35%), structural analysis (32%), LEED/green analysis (32%), and facility management (18%). (The numbers in parentheses indicate the percentage of respondents who had experience with that specific analysis task.)

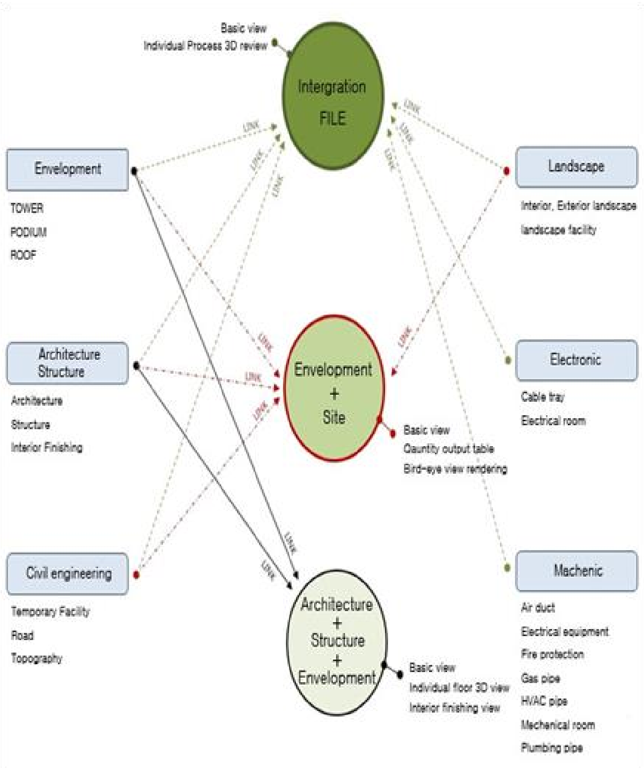


Figure 1: Parametric BIM data integration system

Application of BIM for QTO in South Korea

QTO can be used to determine project profit and construction cost by accurate calculation of the volume of materials required. Throughout the project stage, QTO data is typically revised at least five or six times, even with a simple material shift due to a design change (Cheung *et al*., 2012). The process involves several iterative calculations in parallel with a conceptual or preliminary design, and is referred to by other names such as the rough, preliminary, or feasibility calculation (Bhokha and Ogunlana, 1999). BIM-based QTO could help eliminate negative aspects of the iterative measurement process. If accurate QTO data can be achieved by using the BIM approach, work efficiency would increase considerably and iterative reworks would not be needed in each phase. A revision of BIM modeling caused by any design change leads to an automatic QTO calculation, thereby pre-empting the need for extra work (Kim *et al*., 2009). The use of BIM to improve estimating methods facilitates an increased control of time and costs. At present, BIM is the best way to automate the QTO process (Sattineni and Bradford, 2011). This is because BIM uses an object-oriented parametric model of the work set; i. e., the model is an assembly of the different elements that compose the entire building, as shown in Figure 2.

