How Much Discrepancy Can Happen from BIM-based Quantity Take?

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***Abstract:** Stakeholders of a construction project expect cost savings through fast and accurate cost analysis by performing BIM-based quantity take-off (BQT). However, authors have observed that there can be discrepancies in the results of BQT depending on the level of development (LOD) and modeling methods. In addition, since quantity take-off methods are different depending on the construction work items, the combination of LOD, modeling methods of BIM, features of construction work items can cause serious overestimate or underestimate in BQT results. It is necessary to identify what kind of problems can happen and how those problems can be avoided in various construction work items, since the discrepancy of quantity take-off results has great impact on not only cost analysis but also the determination of contract amount and it can cause claims, poor construction quality, cost overruns, and many others later in the construction project. Therefore, this paper focuses the identification of issues and problems of BQT at each construction work item level based on two categorizations of structural works and interior works.*

***Keywords:** Building Information Modeling (BIM), Level of Detail (LOD), Modeling Method, Quantity Take-off*

I. INTRODUCTION

The most important management element in a construction project is cost. The BIM-based quantity take-off (BQT) is effective for cost management in preventing the omission of quantity and error, compared with the existing methods [1, 2]. Stakeholders of a construction project expect cost savings through fast and accurate cost analysis by performing BQT. However, the quantity calculated from the BIM is not always accurate. Because authors have observed that there can be unexpected discrepancies in the results of BQT depending on the level of development (LOD) and modeling methods [3]. In addition, since quantity take-off(QT) methods are different depending on the construction work items, the combination of LOD, modeling methods of BIM, features of construction work items can cause serious overestimate or underestimate in BQT results [4, 5].

Because the cost calculated from BQT could be a condition of agreement in a construction project, it should be accurately diagnosed and predicted. And, it is necessary to identify what kind of problems can happen and how those problems can be avoided in various construction work items, since the discrepancy of QT results has great impact on not only cost analysis but also the determination of contract amount and it can cause claims, poor construction quality, cost overruns, and many others later in the construction project.

This paper aims to explain the modeling method on two categorizations of structural works and interior works and the difference in quantity following the results of BQT test. The scope of research is at the level of LOD 300 ~ 350 [6], and excludes the rebar and modeling for fabrication and assembly. And this paper focuses on the identification of issues and problems of BQT at each construction work item. It is expected that sharing of the issues and resolution on this topic can be utilized for developing BIM guidelines as well as for facilitating BIM at construction projects.

II. FEATURE OF 3D MODELING METHODS

In 3D CAD or BIM authoring tool, the elements needed for modeling of a building such as columns, beams, walls, slabs and so on are provided as objects. In the 3D modeling method of a building, it is important to identify how various objects interact and how the quantity of object is changed by interaction [5, 7].

Structural works are calculated the quantity for each element, but interior and exterior works are calculated the quantity for each area made of elements. In addition, there is a difference in the methods of expression of interior work item with 3D object. This study aims to examine the characteristics of modeling by dividing into these two categorizations.

A. Structural Works

For structural works, the modeling cases can be divided into three kinds by the interaction of 3D object as in Fig. 1. Though there are more modeling cases than Fig. 1, we selected the representative method used for modeling of buildings.

Case A and B in Fig. 1 have no overlap in elements, but Case C has an overlap in elements. Case A is a case in which the depth of beams and height of columns are maintained and the area of slab is adjusted. On the other hand, Case B is a case in which the area of slab is made the same as the floor area and the depth of beams and height of columns are adjusted.

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In the structural works, it is needed to check the difference in quantity by the interaction of 3D object. If a difference in quantity occurs by the interaction of object, it is needed to examine if it occurs by the same rule in each BIM Tool. In addition, it is needed to check if the difference occurs only internally in the BIM Tool or the difference in quantity occurs also through the standard format such as IFC. It's because in the BIM project, the loss following the exchange of data can bring a greater risk.

B. Interior and Exterior Works

Some BIM Tools support the object for only the modeling for interior materials. However, in general, the modeling of interior materials is conducted by using the object such as structure elements. It's because the objects such as columns, walls and slabs include the properties for interior materials.

In the initial stage of design, in some cases, the modeling of interior materials are conducted together with structure elements as in Case A in Fig. 2 or interior materials are expressed only with Materials and Textures in 3D Window. As design proceeds, the modeling is conducted by separating the interior materials as in Case B and C in Fig. 2 to increase the level of detail (LOD). Case B in Fig. 2 is a case in which the interior materials and structure are separated, but the modeling of interior materials is conducted by using the composite object. Case C in Fig. 2 is a case where the composite object is not used, and the modeling is conducted by separating the interior materials from each other. Case C in Fig. 2 has the highest LOD.

