Smoothing Process of Developing the Construction MEP BIM Model - A Case Study of the Fire-Fighting System

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Abstract –

Conflict analysis is one of the most recognized benefits of employing Building Information Modeling (BIM) to the mechanical, electrical and plumbing (MEP) system, especially at the design stage. However, at the construction stage, the MEP professional still strives to install the MEP system only according to the BIM model due to insufficient information. This is because the BIM model of the MEP system is not well developed from the information requirements of the construction professional. Furthermore, it may also take too much effort to develop an information- sufficient BIM model because of the complexity involved. Therefore, there is a need of taking the more effective and efficient approach that can quickly develop the MEP BIM model from the construction perspective.

This proposed study takes the fire-fighting system as the example to smooth the processes of developing the constructive MEP BIM model. First, a review of the construction specification and an interview with fire-fighting construction professionals are conducted to identify the information requirements. Then an ontology that employs the above result to determine the rules of building the information-sufficient BIM model is developed. Furthermore, a series of Dynamo modules are established to smooth the process of developing the BIM model for the fire-fighting system.

Keywords –

BIM; Dynamo; Ontology; Material Management

1 Introduction

In order to meet the safety and requirement of modern buildings, various functions of the equipment and the pipeline need to be installed in limited space. Due to the space constraints, it's not easy to integrate the MEP items. In addition, the traditional lofting method is not accurate in piping engineering, so the pipeline installation often needs to modify the pipe's length. Conflict analysis is one of the most recognized benefits of employing Building Information Modeling (BIM) to the mechanical, electrical and plumbing (MEP) system, especially at the design stage.

At the construction site, even well-experienced MEP professionals are still unable to avoid mistakes, which results in secondary construction in piping engineering. This is not only time-consuming and laborious, but also difficult to control quality of piping installation. In order to avoid the lack of information, the BIM model of MEP system needs to be developed from the requirements of construction professional. Wu et al. [1] proposed the BIM-based material management framework. He built a database to manage informationized BIM elements, so the material management, inventory, and replenishment management can be implemented in an efficient way. Wu et al. [2] proposed the information flow on various types of components in MEP system. The message providers and receivers were identified in each information flow chart.

This paper takes the fire-fighting system as an example, and it's organized as follows. First, a review of the studies on fire-fighting system, material management and ontology is presented. Next, the methods and the tools which are used in this research are explained. Then, the automatic modeling module is developed to create MEP elements in the model by Dynamo. Furthermore, the advantage and disadvantage of traditional method and using Dynamo were discussed. Finally, the limitations and the contribution of this paper is presented.

2 Literature Review

At present, there is not a detailed schedule in mechanical and electrical construction. MEP subcontractors usually know their work when they arrive at the site. Another problem is that MEP subcontractors could have hard time to keep up with the schedule if other structural-related activities are delayed. It means the waste on time and cost, and the poor quality. Moreover, wages account for 40% and material costs account for 20% of the total cost in the electrical and mechanical engineering. Therefore, proper planning of material management can effectively improve the duration, cost, and quality. Also, the supplier can offer the materials timely, which makes the construction process smoothly [3].

2.1 Fire-Fighting System

Fire system can be divided into four categories— alarm, fire, smoke, and evacuation. Alarm category includes fire automatic alarm system, and fire detection system. Fire category includes automatic sprinkler system, foam extinguishing system, and fire hydrant system. Smoke category includes smoke protection equipment. As for evacuation category, it includes fire emergency illuminating light, emergency fire broadcast system and fire extinguishers [4].

In general construction, automatic sprinkler system, foam extinguishing system, and fire hydrant system are classified into water supply and drainage engineering. Automatic fire alarm system, fire detection system, fire emergency illuminating light and emergency fire broadcast system are classified into electrical engineering [5].