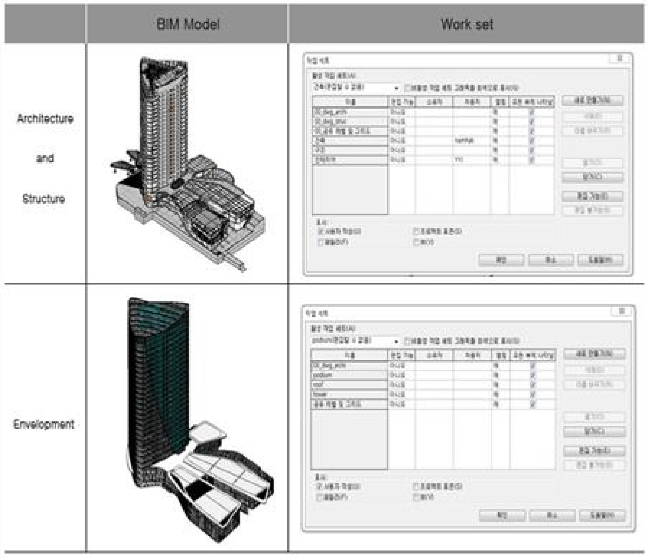


Figure 2: Work set of BIM model

In South Korea, the AEC industry has shown a relatively late interest in BIM, which was not adopted and applied until the 1990s. After its introduction, perception of the practical advantages of BIM spreads out quickly, and it has successfully used in various projects within a short period. This quick proliferation was inevitable in South Korea because a developed computational working environment and a well-established infrastructure were already in place. However, no BIM project cases have, as of yet, been quantitatively evaluated because most of these early cases involved limited aspects of BIM capabilities. For two decades, only limited functions (such as visualization or clash check) have been used in the South Korean AEC industry. Because of a certain bias toward BIM functions, project managers have not been interested in a complete application of BIM. Although some functions, particularly QTO, have shown strong future project value (see Figure 3), there has not been much investment or research in this area.

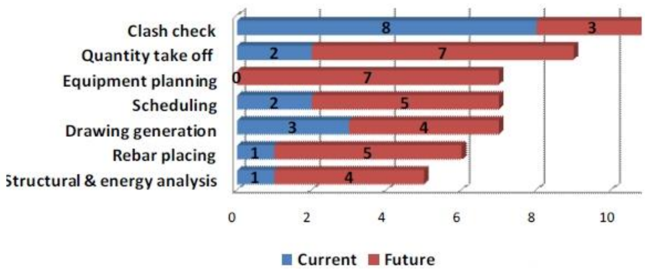


Figure 3: Adopted BIM function in Korea (current and future)(Won *et al*., 2009)

The automatic QTO system, which uses 3-D CAD modeling, was developed in the 1990s by large contractors in South Korea (Won *et al*., 2009). However, system development did not show satisfactory results at that stage. In addition, because much of the drawing process was outsourced, most architectural firms could not attempt 3-D-based QTO work. In early 2000s, several leading contractors began working on full-scale BIM-based projects. Since then, BIM-based QTO has been a core process innovation subject, and architects and engineering companies have started full-scale BIM implementations on their projects (Jung and Joo, 2011).

BIM-based QTO for building frames

Accurate QTO documents are essential for project success. QTO on the building frame plays a critical role in the estimation of project costs in both the bidding and production stage. Particularly, at the initial stage of a large-scale reinforced concrete (RC) project, the calculation of the volumes of the building frames is quite critical in order to accurately predict the whole project cost because the building frame, including its foundation, accounts for about 25% of the total construction cost (Cavieres *et al*., 2011).

Building frame QTO provides crucial information for scheduling. Accurate QTO of building frames at the early project stage provides practical support to help establish the execution plan and choice of design alternatives based on the productivity analysis of the building frame. In addition, BIM modeling corresponds to the QTO of various RC building elements. Actual interactions between the building elements within BIM modeling are possible, and the elements necessary to compile the relevant information into BIM modeling also can be automatically generated (Succar, 2009). This approach makes it possible to create a database based on each element's properties.

RC building frames include footings, columns, beams, walls, slabs, etc., that are professionally drawn in separate layers to distinguish entities and to calculate areas and volumes. The volume of an individual required entity is useful in determining the amount of material to be used in a building frame as a whole. The total project cost is calculated by a summation of all the entities. This BIM-based cost estimate is generally carried out for different project management tasks including bid evaluation, contract changes, work scoping, permits, and approvals (Lee *et al*., 2014). Throughout project stage from schematic design to production stage, quantification and costing become dependent on accurate and easily modified QTO for individual building elements.

RESEARCH METHOD

We compared the accuracy of BIM-based QTO to that of a manual method, and to that of real input of building frame. Because the considered case project is a typical RC structural building in South Korea, this demonstration of accuracy of BIM approach could be applicable to other projects with similar environmental contexts. We investigated three types of building frame QTO: manually-based QTO, BIM-based QTO, and the actual QTO (i. e., that which is aggregated after project closing). Even if this case project was entirely designed by BIM, manually-based QTO was also additionally generated for practical QTO comparison. In addition, the manually-based QTO was calculated by different surveyors using different estimating methods.