In the modeling of interior works, it is needed to check the difference in quantity following the degree of use of composite object and separate object. It is because in the composite object, only the quantity of one object is calculated though there are several interior materials, but in the separate object, a variety of quantity is calculated following the kinds of interior materials.

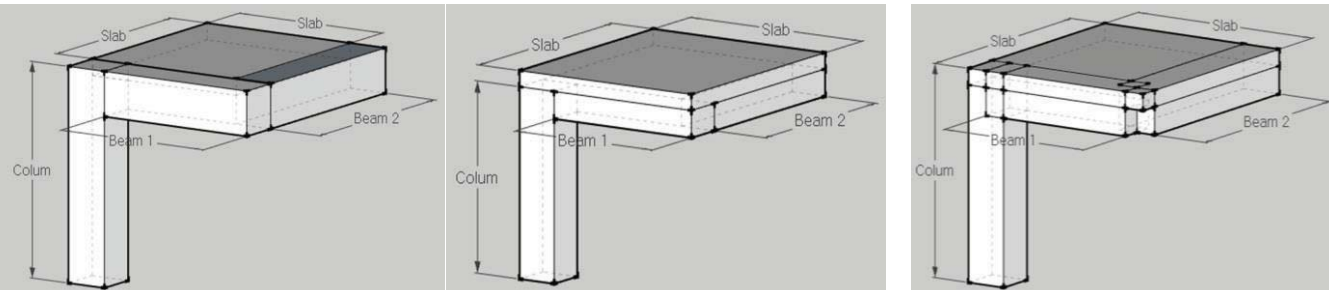
III. BQT Pilot Test

In the structural works, it is needed to check the difference in quantity by the interaction rule between elements, and in the interior finish works, it is needed to check the difference in quantity following the LOD and modeling method [7, 8]. As the categorizations for checking the difference of quantity are different depending on the model, this study conducted the test by dividing the BQT into the structural works and the interior works.

A. BQT for Structural Works

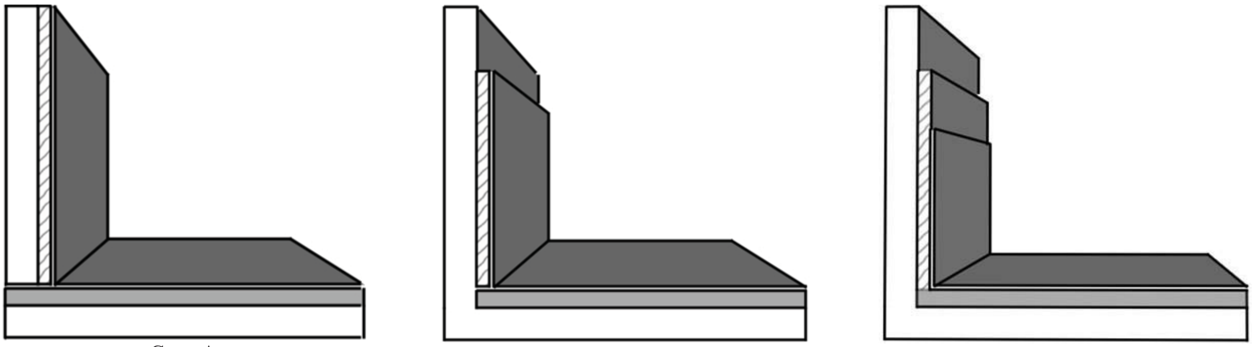
The standard of modeling of structure elements was the three types in Fig. 1, and the four kinds of elements of columns, beams, slabs and walls were selected as the subject of modeling [8]. The test was conducted by testing the interaction of columns, beams and slabs first and testing walls separately so that the review of quantity would be relatively easier. For the BQT test, the two BIM tools well-known in the field of architecture were used, and an additional review was conducted on the quantity calculated internally in the BIM tool and the quantity exported to IFC.

As a result of the test, no difference in quantity was found in the model with Case A and B in Fig. 1 with no overlap of elements as the standard. But, a little difference in quantity occurred in the case of modeling for all elements to be overlapped as in Case C in Fig. 1.(Table 1)



CASE A CASE B CASE C

FIGURE I. 3D MODELING METHODS FOR STRUCTURAL WORKS



CASE A CASE B CASE C

FIGURE II. 3D MODELING METHODS FOR INTERIOR WORKS

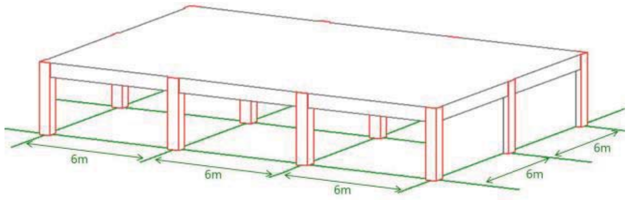


FIGURE III. STRUCTURE MODEL FOR BQT TEST

TABLE I
BQT RESULT OF CASE C FOR STRUCTURE WORKS (m^3)

