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

C. W. Feng [a] and T. F. Hsu [b]

Department of Civil Engineering, National Cheng Kung University, Taiwan
E-mail: [a] cfeng@mail.ncku.edu.tw, [b] wai710040@hotmail.com

Abstract –

In a construction project, the scaffolding system is an important temporary facility to support the process of construction. Without properly assembling scaffoldings, the construction process could be delayed, and workers could be exposed to danger. However, construction workers usually rely on their past experiences to assemble scaffoldings 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 scaffoldings 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 scaffoldings for their needs but don't assemble them back when the activities are completed. This causes the need for additional efforts to restore the scaffoldings. In 2008, Wu et al. [1] mentioned that hanging material, setting up the garbage chute, and other construction needs will make openings of scaffoldings. 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 scaffoldings 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 scaffoldings 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 scaffoldings 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 scaffoldings 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 scaffoldings.

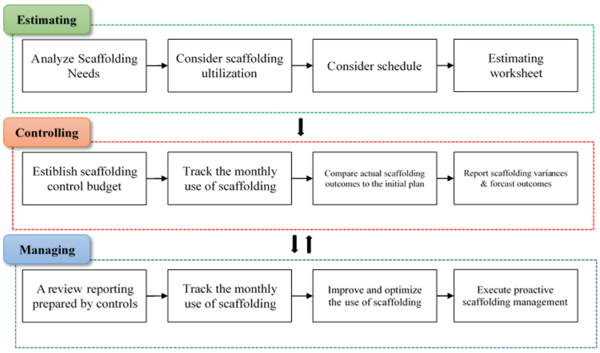

Figure 1. The current industry in estimating, controlling and managing the scaffolding system

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 scaffolder, which can generate the customized scaffoldings 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 scaffoldings 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 scaffoldings 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.

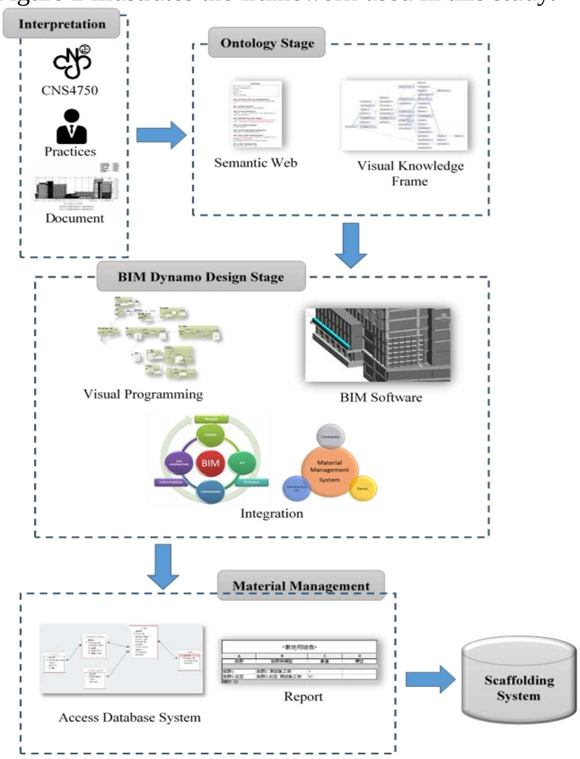

Figure 2. The framework of automate generation of scaffolding system- a material approach

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].

Eating hambergr at home can satisfy him.

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.

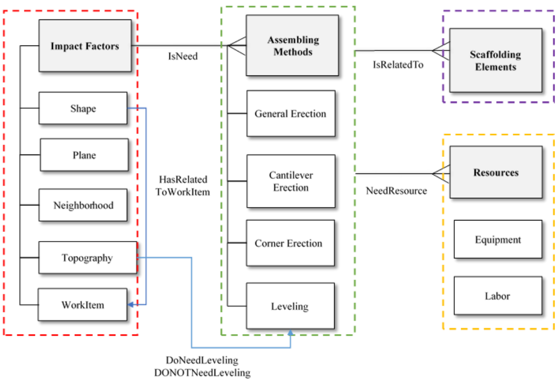

Figure 3. The schema of the ontology model

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.

Table 1. Structure the semantic information

Classes	Subclasses	Subclasses	Datatype	Semantic
Impact Factors	Shape	General plane	Height Width Depth Total Height Material	Means that the surface is flat, no excessive arc, and the top of the base no excessive protrusion or depression, the depth is less than the width of the scaffolding, that is known as the general plane.
	WorkItem		HasWorkItem	According to the schedule, we can know where we need to double check and how to assemble the scaffolding.
Assembling Methods	General Erection	Rectangle	ID	Means that the scaffolding of the adjacent arrangement, no other sporadic components in the middle, and assembled to complete.
	Leveling		HasTopography	How the topography at the site will affect leveling or not.
Resource	Crane	-	HasArmLength HasLoad	Building height is not specified (from the ground to the plane), but the use of cranes to help transport materials need to take into account the arm length and load capacity.
Scaffolding Elements	Frame	-	HasElementHeight HasElementWIdth HasElementLength	Use different frames with the erection.
	Cross Braces	-	HasElementInsideDiameter HasElementOutsideDiameter	Use different cross braces with the erection.
	Board	-	HasElementHeight HasElementWIdth	Use different boards with the erection.
	...	-	...	...