In this study, two kinds of manually-based estimating methods that are widely used in the South Korean AEC industry were applied for higher accuracy of the QTO. The first method is an empirical method wherein a quantity surveyor analyzes previous project data in order to calculate the construction cost. The other method is cost estimation per unit area calculated through an analysis of the drawings.

We hypothesize that the BIM-based approach has a high level of accuracy on QTO, and reduces the time spent on revisions and pre-checks of constructability. We attempted to demonstrate this hypothesis by using a directly comparison with the real amount of input QTO. Although there are several diverse aspects to estimate the construction QTO, we considered only the building frame. BIM modeling was conducted using Autodesk Revit Architecture 2011 commercial software. After BIM modeling, the completeness and accuracy of the modeling was reviewed using Solibri Model Checker (SMC) modeling accuracy inspection software. Through a review of physical modeling errors such as crashes between building elements, the accuracy of the QTO can be improved.

We used a three-stage comparison method. In the first stage, BIM-based QTO was compared to manually-based QTOs. Before comparison, the BIM-based QTO generated by the Revit Architecture program was checked for accuracy using the SMC. In the second stage, BIM-based and manually-based QTO were directly compared with real building frame QTO. Finally, for a better understanding of QTO accuracy, the compared data were aggregated into the QTO checksum.

CASE STUDY

General description

The South Korea AEC industry has a high potential for project value derived from BIM; thus, a real case project was used to best test the methodology of our BIM benefit evaluation. The project was built recently in South Korea. The 27 story RC building is composed of spaces with office and commercial functions on the lower levels, and includes an underground car park (Figure 4). The total floor area is 61, 469 m², and the construction duration is 2. 6 years. All design and construction processes of this building were conducted by BIM including cost estimates, environmental simulation, and detailed design. Further facility management will also be operated based on BIM.

INDEX	DESCRIPTION	
Volume	B2 – 27 Floor	
Function	Public office / Private office / Commercial	
Structure	Reinforced Concrete	
Lot Area	22,850.68㎡	
Floor Area	7,522.79㎡	
GFA	61,469.67㎡	(Gross floor area)
BCR	32.92 %	(Building coverage ratio)
FAR	192.11 %	(Floor area ratio)
Parking Lot	448 EA	

Figure 4: Description of actual case project

QTO of RC building frame

The RC frame is generally used as the main structural element in a wide range of buildings from single-story housing to high-rise buildings. Unless a building is designed for a specific purpose requiring a steel or masonry structure, almost all buildings are designed based on RC structures. In terms of 3-D modeling, RC frame has simple structure and a small number of parameters in comparison with other building structural types (Taranath, 2009). Thus, unless there are no substantial design changes that involve a large number of new parameters or a comprehensive change in modeling, there is no significant difference in the entire QTO (Wijaya kumar and Jayasena, 2013).

As stated in Section 4. 1, the RC structural frame accounts for 25% of the total building cost. Moreover, the cost can be calculated at design phase; after confirmation of the building size and structural system, and before detailed design begins. Thus, early calculation of the cost of the RC frame is very useful to project manager to establish cost plan and execution plan at the early project stage. For example, slabs and foundations represent around 63% of the cost of an RC structural frame (Jadid and Idrees, 2007). Moreover, they are the quickest and easiest to create by BIM modeling compared to other building elements. In this study, the QTO of the RC structural frame includes the basement, columns, beams, walls, and slabs, as shown in Figure 5.