Quantity	BIM Tool				Traditional QT (T)
	A	IFC from A	B	IFC from B	
Slab	28.21	28.21	34.22	34.22	34.22
wall	5.23	5.23	7.2	7.2	5.23
Beam	22.3	22.3	15.72	15.72	16.70
Column	9	9	7.9	7.9	8.55
Total	64.74	64.74	65.04	65.04	64.70

In Table 1, Quantity of Traditional QT and BIM tool A were little difference. But Quantity of Traditional QT and BIM tool B showed a difference of 0.34. The result shows that the total quantity is similar, but element quantities are different depending on the BIM tool.

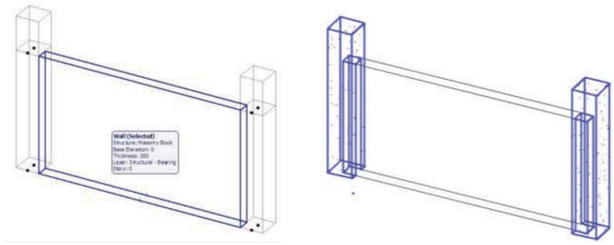
When estimating the quantity of slabs and beams in Table 1, you can see that there is a difference in quantity of BIM Tool A compared with other cases. In BIM Tool A, when one element and another element are intersected internally in the program, the element of higher priority will remain intact [9]. In the BIM Tool A, beams have a higher priority than that of slabs, and beams are intact.

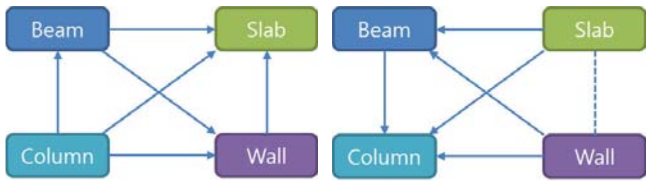
In addition, it could be checked that not only the quantity of beams but also the properties of geometry change through the IFC Viewer. Though the quantity of beams increased in what transferred from BIM Tool A to IFC, the properties of geometry of beam object was maintained as representation. On the other hand, the quantity was maintained in what transferred from BIM Tool B to IFC, but the properties of geometry of beam object changed into boundary extrusion. In BIM Tool B, the elements excluded the overlapped parts and thereby changed the geometry of object.

Especially, it is found the quantity discrepancy according to IFC transfer option in BIM tool A. By the option, It is stored in IFC file that quantity extracted from model overlapping elements or not.

When a wall and a column meet each other, the wall was subtracted as much as the part overlapped in BIM Tool A. On the other hand, in the BIM Tool B, the columns were subtracted. The same phenomenon occurred also when transferring to IFC. When walls and beams interacted, the walls were subtracted in the BIM Tool A, and the beams were subtracted in the BIM Tool B. There was no difference in total quantity in both of them. However, when walls and slabs interacted, it was found that the quantity of overlapped parts was not subtracted in both BIM Tool A and B.

Therefore, the interaction rule of BIM Tool is summarized as in Fig. V. The relationships between beam and column and slab and wall were the same in the BIM Tool A and B. However, the relationship between wall and other elements showed a complete opposite tendency. In addition, other elements are subtracted when elements meet each other, but slab and wall were not subtracted and the quantity was calculated by being overlapped. This remained the same even after the transfer to IFC.


a) BIM Tool A b) BIM Tool B
FIGURE IV. INTERACTION BETWEEN WALL AND COLUMN



a) BIM Tool A b) BIM Tool B

*Legend : A → B A is removed with B,
A - - - B A isn`t removed with B, just overlap

FIGURE V. INTERACTION RULE EACH BIM TOOL

B. *BQT for Interior Works*

In the BQT for interior finish works, the quantity is different depending on whether to use the method to express interior materials, that is, to use the composite object or the separate object. This test aims to use the modeling with composite and separate object with $82m^2$ and $116m^2$ which are the unit household of an apartment house as the subject. In addition, the range of BQT test is the interior finish works excluding the furniture.

As a result of BQT test, it could be known that the quantity gets more accurate when using the separate object, that is, when the LOD of model is higher. In addition, it was found that the quantity gets more accurate due to the combination of the materials in which the quantity of interior finish works increases and the materials in which the quantity of interior finish works decreases. So, the results were arranged into the case that the quantity from composite object model is greater than the one from separate object model and the case of the other way as shown in Table 2. It is found that the average and SD are even greater, which explains that composite object model does not always generate more quantities for interior work items, and less work quantities were also observed in some cases.

