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CRITICAL FACTORS FOR ASSESSMENT OF BIM BASED QUANTITY-TAKE OFF

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ABSTRACT: Quantity take-off (QT) is one of the most important tasks for determining the total cost of a construction project, and it requires accuracy and reliability for the result. Accuracy and reliability in BIM-based QT are also required to assure the completeness of the result. However, there has been no basis to measure the completeness of the BIM-based QT result. As BIM is increasingly being adopted in the construction industry with a wide variety of purposes, it becomes more important to have a method to improve the completeness of BIM-based QT and criteria to measure it. This research focuses on the hypothesis that the completeness of BIM-based QT relies on the accuracy and reliability of BIM and the BIM-based QT process. As a basic research to determine the completeness of BIM-based QT, this research analyzes and derives factors that affect the completeness of BIM-based QT.

Keywords: Building Information Modeling; Estimation; Quantity-take off; Evaluation Factor

1. INTRODUCTION

Building information modeling (BIM) based estimation is expected to have a great improvement in accuracy of estimation as well as efficiency in time and efforts [1], since the majority of the bill of quantity (BOQ) can be automatically taken-off out of properties of 3D models. However, although BIM is a very effective method to communicate and understand design information among participants, there has been a limit on the accuracy of quantity take-off since all the 3D models cannot be modeled at the same detail level as the actual facility.

It has been demonstrated through the authors' pilot projects for BIM-based quantity take-off (BQT) that the result of BQT can be varied depending on the degree of preparation for BIM data. That is, the accuracy of the BQT is greatly dependent on the level of detail (LOD) of the 3D model, modeling scope, and many other aspects. For example, the result of BTQ at the design development (DD) phase differs from that at the construction documentation (CD) phase. In addition, BTQ at the 1/100 scale-LOD shows a different result from BTQ at the 1/1 scale-LOD. Differences can be observed in work items that are modeled in BIM, since not all the work items are modeled. Since a more accurate and detailed BIM coincides with a more accurate and reliable BQT, the completeness of BQT can also be an indicator for the quality of BIM.

Therefore, the following questions are raised about BQT. What is the degree of completeness of a given BIM? What degree of completeness for BQT can be expected? If the completeness of BIM can be measured, the amount of accuracy that could be expected from a given BIM throughout the project life-cycle could be easily seen. In addition, the owner can specify the degree of completeness of BQT as a criterion that contractors should comply with when they submit BIM at each contract or by the completion of a building construction project. A BIM service provider can also show how much of the completeness can be improved with his/her service.

Therefore, the objective of this paper is to derive critical factors that affect the completeness of BQT, while the ultimate goal of this research is to develop a framework that can assess the completeness of BQT. First, this paper describes factors that affect estimation in the conventional way. Secondly, factors that affect the result of BQT were described with some examples based on the pilot projects performed by authors over several years. The factors are then reorganized and summarized followed by discussions and conclusions. Based on these factors, a framework is under development to measure the degree of completeness of BQT, and hopefully the prototype of the framework can be presented during the conference.

2. FACTORS THAT AFFECT EXISTING QUANTITY-TAKE OFF

Existing literatures include research projects [2, 3 and 4] that derived major factors that affect the accuracy and reliability of estimation. NRC (1990) proposed twelve categories of the factors with the seven aspects of

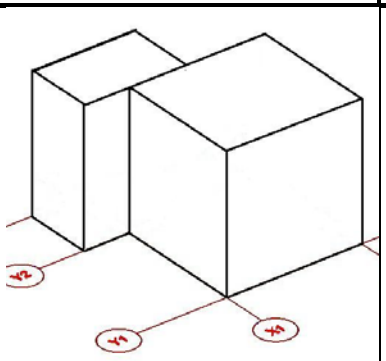
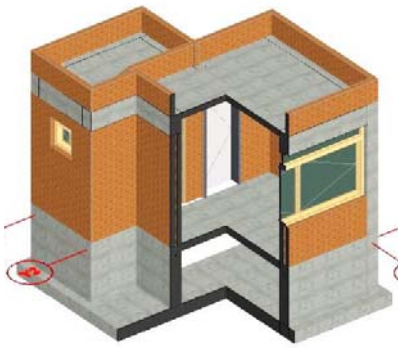
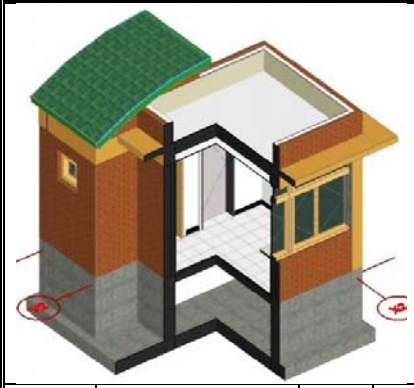
estimator's quality, information provided for estimation, arbitrary cuts, time for preliminary estimation, lack of information, and lack of design management. Based on the existing research, the common factors to improve the accuracy of estimation can be categorized as estimation method, procedure, quality of information provided, and estimator's quality and ability.

