Using BIM to Automate Information Generation for Assembling Scaffolding - A Material Management Approach

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Abstract –
In a construction project, the scaffolding system is an important temporary facility to support the process of construction. Without properly assembling scaffolding, the construction process could be delayed, and workers could be exposed to danger. However, construction workers usually rely on their past experiences to assemble scaffolding without detailed planning. Consequently, lack of necessary components delivered to the site, assembling does not match with the construction process, or staggered with the floor of the building, could occur and jeopardize the construction project.

Building Information Modeling (BIM) is the emerging technology that can help construction engineers obtain information for detailed planning. However, the scaffolding system is not usually developed in the BIM model. Although several researchers have developed programs that can automate assembling scaffolding in the BIM model, the results could not provide construction managers with sufficient information to make decisions in terms of various environmental scenarios.

This research establishes a mechanism to automate information generation for assembling scaffolding from the perspective of material management. First, a thorough interview with stakeholders related to the scaffolding system is conducted to identify the uses and information requirements. Then, an ontology model is employed to determine the specification to develop the scaffolding system within the BIM model. Afterward, a series of Dynamo modules are developed to automate assembling scaffolding in the BIM model. Finally, the result shows that with the implementation of Dynamo modules, the detailed information of assembling scaffolding can be effectively and efficiently obtained.

Keywords –
Automate Scaffolding System; BIM; Ontology; Dynamo; Material Management

1 Introduction
The scaffolding system is an important temporary facility to support the construction and preserve safety at the construction site. Therefore, a good planning of scaffolding is crucial to the success of the construction project. However, the planning of the scaffolding system typically relies on the experiences of construction engineers or workers without detailed analysis. Consequently, lack of necessary components delivered to the site, assembling does not match with the construction process, or staggered to the floor of the building, could occur and jeopardize the construction project. All of these incidents will increase the risk of falling events and danger worker’s lives. In addition, workers usually dismantle scaffolding for their needs but don’t assemble them back when the activities are completed. This causes the need for additional efforts to restore the scaffolding. In 2008, Wu et al. [1] mentioned that hanging material, setting up the garbage chute, and other construction needs will make openings of scaffolding. Consequently, the scaffolding attached to an external wall may not continue in both horizontal and vertical direction, which could be structurally unstable and dangerous to workers. Such incidents not only could delay the project but also increase the costs.

Building Information Modeling (BIM) is the emerging technology that can help construction engineers obtain information for detailed planning [2]. However, the scaffolding system is not usually developed in the BIM model. Although several researchers [4] [5] [7] have developed programs that can automate scaffolding assembling in the BIM model, the results could not provide construction managers with sufficient information to make decisions in terms of various environmental scenarios.

This research establishes a mechanism to automate information generation for assembling scaffolding from the perspective of material management to provide information for detailed analysis. First, a thorough interview with stakeholders related to the scaffolding system is conducted to identify the uses and information...
requirements. Then, an ontology model is employed to determine the specification to develop the scaffolding system within the BIM model. Afterward, a series of Dynamo modules are developed to automate assembling scaffolding in the BIM model. Finally, the result shows that with the implementation of Dynamo modules, the detailed information of assembling scaffolding can be effectively and efficiently obtained.

This paper is organized as follows. First, a review of the studies on planning and managing the scaffolding system is presented. Next, the framework and methods of this study are explained in detail. The implementation of automatically constructing scaffolding in BIM is demonstrated in the section as well. Then, the proposed system is validated through a case study in which the limitations and the contribution will be discussed. Finally, a research orientation for future works is suggested.

2 Background and Problem Statement

In 2012, CII [3] (Construction Industry Institute) collected information by conducting interviews with 56 experts to build the current industry in estimating, controlling and managing the scaffolding system as shown in Figure 1. In the estimating phase, the construction cost plan is established. Project participants began to analyze the needs of scaffolding by taking the initial construction schedule and the estimated amount of monthly use into account to generate the expected worksheet. This worksheet is based on the fuzzy theory to estimate the materials used and the associated costs. During the control phase, the monthly used amount of scaffolding must be tracked and compared with the initial plan. These differences and expected results will be reported at a regular meeting and discussed during the management phase to improve the efficiency of construction management. A complete management includes changing materials, preventing improper assembling methods and removal and optimization of using scaffolding.