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.

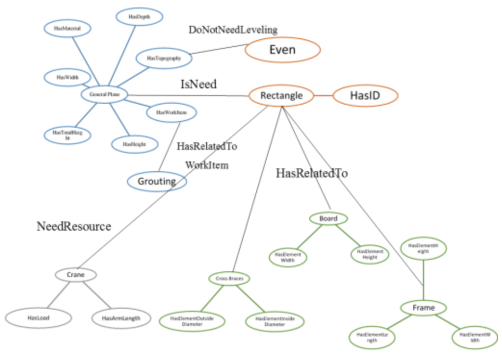

Figure 4. The relationship between classes and their data properties

Table 2. Ontology rules of scaffolding systems

Classes	Rules
Assembling Methods	Shape(?X) ^ HasDepth(?X, ?D2) ^ swrlb:lessThan(?D2, "77"^^xsd:integer) ^ Rectangle(?Y) -> Shape(?X) ^ isNeed(?X, ?Y) ^ Rectangle(?Y)
	Shape(?X) ^ HasTopography(?X, "Even") ^ Even(?Y) -> Shape(?X) ^DONOTNeedLeveling(?X, ?Y) ^ Even(?Y)
Impact Factors	Shape(?X) ^ HasWorkItem(?X, "Grouting") ^ Grouting(?Y) -> Shape(?X) ^ HasRelatedToWorkItem(?X, ?Y) ^ Grouting(?Y)
Resource	Shape(?X) ^ HasTotalHeight(?X, ?TH) ^ swrlb:greaterThan(?TH, "500"^^xsd:integer) ^ swrlb:lessThan(?TH, "800"^^xsd:integer) ^ crane(?Y) -> Shape(?X) ^ NeedResource(?X, ?Y) ^ crane(?Y)

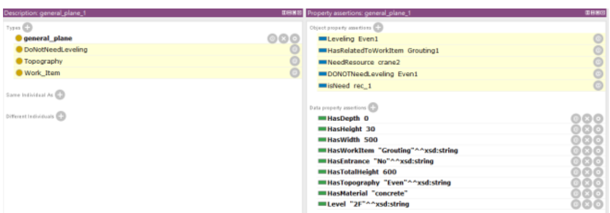

Figure 5. Inferred results of the ontology model

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.

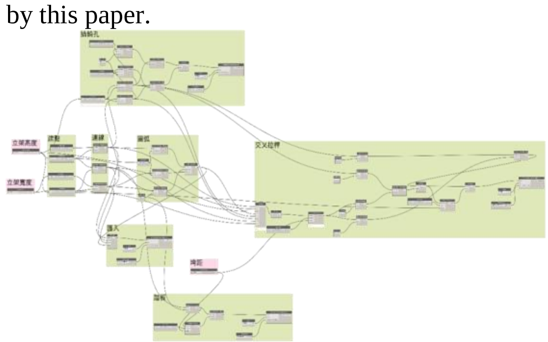

Figure 6. Dynamo module of scaffolding components

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 scaffoldings 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.

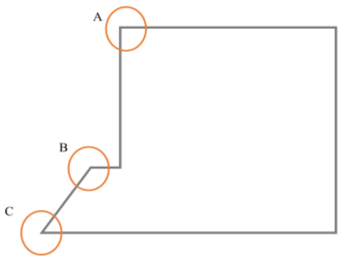

Figure 8. The angle type

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.

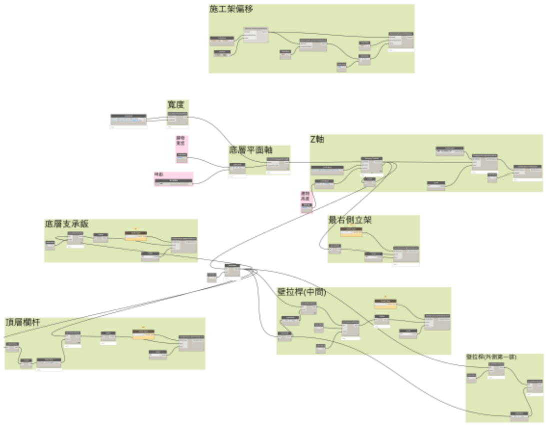

Figure 9. Dynamo module of automating assembling scaffolding

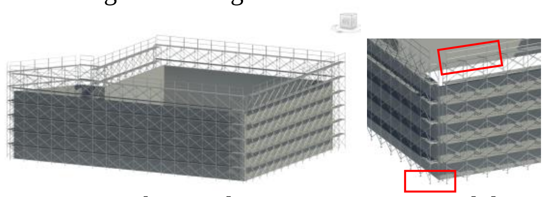

Figure 10. The result using Dynamo module to automate assembling scaffolding

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.