3. FACTORS THAT AFFECT BIM-BASED QUANTITY-TAKE OFF

The method of the present building design is still dependent on two dimensional (2D) drawings, such as sketch, plan, section, elevation and perspective. Since 2D drawings can easily contain discrepancies between drawings and omissions in design details, many companies have their own manual to support fast, consistent, and accurate quantity take-off without the delay caused by discrepancies and omissions. Since it takes a great deal of time to understand the manual and apply it to quantity take-off effectively, the personal experience and skill of the estimator has a great impact on the result of quantity take-off and estimation.

Compared to the conventional method of quantity take-off, BIM-based estimation has less impact from the estimator's experience and knowledge since the majority of the quantity can be automatically derived from BIM. That is, the accuracy of BQT is greatly dependent on the accuracy of BIM data. While the basis for calculating quantities is provided in the conventional way of quantity take-off, there has been a lack of a method to verify the results generated from BIM automatically in BQT. Therefore, it is necessary to measure or forecast the accuracy of the result for BQT. To do so, it is essential to derive the factors that affect the completeness of BQT, which means the accuracy and reliability of the BQT result in this research.

Table 1. Differences in Quantity Depending on LOD of BIM

Preliminary Design				Schematic Design				Design Development			
											
Object ID	Specification	QTY	Unit	Object ID	Specification	QTY	Unit	Object ID	Specification	QTY	Unit
0Z10	Office Room (Interior Finish)	8.40	M2	1F10	Waterproof	7.01	M2	1F10401	liquid water-proofing cement	7.01	M2
					Clay floor tiles			1F11008	terrazzo tile$Floor,T30	7.01	M2
				2C10	Insulation	7.01	M2	1C10102	The installation of insulation Ceiling	7.01	M2
									Expandable Poly Styrene for insulation$T125	7.71	M2
					Light Weight Metal Frame for Ceiling			2C11601	Light Weight Metal Frame for Ceiling$ M-BAR	7.01	M2
					Rockwool board				Rockwool board	7.36	M2
				3W10	Cement Mortar $wall	21.42	M2	3W10605	Cement Mortar $W18	14.09	M2
					Water(-based) paint			3W12002	Water(-based) paint$ External,	13.92	M2
					AL moulding	0.90	M	4M11801	AL moulding	10.60	M
					base paint			5B12021	base paint	0.9	M
								3W10103	The installation of insulation $wall	0.69	M2
									Expandable Poly Styrene for insulation$T125	0.76	M2

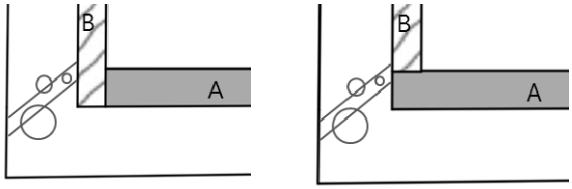
As project information evolves in terms of quality and quantity during the project life-cycle, BIM also evolves with the addition of more information at a more detailed level. In BQT, since not all the design information can be modeled practically, the accuracy level of the quantity take-off can differ somewhat depending on the level of detail of 3D models and their properties. Table 1 shows an example on how the results including bill of quantity items as well as the accuracy of those item quantities can differ depending on LOD of BIM.

The scope of 3D objects in BIM contributes dramatically to the accuracy and reliability of BQT. If BOQ items that occupy the majority of the total project cost, e.g. structural components and exterior walls, are modeled with a high level of detail, the accuracy of BIM can be greater, while building elements that occupy the small portion of total cost could be omitted or represented by other objects while considering the efficiency of BQT. However, the degree of completeness that can be achieved from the BQT is still unknown.

Another important factor to determine the accuracy of BTQ is the usage of composite objects that model various materials/components as a single object in BIM as shown in Table 2. Composite objects are complicatedly presented in 2D drawings, while in BIM they can be simple or complicated objects depending on how they are modeled. Table 1 shows that differences in quantity take-off can occur depending on how objects are modeled in BIM. Since it takes time to model composite objects with a high level of detail, modeling for interior parts is skipped or modeled in a simple way in many cases. However, the more composite are the objects used in BIM, the lower is the accuracy of BQT.

As the project develops to the construction documentation phase, the level of detail for BIM can be improved so that the building interior can be presented in 3D models. At this time, to assure the accuracy of BQT, it is necessary to reflect the construction sequence of the finish material for the building interior during model building, since the sequence can affect the quantity take-off results as shown in Fig. 1.