2.2 Application of BIM in MEP Material Management

Lee et al. [6] proposed the significance of enterprise management— the purchasing department of the company is responsible for purchasing quality and price control, and the construction site is responsible for the acceptance of quality and quantity control. Wu et al. [1] proposed four factors of material management— material trends, storage management, stock control and replenishment management. He also used IDEF0 to analyze the information needs and information flow at each stage.

In order for the BIM model component attributes to meet the material management information requirements, Lee et al. [7] divided mechanical and electrical system into three levels— system, circuit, component. He also established BIM extension properties that meet the construction requirements (Estimation, Procurement, Allocation, Priority, and Testing) in pipe, wire, fitting, support, equipment and panel board. So, an information framework of MEP model was proposed.

2.3 Ontology

Ontology is a philosophical term. It's a research that explores the nature of life or the existence of biology [8]. Ontology defines a collection of representational primitives, and establishes a field of knowledge or a model of the paper [9]. The concept of ontology is to convey knowledge and experience in a simple but systematic and logical way. By the cause of fault analysis and semantic decomposition, the smallest unit in the lowest level of the class can be obtained. In this study, Facility Product Model and Maintenance Model were created, object attributes and associations were clarified by semantic analysis. As a result, different categories can be connected according to attribute and association [10].

Following are the steps of ontology building [11]:

1. Determine the domain and scope of established ontology.
2. Consider using existing ontologies.
3. List important words in ontology.
4. Define classes and levels of the classes.
5. Define the property of category (Property or Slot).
6. Defines the direction of attribute
7. Create instance(Individual).

2.4 Literature Summary

In the past, material management which applied to BIM was developed to manage the building materials. With the improvement of MEP modeling, more and more people are engaged in MEP material management which applied to BIM. According to MEP engineering characteristics, Lee et al. [7] classified the components and defined the attributes required for MEP construction. Wu et al. [1] developed the material management database framework as a reference for another field of material management database which applied to BIM. Noy et al. [11] provided the steps to create an ontology model. Wang et al. [10] defined ontology concept and constructed an ontology model based on facility maintenance.

Although, a lot of model information needed to be expanded or customized in the past literature, the information is not easy to be created in the model. In other words, if there is no effective way to handle these processes, it's hard to match model information with practice.

3 The Framework of Developing the Construction MEP BIM Model

In this paper, a framework was established to smooth the process of developing the construction MEP model. First of all, fire-fighting engineers are interviewed to identify the construction method of fire-fighting equipment and materials supply in the construction site. In addition, 2D document such as CAD drawings, was used to identify the material requirements. Apart from this, the specification of materials needs to be confirmed on the basis of

"Standard for Installation of Fire Safety Equipment".

In order to interpret the knowledge of material management obtained from the interview with fire-fighting engineer, material supply process was analyzed and developed by IDEF0 method. Thus, the material management requirement was identified in each phase.

Then, a fire-fighting engineering ontology model was created to integrate the material management requirement and BIM elements. So the rule for establishing BIM model can be defined from the ontology. Moreover, the knowledge-based model can be modified and used.

Finally, Autodesk Revit 2017 and plug-in software, Dynamo, were used for modeling and giving information automatically. As a result, the list of BIM elements can be imported into Access to create a project database which can provide construction information. Figure 1 shows the framework of this paper.