The causes of quantity difference are divided into three kinds: 1) level of detail or level of development (LOD) of 3D model, 2) derivation of wrong length from 3D object due to material thickness, and 3) unnecessary modeling of finish material in composite object-based models. In addition, these causes act in combination. If the No. of Occurrence is realigned as Cause of Quantity Difference, it is the same as Table 3.

TABLE II
ANALYSIS OF QUANTITY DISCREPANCIES

Quantity Difference		No. of Occurrence	Average	Standard deviation
Case B < Case C	$82m^2$	10	18.9%	0.114
	$116m^2$	17	16.4%	0.109
Case B > Case C	$82m^2$	26	28.3%	0.223
	$116m^2$	26	30.8%	0.226

TABLE III
OCCURRENCE FREQUENCY BY CAUSE OF QUANTITY DIFFERENCE

Cause of Quantity Difference		Case B < C		Case B > C	
		$82m^2$	$116m^2$	$82m^2$	$116m^2$
1	Level of Detail	10	14	6	4
2	Derivation of Wrong Object Length	-	3	9	12
3	Unnecessary modeling	-	-	6	8
1,3	Combined Causes	-	-	5	3

The derivation of wrong object length is the reason why the quantity of composite model is less than the quantity of separate model. The reason why the quantity of composite model is more than the quantity of separate model is that there are the parts that cannot be expressed with a model due to level of detail, and the quantity cannot be calculated due to that.

The composite model with a lower LOD cannot help having an unnecessary modeling relatively. The representative example is the case in which the final interior materials are excluded due to built-in furniture. In Korea, the final interior materials are not installed in the elements where built-in furniture is installed. In the composite model, one cannot subtract specific materials in a specific element, and thus an unnecessary modeling occurs.

IV. ISSUES OF BQT RESULTS

This paper analyzed the characteristics of 3D modeling by dividing into structural and interior finish works, and analyzed the difference in quantity following the modeling method and LOD through the BQT test.

First, it is important to prevent the overlap following the interaction of elements and addition of quantity due to that in the 3D modeling for structural works.

In the BIM tool mainly used in the field of architecture, the overlapped parts of elements are solved through the interaction rule internally in the program. However, the supported interaction rule is different depending on the BIM Tool, and not the overlap of all elements is solved.

In addition, in the 3d party program directly connected to the BIM Tool, the quantity is subtracted by the overlap of elements, but, the quantity is not subtracted when exchanging to IFC. The quantity is added because the IFC translator ignores the interaction rule of BIM tool and saves the properties of 3D object as they are. Meanwhile, even though the IFC translator saves the results with overlap of elements removed by the interaction rule and the quantity is not added, the properties of geometry of 3D object comes to change. The 3D modeling method should be determined through the cooperation with various participants paying attention to this issue.

The best is to conduct the modeling so that there will be no overlap of elements at all, but, when it is impossible, this can be reviewed through a program that automatically checks the parts overlapped between elements such as Solibri Model Checker. However, there is a tendency that even the minute parts such as the overlap of column and slab are reported as an error in the results of automatic check through a program. Hence, it is needed to double-check if the results automatically verified by a program agree with the actual conditions.

In the interior finish works, a difference in quantity occurred following the LOD and construction method not like in the structural works. This difference in quantity was due to the combination of increase and decrease of quantity. It was found that the main causes for increase of quantity are Level of Detail and Level of Development, and that the main causes for decrease of quantity are Derivation of Wrong Object Length and unnecessary modeling.

The fact that there is a difference in quantity following the LOD of model in the BQT for interior finish works means that the quantity calculated from the model with lower LOD (Design BIM) is different from the actual quantities. The increase in construction cost due to the difference in the quantity of materials can cause claims, fall in quality of construction, shoddy and fault construction and so on.

Theoretically, the BIM completed in the stage of design has a LOD not higher than that of the BIM completed in the stage of construction. One should not unconditionally believe the quantity calculated from the BIM completed in the stage of design, because the quantity and construction cost calculated from the model with a lower LOD are different from the actual cost.

V. CONCLUSIONS

This study closely examined the realities and problems of calculation of quantity of each work type by dividing into the structural works and interior works on the basis of the results of test of quantity calculation based on BIM. As a result, it was found that the cause for discrepancy is different between structural works and interior finish works.

As the difference in quantity of structural works in BQT is due to the overlap of elements, it can be solved internally in the program. But, attention should be paid when transferring to IFC. On the other hand, in the interior works, a difference in quantity occurs following the LOD and construction method, and this is not solved internally in the program. In the BQT for interior finish works, a proper plan for each stage should be established, and it should be able to reflect the difference in quantity following the LOD and construction method.

It is expected that sharing of the issues and resolution on this topic can be utilized for developing BIM guidelines as well as for facilitating BIM at construction projects.

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