Fig. 1-a) shows the case where the finish material for the wall is constructed before the finish material for the floor, while Fig. 1-b) shows the opposite case. If the actual construction is to be carried out as shown in Fig. 1-a) but BIM is modeled as shown in Fig. 1-b), the difference in the quantity of B material can be as much as the thickness of A material multiplied by the wall length.



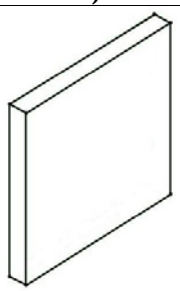
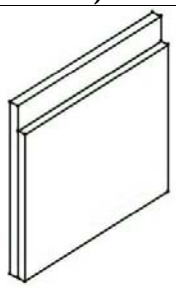
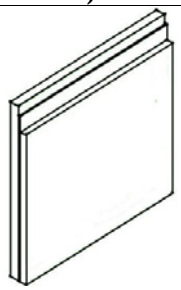
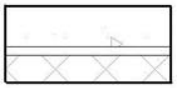
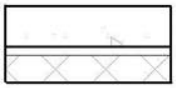
a) **b)**

Fig. 1 Section Detail for Finish Interior

Generally, there is a limit to obtaining accurate quantities using BIM created during the design phase. One of the reasons is the intersection of objects that consist of BIM. During the design phase, modelers are not concerned about the intersection of objects, particularly those such as structural components and finish materials as shown in Fig. 1, since the three-dimensional view does not reveal the overlap or the intersections appear to be handled automatically by BIM software. However, the intersections of objects can cause a dramatic impact on the quantities and cost.

Therefore, it is essential to check whether there are intersections of objects in BIM and whether the overlapped areas or volumes of the intersections are automatically deducted by using BIM software. With the verification process, BIM needs to be modified and it is necessary to confirm that the quantities generated from BIM are correctly allocated to the bill of quantities (BOQ) items. (Fig. 2-a)

Table 2. Use of Composite Object

Type		**a)**	**b)**	**c)**
Presentation of Walls with interior parts	3D			
	2D			
No. of Objects		1	2	3
Composite Objects		Both structural and interior components are modeled as a single composite object.	The Structural component is modeled as a single object, but interior parts are modeled as a single composite object.	All the components are separately modeled as different objects.

Omission of objects in BIM is similar to an omission of BOQ if it is not intentional. Omission as well as redundancy in BIM needs to be checked in a structural way to minimize the mistake.

Libraries of 3D objects are another factor that can improve the efficiency and accuracy of BQT. As more libraries are available, more efficiency can be obtained for the given project.

At the current level of BIM technology, it is relatively not effective and efficient to derive quantities of all BOQ items from 3D objects of BIM only. For example, it is possible to model reinforcing bars and forms, but it is not efficient because of the limits of experts and work time needed for modeling unless a specific tool is used for modeling these. Still, to have a parallel operation of conventional quantity take-off and BIM-based quantity take-off is judged to be more effective and efficient than using various BIM tools to model everything in BIM. Therefore, when building BQT plans, it is necessary to include plans for which quantities of parts are to be derived using the conventional method and which quantities of parts are to be generated from BIM. In addition, BOQ items can be effectively derived without being lost if they have a history database for BOQ. Then, it is necessary to determine whether the quantity for each BOQ item would be calculated based on BIM, 2D drawings, or other source of information.

The existing quantity take-off process can have a dramatic impact on BIM data and quantities of material. For example, with the conventional method of quantity take-off for cement mortar for the ceramic tiles of a bath-room wall, the existing method recommends to assume that the cement mortar is applied 100mm over the ceramic tiles as a quantity contingency. However, with BIM, it is necessary to determine how these contingencies are reflected in quantity take-off since BIM data might not be able to include the model for the part of 100 mm over the ceramic tile (Fig. 2-b). A more effective method would be to have an adjustment coefficient while BIM needs to look as real as possible. Therefore, the modeling strategy including the plan and criteria for consistent BQT should be set up to assure the accuracy of BIM regarding quantity take-off in a more consistent way.

4. CRITICAL FACTOR FOR ASSESSMENT OF BIM BASED QUANTITY-TAKE OFF

This paper describes factors that affect the accuracy and completeness of BQT in the previous section, and these factors can be summarized as follows.

1) LOD of BIM
2) Use of composite objects in BIM
3) Scope of BIM
4) Reflection of construction sequence in BIM, particularly for interior parts
5) Verification of intersections between 3D objects
6) Verification of omissions of 3D object
7) Degree of Library
8) Parallel operation of conventional quantity take-off
9) Reuse of history data for derivation of BOQ items
10) Plan and Criteria for modeling methods regarding quantity take-off

These factors can be categorized into three aspects, such as 3D models, Plan for BQT, and preparation of BOQ. With these aspects, an analysis was carried out to determine how these factors affect the completeness, i.e., the accuracy and reliability, of BQT overall.