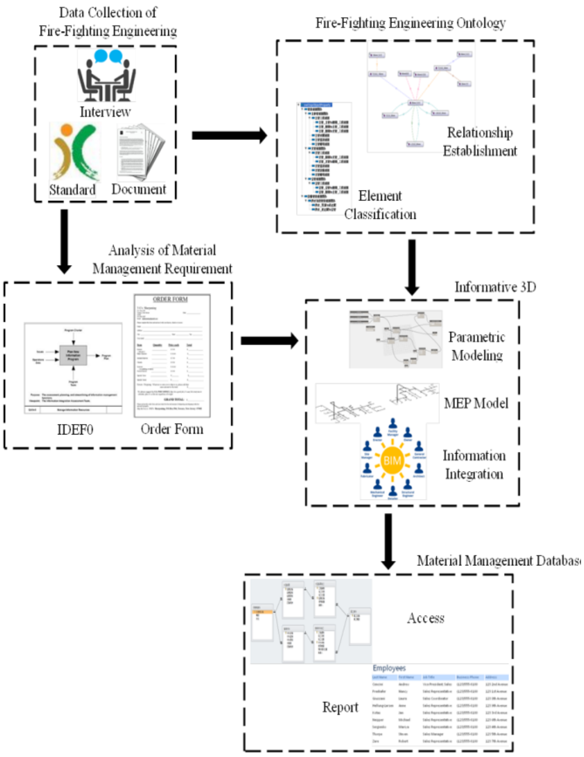

Figure 1. Framework of material management

3.1 Analyze the Process of Material Management and Information Requirements Applied to BIM

In order for the BIM model to meet material management requirements, it's important that material information need to be considered in modeling process. Material management process is divided into five stages— procurement, delivery, warehouse, construction and track, as shown in Table 1.

Table 1. Work contents in material management

Stage of Material Management	Contents
Modeling	In modeling step, BIM model was created with correct information according to the usage purpose (Component name, specification, type, function, delivery date, warehouse location, construction date, construction location, etc.). Also, these systems and circuits in the MEP model need to be defined according to their function.
Procurement	The component database and material requirement plan (MRP) were created on the basis of the information from the model. Then, the material can be ordered with the correct specifications, types and quantity of the equipment components on a correct date.
Delivery	Check the material quality and equipment function according to specification, and reject failed items.
Warehouse	Determine the most suitable storage location and supply path, considering the restrictions of construction path, material timeliness and storage method.
Construction	Supply the correct construction materials timely according to construction sequence and method.
Track	Material management system was established to control stock and replenishment. Then the results were feedbacked to the procurement stage to improve material requirements plan.

This study proposes material management process and information requirements which applied to BIM. Further, IDEF0 method was used to analyze the items and participants of each stage from the procurement stage. Then, material information which needs to be given or expanded on BIM model can be obtained. Figure 2 shows the material management process.

3.1.1 Model Informationization Stage

Model informationization process is divided into two steps: drawing modeling and informationization of model components. The input from the left side is 2D drawing, a 3D model can be created through the modeling program with full discussion and drawing explanation by modeling staff, designers, and MEP professional contractor. According to the purposes and requirements, parameters and information were given to the elements which were built in BIM model. As a result, informative elements list which was exported from the model at A1 stage was generated.

3.1.2 Purchase Informationization Stage

Procurement informationization stage can be divided into the establishment of project component database and the material requirements plan. The database which includes material information from the BIM elements list was created. In addition, the supplier's ability to provide enough materials needs to be confirmed for the project according to the order form and vendor catalog. Then, material requirement plan was developed according to the construction sequence, progress, and logic. Lastly, project order information can be generated.

3.1.3 In-Site Material Information Management Stage

After the materials were sent to the construction site, the material manager needs to confirm the quantity, specifications, and quality of the material. They need to reject the failed product according to the inspection process and purchase records in delivery stage. Then MEP professional contractor follows the piping logic and equipment functions to sort the materials according to different systems or circuits. Material manager and warehouse manager have to coordinate and determine whether it is necessary to store based on material properties and space constraints. If the materials need to be stored, the storage location should be determined according to the material timeliness and construction sequence. Storage methods and construction path restrictions also need to be considered. Finally, the material configuration information can be obtained from requisition for materials after construction. After material manager and MEP professional contractor confirm the correctness of material configuration information according to the construction sequence and drawings, the material usage information can be generated.

3.1.4 Stock Control and Replenishment Management Stage

In A4 stage, it's divided into database update, materials quantity check, and the stock analysis. First, the construction progress was updated in the database from the material usage information and material stock in the construction site. Additionally, the material stock need to be inspected at the construction site by comparing materials that have already arrived and the ones that have been used. After warehouse staff confirm the inventory, the progress and construction sequence can be used to analyze the current stock and determine whether the order needs to be added or reduced.