![Figure 1. The current industry in estimating, controlling and managing the scaffolding system](image)

From this process, there are still some drawbacks to establish the scaffolding system. In addition, the amount of scaffolding materials and the costs are estimated according to the printed drawings. If changes in the printed drawings are not promptly identified, the information could be inconsistent and confusing.

2.1 Existing Methods of Scaffolding Management

Kim and Fischer [4] established an automatic temporary facility type selector to analyze the geometric information of the model based on the work face and the base surface in 2007. However, in their research, the work face and the base surface still need to be determined manually.

Additionally, CADS [5] is a smart scaffolding system developed by smart scaffoldor, which can generate the customized saddlings based on building walls. But, aiming at different works or schedules, it will not meet with the construction progress and rely on the experience of field workers to make decision. Although CADS can be used in BIM environment, it takes more time to check the compatibility resulting in increasing the time to integrate the data.

In 2016, Kim et al. [6] used BIM to integrate the construction sequence to discuss the safety management of the scaffolding and produce preventive measures. However, only a few of rules are identified, and information related to tools and materials that used to assemble scaffolding is not provided.

2.2 Using BIM in Automating Construction of Scaffolding

Kim et al. [7] proposed an automate assembling scaffolding planning system in 2014. First, they defined the rules of assembling scaffolding according to the practical experiences provided by contractors or suppliers and regulations required. Then, by manually identifying the work face and the base surface, the geometry of the BIM model can be interpreted to build the scaffolding system. After the final design is completed, a report to make communication more smoothly can be generated as well. This approach can make assembling scaffolding in BIM be planned in advance to avoid unexpected costs.

However, for the connection between the work face and the base surface is still manually decided, which may be time-consuming and error-prone.

Based on the above discussion, there are still several issues needed to be solved:

1. A more systematic approach to identify the information requirements for assembling the scaffolding system in BIM according to material management.
2. The process of developing scaffolding systems in
BIM should be more effective.

(3) The information should include the detailed bill of material for the scaffolding system along with the construction progress.

3 The Proposed Framework

Figure 2 illustrates the framework used in this study.

First of all, the specifications of the scaffolding system required by Taiwan government are employed to obtain the constraints for assembling the scaffolding system. In addition, field experts are interviewed to identify the critical factors and important information requirements. 2D drawings or BIM is then used to provide the geometry information of the building.

Next, an ontology is developed to interpret the knowledge obtained from the government requirements and the interview with experts. Then, the rule for developing the scaffolding system in BIM will be established that can satisfy the information needs in terms of material management.

In the research, Autodesk Revit and its visual programming tool, Dynamo, are employed to automate the process of building the scaffolding system in BIM [8].

Finally, the information related to the scaffolding system in BIM is exported to Microsoft Access to produce the bill of material of assembling the scaffolding system according to the construction progress.

3.1 Ontology for Assembling Scaffolding in BIM

To automate the information generation for assembling scaffolding, the interpretation of the field practice at the construction site is needed. In this research, organizing the rules and the interview contents to know the current operation of assembling scaffolding is required. Then, we use the information to build the ontology model that includes classes, attributes, data properties and their relationships between the classes. [9] Figure 3 shows the ontology schema used in this study.