To assure more accurate and reliable BQT in terms of building 3D models, it is important to have a higher LOD based on the effective scope of modeling for BQT; to reflect the construction sequence in 3D models; and to verify the intersections and omissions of 3D models.

In terms of building a plan for BQT, procedures and guidelines for BQT are necessary and a sufficient library is required to support the efficient process of BQT. A strategy for the parallel operation of conventional QT and BQT is considered to be necessary at this time based on an understanding of the limits of BIM related technology.

The preparation of BQO is also an important factor since the reuse of historical data and use of a standard breakdown structure for BOQ can contribute a great deal to not only the completeness but also the productivity of BQT.

Furthermore, Fig. 3 shows that the factors for BQT are comprehensive of the factors that affect the conventional estimation mentioned in Section 2. The estimator's experience and knowledge governs significantly in the conventional way of quantity take-off since much of the information is hidden in 2D drawings. However, the authors of this paper insist that the estimator's quality is absorbed into the plan and criteria in BQT, because the completeness of BQT is governed by how a given BIM is built based on the plan and criteria.

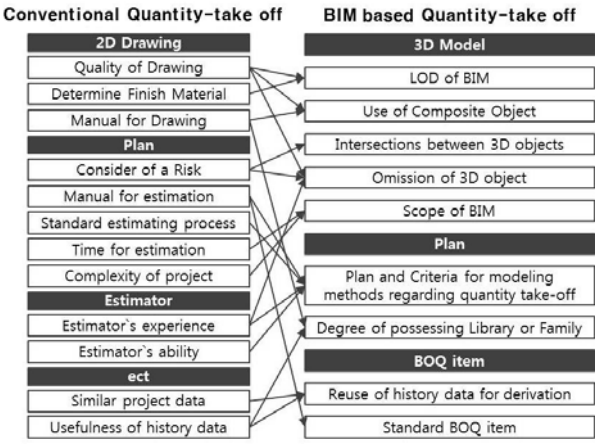


Fig. 3 Comparison of the factors that affect the conventional Quantity-take off and BIM-based process

5. CONCLUSIONS

While we do not insist that the completeness of BQT must be perfect, we insist that it is necessary to know the degree of completeness of BQT. Throughout the project life-cycle, BQT can be performed many times with a different degree of completeness.

This paper focuses on how the completeness of BQT can be measured based on the various types of factors. This paper showed that the completeness of BQT could be varied depending on critical factors as shown in Fig. 4. It is judged to be important to measure the completeness of BQT more effectively, if the factors can be grouped into more representative factors and can be measured quantitatively since they are also related to each other.

With this in mind, a framework that can assess the completeness of BQT in terms of accuracy is currently under development. When the framework is developed and enough case studies are performed to measure the completeness of each case, it would be possible to suggest a guideline on the appropriate degree of completeness of BQT at each phase of a project life-cycle.

Participants of a BIM-based project could use the framework to measure the completeness of BIM to determine how much a given BIM is improved through their services.

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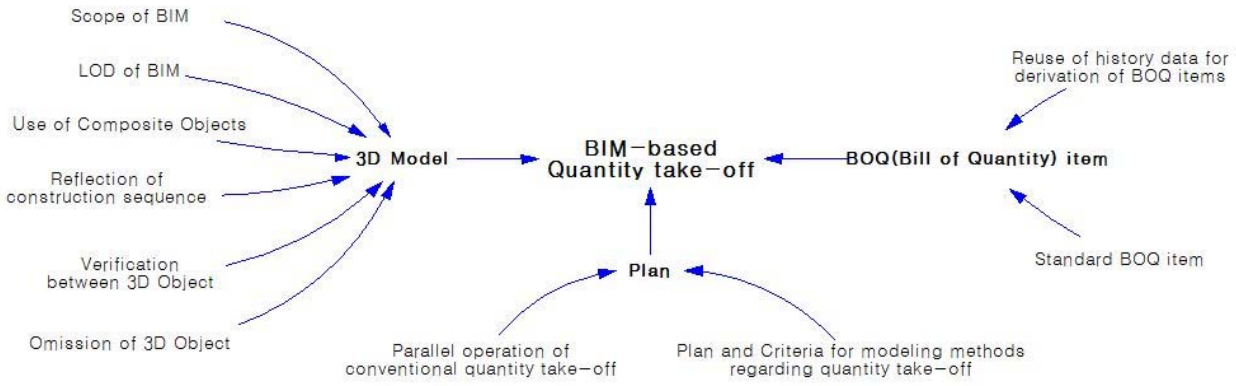

Fig. 4 Critical factors for Assessment of BIM based Quantity-take off