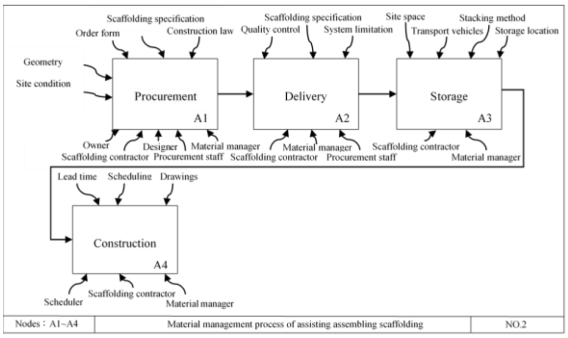

Figure 11. The data flow of the material management

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.

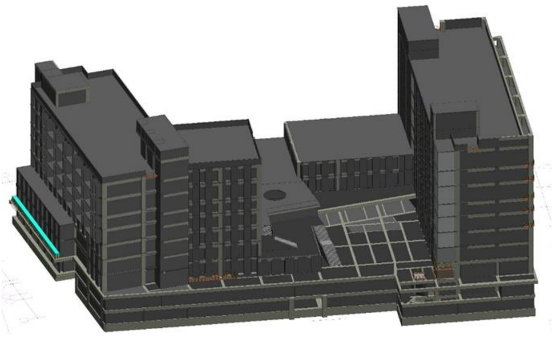

Figure 12. The case study building

The two faces of the facility are chosen to assembling the scaffoldings. The depths of the work faces are less than 77 cm, so a full set of scaffoldings 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 scaffoldings, and the other face needs tripods in the bottom scaffoldings. Table 3 and Figure 13 shows the parameters which are put into the ontology model and the inferred results.

Table 3. The input parameter and the inferred result from ontology model

parameter	Value	Inferred result	parameter	Value	Inferred result
Height	450		Height	400	
TotalHeight	450	Do not need leveling	TotalHeight	850	Do not need leveling
Length	2107		Length	4600	
Depth	0	Need crane1	Depth	0	Need crane3
Topography	Even		Topography	Even	
Entrance	No	Need rectangle erection method	Entrance	No	Need rectangle erection method
WorkItem	Grouting		WorkItem	Grouting	
Level	1F	Need adjustment	Level	2F	Need tripods
Position	East		Position	North	

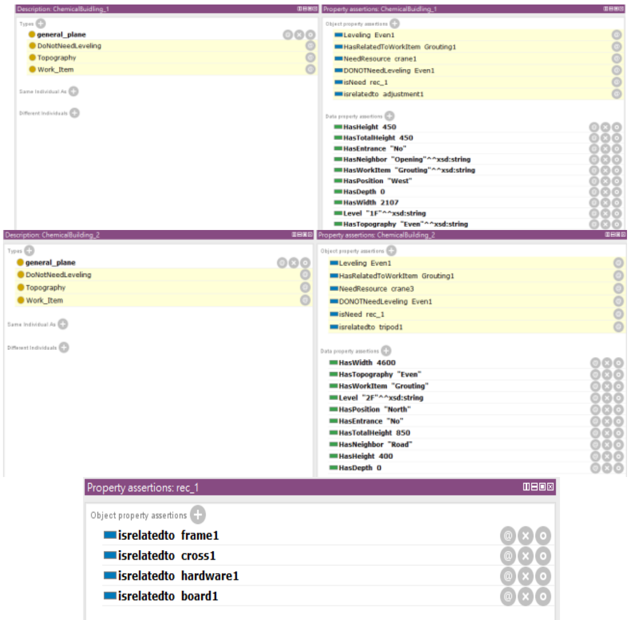

Figure 13. The inferred result in the Ontology model

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.