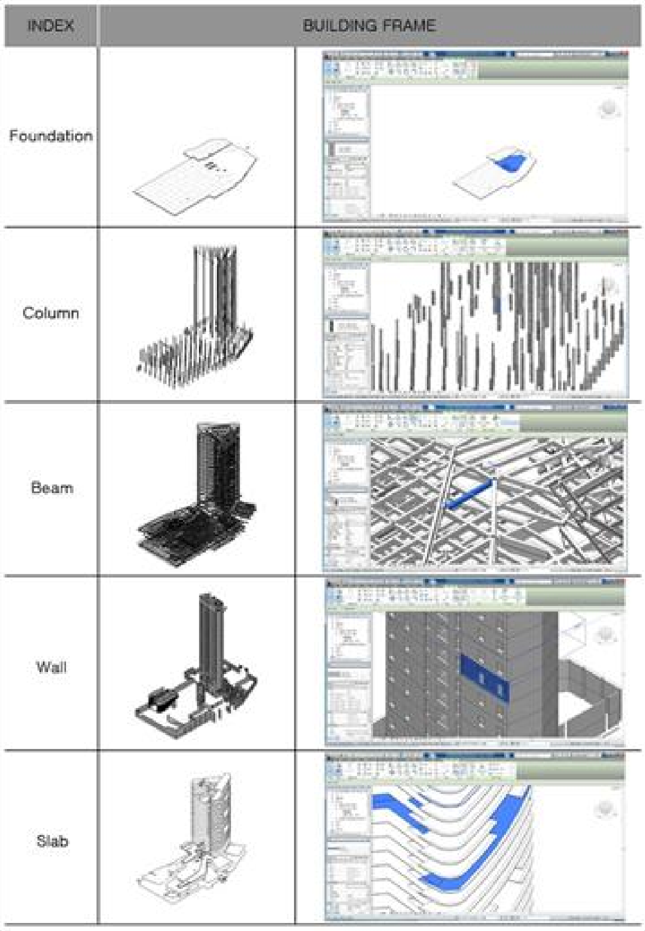


Figure 5: Individual RC structural frame modeling

This building has a mixed structure. Small parts of the lower podium structure are made of steel. However, because the steel structure makes up just 5% of the total building frame, the amount of steel frame was excluded from this investigation. Similarly, even if the staircases and ramps were also designed using RC, for efficient comparison they are excluded from this calculation.

Result of comparative analysis

Diverse BIM studies have tied to examine practical BIM benefits with respect to cost estimates and QTO. However, only a few studies could provide the details of the differences in the QTO calculation results between the traditional method and the BIM-based method. Because the cost estimation process aims to predict and calculate the actual construction cost, a practical comparison between real input and simulated quantities is not easily accessible.

Table I: QTO comparison between two manually-based approaches

Element	Count	Manual-based QTO		Deviation (%)
		Empirical QTO Volume (m³)	Drawing analysis QTO Volume (m³)	
Foundation	89	9, 034. 78	8, 783. 57	2. 86
Column	1, 209	2, 060. 62	2, 140. 02	3. 71
Beam	3, 659	5, 485. 10	5, 775. 01	5. 02
Wall	1, 358	10, 613. 94	10, 184. 17	4. 22
Slab	76	9, 199. 16	8, 965. 17	2. 61

In this study, which uses a real case project, firstly the QTO difference between the two types of manual QTO is compared in order to select more accurate manual QTO, as shown in Table I. Selected QTO will be used for next step comparison with other types of QTO. The difference in the QTO calculated by two manual methods is about 2% to 5%. This is a very small difference, even considering that both manual QTO were calculated only for the RC structural frame. Between the two methods, we selected a drawing analysis QTO method for comparison with BIM-based and real input QTO results, because the BIM-based QTO was also calculated based entirely on 3-D drawings.

In terms of the BIM-based QTO, SMC, which was already used for a review of the accuracy of BIM modeling, was used again for comparison with the QTO calculated by using the Revit Architecture program. The Revit Architecture analysis was carried out using data that were calculated automatically based on the Industry Foundation Classes (IFC) (Fu *et al*., 2006). However, in terms of the SMC, after entering the geometric numerical values of the BIM objects generated by Revit Architecture, the area and volume were calculated within the SMC system using the Information Take Off (ITO) module. A comparison of BIM-based QTO results between the Revit and SMC are shown in Table II.