Figure 3. The schema of the ontology model

This study develops the ontology model by four classes: impact factors, assembling methods, scaffolding elements, and resources. Impact factors are shape, plane, neighborhood, topography, and work item. Assembling methods are general, cantilever, corner, and leveling. Impact factors will be linked to the required assembling methods by using “IsNeed”. Work items will be marked by using “HasRelatedToWorkItem”. This relationship can define that the assembling schedule will match with the project schedule. Assembling methods are defined according to the required elements and resources by using “IsRelatedTo” and “NeedResource”, respectively. After the ontology model is established, the assembling methods can be identified according to the inferred results. For example, if the exterior wall of building is plane, the scaffolding can be tightly arranged. In addition, if a crane is required to assemble scaffoldings, the required arm length and load capacity of the crane can be determined. Furthermore, the topography of the construction site can be determined if the construction site requires leveling. Table 1 shows the structural information.
Then, the semantic information is input into the ontology categories to establish the data attributes and connect all related classes. This classification allows the ontology to inherit knowledge so as to provide the rules for assembling the scaffolding system. Figure 4 shows the relationship between classes and data properties. In order to gain the relationship, SWRL rules need to be written, as shown in Table 2. After running the rules in the Protégé, the inferred result can be obtained as shown in Figure 5.

### 3.2 Dynamo Modules for Developing the Scaffolding System

#### 3.2.1 Scaffolding Composition Elements

In this study, Dynamo is utilized to create necessary scaffolding components according to CNS4750 A2067, which is the specification for the scaffolding system in Taiwan.

The procedures of developing the scaffolding elements is as follows.

1. Organize the current specification size and analyze the different needs:

   Depending on the type of project, such as regional restrictions, contractual content, building geometry, etc., there are different requirements of scaffolding components.

2. Build the main component by specification:

   Dynamo is used to design the composition mainly by the point, line, and surface, followed by the size of the specification. Drawing in the sequence of the frame, cross braces, and the board as shown in Figure 6.

3. Other components:

   Such as wall ties, tripods, etc. are also required to be drawn depends on different projects. And some of the pieces of hardware can be obtained by the back-end operations, it does not need to be drawn in particular. Figure 7 shows the components made by this paper.

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**Table 1. Structure the semantic information**

<table>
<thead>
<tr>
<th>Class</th>
<th>Subclass</th>
<th>Subsubclass</th>
<th>Attribute</th>
<th>Datatype</th>
<th>Semantic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Support Factors</td>
<td>Generalize</td>
<td>Height, Depth, Unit Height, Material</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 2. Ontology rules of scaffolding systems**

<table>
<thead>
<tr>
<th>Class</th>
<th>Rules</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assembly</td>
<td>Shape('X') | HasFoundation('X', 'X'), 'O', | with lessThan('O', 'O'), | with greaterThan('O', 'O'), | Height('X'), | Shape('X') | inShape('X'), 'Y', 'Y') | Rectangle('Y')</td>
</tr>
<tr>
<td>Impact</td>
<td>Shape('X') | HasFoundation('X', 'X'), 'O', | with greaterThan('O', 'O'), | with lessThan('O', 'O'), | with greaterThan('O', 'O'), | with lessThan('O', 'O'), | inShape('X'), 'Y', 'Y') | NonResource('X')</td>
</tr>
</tbody>
</table>

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**Figure 4. The relationship between classes and their data properties**

**Figure 5. Inferred results of the ontology model**

**Figure 6. Dynamo module of scaffolding components**

**Figure 7. The component made by Dynamo module**
3.2.2 Automate the Process of Assembling the Scaffolding System in BIM

Scaffolding is usually not developed in the BIM model due to the mature of its supportive uses. In addition, the process of developing scaffolding requires a lot of effort to make the model match with the construction progress. In this study, Dynamo is employed to automate the process of assembling the scaffolding system within the Revit environment. The following section describes the procedure performed by using Dynamo in Revit.

1. Retrieve the boundary condition:
   The boundary condition can be identified based on the length and height of the building, the width between the building and the scaffolding, and the angle between the adjacent exterior walls of the building.
   The length and height of the building are used to determine the locations for placing the scaffolding composition elements developed in the previous section. The locations are determined every 1800mm and every 1700mm along the length and the height of the building, respectively. For the corner, the angle is the important parameter. Figure 8 shows the angle types. There are three angle types: A. Right angle, B. Obtuse angle and C. Acute angle and two polygon shapes: concave and convex. These are important parameters considered to automate the process of assembling the scaffolding system.