3.1.5 Information Feedback Stage

The productivity of MEP professional contractor can be analyzed according to the comparison between scheduled progress and actual progress in information feedback stage. Then, the material requirement plan can be improved by the productivity of contractor and replenishment requirement. As a result, the optimal order which can meet the real productivity was generated.

3.1.6 Information Requirements

Through the analysis of material management process above, the information requirements are summarized in Table 2.

3.2 Ontology for Material Management of Fire-Fighting System in BIM

In order to confirm BIM model meet the requirements of the order, in this study, a fire-fighting engineering ontology was not only used to integrate the material management requirement and BIM elements, but also used to establish the interrelationships among various elements.

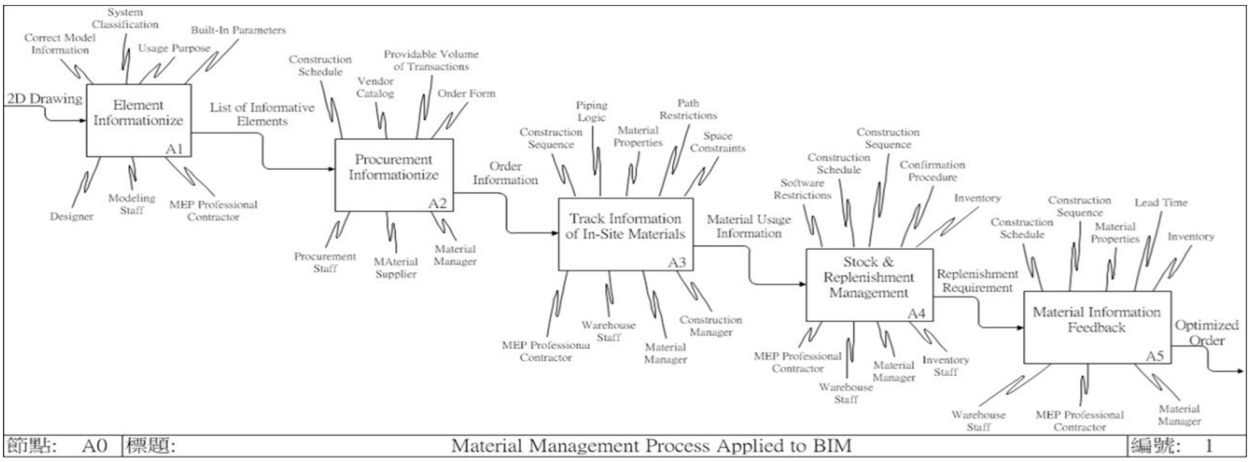

Figure 2. Analysis process of information requirement

Table 2. Information requirement in each item

Stage	Items	Information Requirements
Procurement	Confirm the material information	Material name, quantity, size, type
	Confirm the form of material order	Order form
	Identify supplier capability	Identify capacity of supplier
	Build the component database	Integrate the materials and required information for the project
	Set up a material requirements plan	Expected construction schedule, material lead time
Delivery	Confirm material entry	Entry sequence, space planning, transportation equipment and methods
	Inspect material	Inspection process, methods and standards
	Build purchase records	Integrate the information of delivered material
Warehouse	Classify system and circuit	Construction sequence, equipment function
	Analyze the path	Restrictions of the storage area
	Analyze the storage space	Material type, volume, stock quantity, storage method
	Integrate material configuration information	Material storage location
Construction	Establish the information requirement for construction	Pre-item, construction drawing and sequence, material requirement
	Analyze the supply path	Path restrictions of storage area and construction area
	Create material usage information	List of requisition for materials
	Update the component database	Construction schedule, material stock
Track	Check the quantity of storage materials	Material inventory list
	Analyze replenish requirements	Future construction schedule, material stock
	Analyze the productivity	Scheduled construction progress and actual construction progress
	Optimize future orders	Construction sequence and schedule, lead time, material stock, professional contractor's actual productivity

3.2.1 BIM Elements

To fully describe the relationship between the components of fire-fighting system, in this paper, the fire-fighting system is divided into five categories— "Pipe", "Equipment", "Machine", "Fitting" and "Valve".