Table II: QTO comparison between two BIM-based approaches

Element	Count	BIM-based QTO		Deviation (%)
		SMC Volume (m³)	Revit Architecture Volume (m³)	
Foundation	89	10, 008. 10	9, 926. 71	0. 82
Column	1, 209	2, 231. 69	2, 282. 13	2. 21
Beam	3, 659	7, 510. 59	7, 294. 67	2. 96
Wall	1, 358	10, 677. 43	10, 505. 15	1. 64
Slab	76	10, 083. 54	9, 849. 14	2. 38

The difference between the BIM-based QTO calculated by Revit Architecture modeling and SMC is under 3%. For this research, Revit Architecture modeling was selected to be compared with the real input QTO, because it is more widely used and compatible with various BIM programs in AEC industry (Nguyen *et al*., 2010). A comparison of results of the real input QTO with both the manual-based (drawing analysis) QTO and BIM-based (Revit Architecture) QTO is shown in Table III.

Table III: QTO comparison of RC main building frame

Element	Real input		Manual-based	BIM-based		
	Volume (m³)	Count	Volume (m³)	Rate on the basis of Real input	Volume (m³)	Rate on the basis of Real input
Foundation	9,614.25	89	8,783.57	91.36 %	9,926.71	103.25 %
Column	2,437.66	1,209	2,140.02	87.79 %	2,282.13	93.62 %
Beam	6,917.01	3,659	5,775.01	83.49 %	7,294.67	105.46 %
Wall	11,030.19	1,358	10,184.17	92.33 %	10,505.15	95.24 %
Slab	10,114.14	76	8,965.17	88.64 %	9,849.14	97.38 %

In terms of the foundation, there is a relatively small QTO difference between the manually-based and BIM-based calculation. This is because the foundation has the smallest surface area connecting with other structural elements, as well as a simple shape.

The biggest QTO difference is in regard to beams. In this case project, many beams were used (3, 659). Due to the triangular shape of the building, all beams vary in size, length, and form. Diagonal and trapezoidal beams require a particularly complex calculation process that causes omissions and errors in a manually-based calculation. However, the results of the BIM-based QTO indicate a 5. 46% gap in comparison with real input (one-third of the difference of the manual QTO, which has a 16. 51% error).

Almost all the walls are bearing walls, which are basic building structures. Most bearing walls are connected with different structural members such as slabs, beams, and columns. Therefore, there is high possibility of omission or double counting of the QTO at the end points of a wall that are connected with other members. However, the actual difference is not high, at 4. 76% (BIM-based) and 7. 67% (manual). This is because the walls comprise the structural core of the building, and the thickness and shape of all walls are constant, even on different floors.

In the BIM-based QTO, the slab calculation shows the highest accuracy (97. 38%). However, the gap between the manual QTO and BIM-based QTO is very high. In this case project, manual calculation of the slab QTO is not easy due to the curved and triangular floor shape. However, because the floor is not a geometric form and the same slab shapes are repeated on a typical floor, there is a comparatively small gap in the BIM-based QTO (97. 38%).