2. Place the components:
   According to the above step, the placement of the scaffolding composition type and the reference floor are determined. The scaffolding compositions are placed at the locations determined in step 1.

3. Joint the components and adjustments:
   After placing the scaffolding compositions, the distance and the corner between the scaffolding and the building can be adjusted according to specifications.

4. Place other components:
   It is learned from the interview experience that the wall tie should be placed in every three scaffolding units horizontally and every four scaffolding units vertically. Guardrails will be placed on the top level of the scaffoldings. Tripods and adjustments will be placed on the bottom level of the scaffoldings. Figure 9 shows the Dynamo modules of automating assembling scaffolding, and Figure 10 shows the assembling results.

3.3 The Implementation of Material Management

The material supply needs to keep up with the construction schedule. The amount of scaffoldings required is usually calculated by areas. Practically, scaffolding contractors roughly estimate the quantity of material needed for scaffolding without detailed information. If the materials needed for assembling scaffolding are not adequate in terms of size or quantity, the subcontractor may need extra time to transport the materials, which may delay the construction progress. In addition, if the materials are excessive, they will be placed on the site at the construction, which will increase the risk of being stolen and corrosion.

After the scaffolding system is built in BIM, the detailed information of assembling scaffolding can be produced, and those required to assemble scaffoldings will be managed by Microsoft Access in this study. Figure 11 shows the data flow of the material management in this research.
4 Case Validation

The science and technology college building at National Cheng Kung University in Taiwan, as shown in Figure 12, is used for verifying the proposed approach. The exterior of the facility is over 50 meters in height, therefore scaffolding of CNS4750 must be used according to the construction specification.

There are three sections of this facility. Two buildings are with 7 and 8 floors, respectively, and a corridor that connects these two buildings.

The two faces of the facility are chosen to assembling the scaffolding. The depths of the work faces are less than 77 cm, so a full set of scaffolding is not required. And the topography is even, laid leveling is not required. Cranes are required to transport the scaffolding materials because of the total height. One face needs adjustments in the bottom scaffolding, and the other face needs tripods in the bottom scaffolding. Table 3 and Figure 13 shows the parameters which are put into the ontology model and the inferred results.

Then, based on the inferred ontology results, the proposed Dynamo modules are applied to develop the scaffolding system in BIM. Figure 14 is the Dynamo module of this case study. Through the use of Dynamo modules in the BIM model, as shown in Figure 15, it can immediately demonstrate the adjustments and the tripods which are needed to be considered in this model.
After automating the process of assembling scaffolding, the bill of material to the scaffolding is generated with the schedule. Figure 16 shows the output from the material management system developed by using Microsoft Access. The upper one is the bill of material according to the delivery time. In this bill of material, this study places the work item in order to match the schedule. The other one is the bill of material according to the purchase order number. With this bill of material, the owner can easily know the cost flow, and where the material will be used.

5 Conclusion

In this study, a framework that can automate the process of generating information for assembling the scaffolding system is developed in terms of material management. This study analyzes the boundary conditions and impact factors to make the process of assembling scaffolding more efficient. In addition, this study also helps others for sharing the knowledge of assembling scaffolding. The implementation of Dynamo shows that the process of generating information for assembling scaffolding system can be optimized. Finally, the detailed information for assembling scaffolding can be effectively generated from the BIM model developed and then output for the use of the management system.

Several issues are not discussed in this study and can be studied in the future. 1. The complex of the geometric shapes of the exterior of the building. 2. Various types of scaffolding employed. 3. More detailed construction activities related to scaffolding.

Acknowledgement

This work was supported by the Ministry of Science and Technology, Taiwan under Grant MOST105-2221-E-006-047-MY2.

References