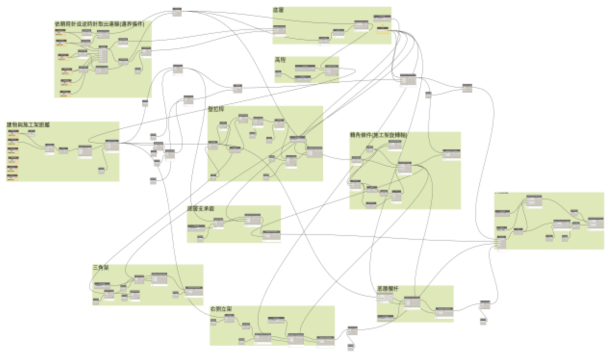

Figure 14. The Dynamo Module of the test area

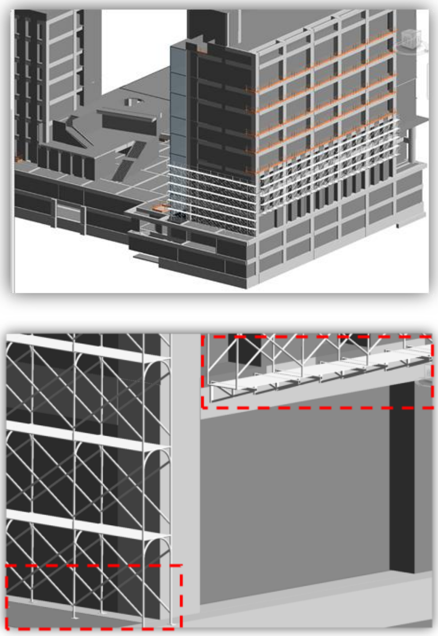

Figure 15. The visualization of BIM model

After automating the process of assembling scaffoldings, the bill of material to the scaffoldings 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 wok 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.

Bill of Material According to the Delievery Time (Section)

Delievery_Time	Project_Name	Section	WorkItem	Product_Name	Number
2017年4月15日	The science and technology	Chemical South1F	Grouting	adjustment	26
				board	36
				braces	72
				cross braces	72
				frame	39
2017年4月25日	The science and technology	Chemical North2F	Grouting	board	100
				braces	200
				cross braces	200
				frame	104
				guardrail	25
				tripod	50
				wall tie	8
2017年4月25日	The science and technology	Chemical South2F	Grouting	board	36
				braces	72
				cross braces	72
				frame	39
				guardrail	12
				wall tie	5

Bill of Material According to the Purchase Order Number

Project_Name	Principle_Name	Emplyee_Name	Section	WorkItem	Purchase_Order_No	Product_Name	Number
The science and technology	Principle1	Emplyee1	Chemical North2	Grouting	HH1003020GH	board	100
					HH1003020GH	braces	200
					HH1003020GH	cross braces	200
					HH1003020GH	frame	104
					HH1003020GH	guardrail	25
					HH1003020GH	tripod	50
					HH1003020GH	wall tie	8
The science and technology	Principle1	Emplyee1	Chemical South1	Grouting	HH1003020AA	adjustment	26
					HH1003020AA	board	36
					HH1003020AA	braces	72
					HH1003020AA	cross braces	72
					HH1003020AA	frame	39
The science and technology	Principle1	Emplyee1	Chemical South2	Grouting	HH1003020GH	board	36
					HH1003020GH	braces	72
					HH1003020GH	cross braces	72
					HH1003020GH	frame	39
					HH1003020GH	guardrail	12
					HH1003020GH	wall tie	5

Figure16. The bill of material in this case study

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 scaffoldings more efficient. In addition, this study adds work items and sections to match with the construction schedule. Working regulations and practices at the construction site are considered to define the BIM development guide through the ontology model. This also helps others for sharing the knowledge of assembling scaffoldings. The implementation of Dynamo shows that the process of generating information for assembling scaffolding system can be optimized. Finally, the detailed information for assembling scaffoldings 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 the scaffolding.

Acknowledgement

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

References

[1] Wu G. Y., the precaution of discharging place and garbage slag of external wall scaffolding, *Safety and Health of workers*, Taiwan, 224:8-15, 2008.

[2] Lin Z. H. and Feng C. W., Using Ontology and BIM to Coordinate Trades of the Interior Renovation Project， Taiwan， NCKU thesis, 2016.

[3] Construction Industry Institute， *Playbook of Leading Industry Practices for Estimating, Controlling, and Managing Indirect Construction Cost*, The University of Texas at Austin, 2012.

[4] Kim J., Fischer M., Formalization of the features of activities and classification of temporary structures to support an automated temporary structure planning, *in: Proceedings of the 2007 ASCE International Workshop on Computing in Civil Engineering*, 338-346, 2007.

[5] CADS, websites, http://www.cads.co.uk/, Accessed:20/03/2017

[6] Kim K., Cho Y., Zhang S.， Integrating work

sequences and temporary structures into safety planning: Automated scaffolding-related safety hazard identification and prevention in BIM, *Automation in Construction* 70, 128-142, 2016.

[7] Kim K. and Teizer J., Automatic design and planning of scaffolding systems using building information modeling, *Advanced Engineering Informatics* 28, 66-80, 2014.

[8] The Dynamo Primer, http://dynamoprimer.com/en/, Accessed:20/03/2017

[9] Noy N. F. and McGuinness D. L., Ontology Development 101: A Guide to Creating Your First Ontology, *Stanford University*, 2001.