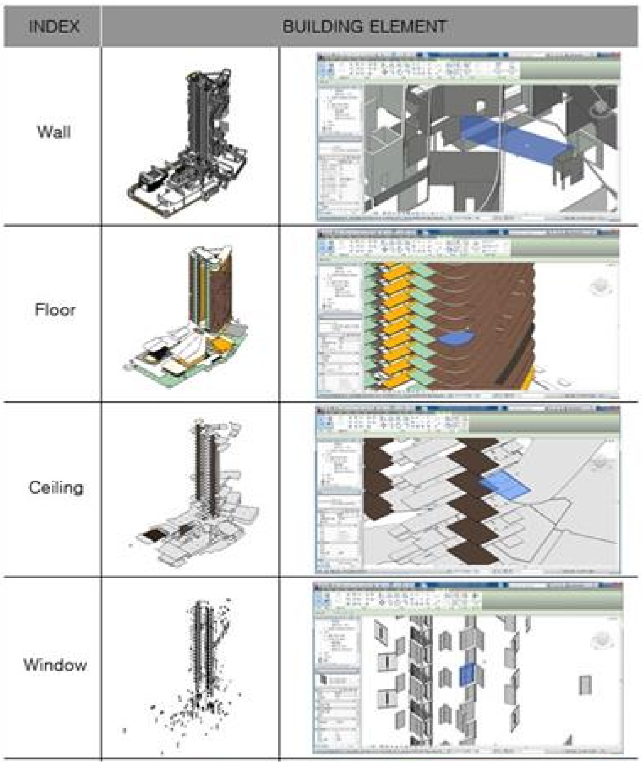
RESULTS

Despite slight QTO deviations, the overall BIM-based QTO shows average 95% accuracy in the RC structure quantity, whereas the manual QTO calculation indicates less than 89% accuracy. BIM-based QTO also shows around 94% accuracy at other building parameters, except for RC. Because we concentrated on only the RC structural frame and paper limitations, explicit result of other building parameters such as curtain wall or internal piping and duct were not expressed in this study.

In terms of manually-based QTO, 89% accuracy is not a high. Unlike a normal manually-based project in which all design and QTO calculations are carried out by hand, this case project was drawn using full-scale BIM modeling and only QTO was calculated by a manually-based approach. Given the increased completeness of the drawings that are generated by BIM for the calculation, 89% accuracy is not a high rate.

Analysis reveals that the quantity of all RC elements in the manual QTO is consistently lower than the quantity of real input, whereas the amount of BIM-based QTO indicates higher and lower aggregation in comparison with the quantity of real input. Fewer QTO calculations compared to the case of real input could result in additional costs during the construction stage (Firat*et al*., 2010). This problem is more likely to occur in other building elements calculated using the traditional approach, including curtain walls, cement, and mortar, all of which are used in substantial quantities. Thus, in the application of BIM-based QTO, project manager can reduce the potential cost risk during the construction stage.

All building elements should be easily identified in terms of which element belongs to a particular building part. As shown in Figure 6, when BIM-based QTO is applied in a project, all building elements can be aggregated, recombined, and categorized individually and automatically according to their purpose and circumstance (Jadid and Idrees, 2007). Because the location and the number of units are presented according to building element categories, partial QTO calculations and quantity re-checks are also quite easy in the BIM-based approach (Wang *et al*., 2014), which can reduce unnecessary drawing modification time. Moreover, because all connected parameters are modified automatically, drawing errors and omissions can be reduced significantly.



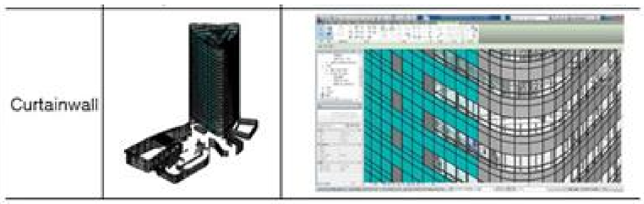


Figure 6: Attribute-specific building elements

CONCLUSION

BIM has recently been applied to address project complexity and increase project value. To improve the practical benefit of BIM, which is recognized to have a variety of important functions, we focused on BIM-based QTO. Accurate QTO is recognized as a critical factor in increasing project value. In this study, a real case project was analyzed for an objective and reliable comparison between BIM-based QTO and manual QTO.

Our findings reveal that the BIM-based approach is more feasible for a real project due to its accuracy and convenience. A BIM-based approach shows an accuracy rate (95%) that is higher than the manual approach (89%). The accuracy rate is also similarly high with respect to the QTO of other building materials such as certain walls, cement mortar, and gypsum board. Project participants can obtain all the necessary and available information about cost management by using BIM. In addition, when considering other advantages such as automatic modification and categorization, the benefits of BIM can support practical project management and increase project value. If further studies help improve the practical benefits of BIM in other aspects of construction, the BIM-based approach will take a key role in complex and large-scale projects.

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