1. "Pipe" includes standpipe (riser), main-pipe, and branch.
2. "Equipment" means the elements which are connected to terminal pipes, such as sprinklers.
3. "Machine" means the elements which can provide water or electricity in the system, such as pump.
4. "Fitting" includes various types of connectors, such as straight joints, elbow joints, and T-joints.
5. "Valve" includes various water valve devices which are placed in the pipe or machine to control water.

3.2.2 Establish Relationship between Classes

In language, "connect" is an only word to describe the connection of the pipeline, but we can't use a word to describe all connections between the elements in the ontology. For example, there are three different types of connection which has a similar meaning in T-joint on the main-pipe — "main-pipe to the T-joint", "T- joints to the main-pipe", "T- joints to the branch". Although they are all relationship of connection, the objects which were described in these three connections are all different in the ontology model. So, if there isn't a clear division among their relationship, the reasoning process will be confused in each class.

In this paper, the fire-fighting engineering ontology was developed with four main classes — BIM elements, fire-fighting system, construction information requirement and storage information requirement. "Fire-fighting system" will be connected with "BIM elements" by relationship "HasInstances". Apart from this, "Fire-fighting system" is linked to "construction information requirement" by using "HasWorkitemInformation". "BIM elements" is linked to "storage information requirement" by using "HasElementInformation". Thus, the requirements of material management and construction can be described by these relationships. Figure 3 shows the ontology schema used in this study.

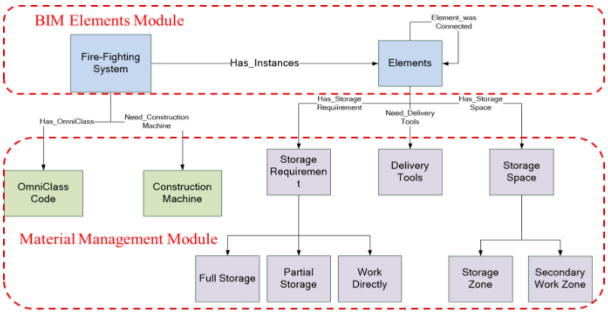

Figure 3. The schema of the ontology model

3.2.3 Reasoning Result

Due to the expanse of knowledge, it's not easy that integrate all requirements and BIM elements. In order to solve this problem, SWRL language was used to encode the rule. The semantic of fire-fighting engineering knowledge was translated into computer language to establish the attributes and relationships. Thus, the BIM elements can be classified into different systems. Besides, the requirements of material management can be identified. Then, the modeling rules can be followed according to the information which was obtained from ontology.

For example, omniclass number which is in "construction information requirement" class is used to classify the location of the work item. But it's not easy to identify all materials in ontology, SWRL language can help us to classify the materials into a different omniclass number according to material's attribute, as shown in Figure 4.

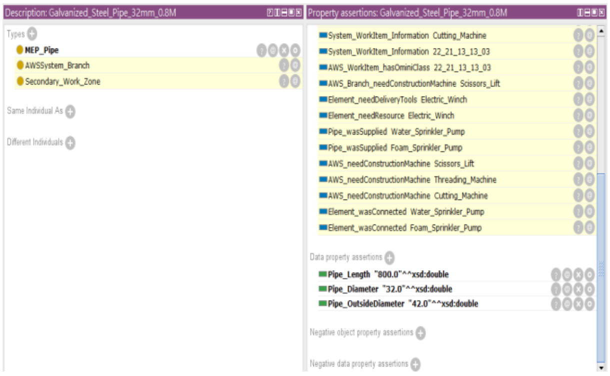

Figure 4. Reasoning results of SWRL rules

3.3 Automated Modeling with Dynamo Parametric Design Software

In recent years, with the vigorous development of BIM software, various BIM software developers also commit to reduce the obstacles of model drawing. The modeling software used in this study was Revit which was developed by Autodesk Company. Even if the method of MEP modeling is increasing, traditional MEP modeling methods still cost a lot of time to create and check the model to solve the more complex system circuit. So the plug-in software, Dynamo, which was developed by Autodesk Company was used. Comparing to traditional manual modeling method, Dynamo is able to place the components in correct position and reset the component attributes in a parametric way. In MEP modeling stage, the modeling rules were followed and Python language was used for automatic modeling.

This paper takes automatic sprinkler system as an example. MEP automatic modeling is divided into six main processes, and these six processes were integrated as a prototype of automated modeling in the future. The Dynamo module was shown in Figure 5.

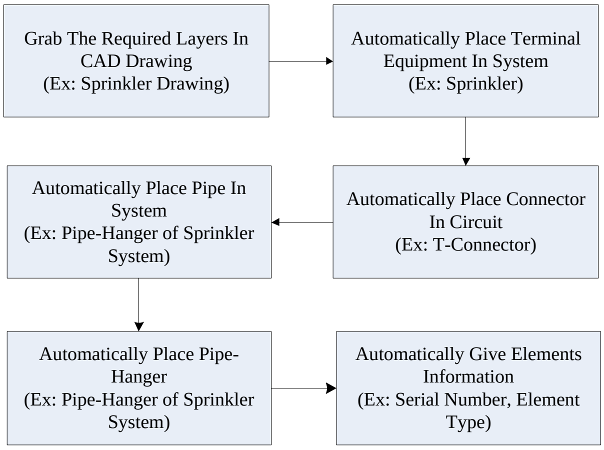

Figure 5. Automated modeling module

3.3.1 Grab the Required Layers in CAD Drawing

Because CAD layer is complex, if we want to build a 3D model, we need to remove the useless information and layers. Then, the required layers were imported into the BIM modeling software. Due to the complicatation of the process, Dynamo function node was used for layer selection. Further, the target layer can be captured according to usage requirement.

3.3.2 Automatically Place Terminal Equipment in System

Because the coordinate of the equipment is a single point in the drawing, the deleted function can be used to delete information other than "point". Therefore, Dynamo built-in function node was used to create elements on these points. In addition, parameter modification function node was used to modify elements' parameters such as displacement.

3.3.3 Automatically Place Connector on Circuit

The purpose of this stage is to establish the connector elements in the system and circuit. We focus on the intersection of each line. First, the deleted function was used to delete information other than "Line" and "Poly Curve". Then, they were divided into two lists, line and poly curve, and made them intersect with each other to find out the intersection point. Finally, these points were used to place the connectors.

3.3.4 Automatically Place Pipe in System

Due to complications of the MEP piping path, it's not easy to create the piping model in the traditional way. Therefore, Python script was edited to establish a rule which can create pipes in the model. In addition, both the system and the type of pipe need to be defined in the model at first.

3.3.5 Automatically Place Pipe-Hanger

First, the pipes which need to generate the hanger was selected. Then, the pipe-hangers are created with the appropriate height and location by the input of parameters. Finally, parameter modification function node was used to modify elements' parameters such as displacement and angle.

3.3.6 Automatically Give Elements Information

In order to meet the material management requirement, the information of BIM elements needs to be expanded, such as serial number and manufacturer. However, it's not easy to choose the target in hundreds of elements in MEP model. Dynamo function node was used to select the elements of a specified parameter, so that the process can be smooth. Figure 6 shows the process of automation.

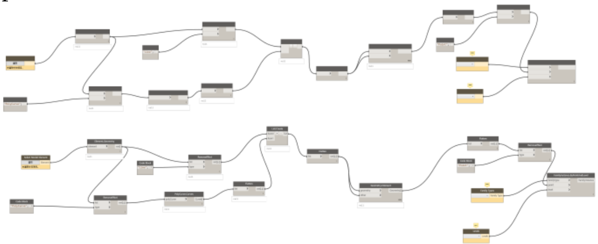

Figure 6. The Dynamo nodes of information giving

3.4 Comparison of Common Practice and Automated Modeling Method

In this study, the Dynamo module is used to change the traditional modeling method. MEP model was created by automated modeling module, as shown in Figure 7. Parameter design not only makes the modeling process faster and more efficient, but also makes the model change or update more convenient. Table 3 shows the advantages of modeling and informing with Dynamo.

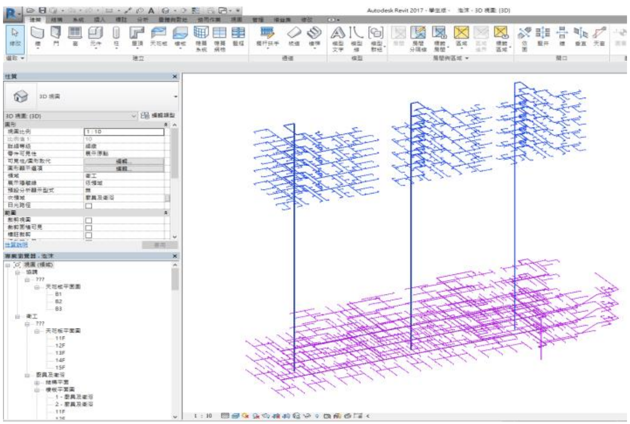

Figure 7. MEP model of the case study in BIM

Table 3. Comparison of traditional method and using Dynamo

Phase	Method	Process	Advantages & Disadvantages
Modeling Phase	Traditional Method	Placing the equipment before establishing the piping system or creating pipe element directly.	Advantage: The modeling process is simple and easy. Disadvantage: The process is time-consuming and the accuracy is low.
	Dynamo	Using Dynamo modules to place the equipment, fittings, and pipes.	Advantage: Quick modeling and quick modification. Disadvantage: The modeling procedure is complex.
Information Given Phase	Traditional Method	In addition to the model built-in information, components of different attribute need to be distinguished manually.	Advantage: n.a. Disadvantage: The process is laborious and inaccurate.
	Dynamo	Filtering different attributes and properties of the components by Dynamo module, and give the element information automatically.	Advantage: Quickly select the target component and edit the information. Disadvantage: Parametric method may cause the error, so the input of the parameters should be cautious.

4 Conclusions

As the discussion and analysis above, this paper proposes a MEP material management which applied to BIM. We hope to provide more and more effective information for MEP professional contractors by means of technology-based and informatization. The information not only enhance the efficiency of MEP professional contractor, but also achieve the purpose of cost control.

In this study, the method of MEP construction was recognized to know the MEP engineering sequence. Further, the sequence and requirement of material supply were identified to establish a framework of material management. In order to establish a modeling rule which is based on MEP material management, the fire-fighting ontology model was developed. Then the BIM model was used to be an information integration tool to provide required information to the elements. In order to smooth the process of developing the MEP BIM model, Dynamo parametric plug-in software was used to develop the modeling automation module. It can quickly establish the MEP model according to the drawing of complex system or circuit. Thus, the accuracy and time required for MEP model can be improved.

As a result, the elements data sheet which contains the required information was used to be the basis for material supply. Apart from this, the inventory could be maintained in the best range to achieve the material requirement plan by analysis of contractor's productivity and material stock. Through the above procedures, the model can provide construction workers not only the material, but also allow MEP professional contractors to clearly understand the construction location and time course of these materials.

Due to the current constraints, there are some issues which supposed to be solved are not completed:

1. Other categories of fire-fighting system in the building.
2. The common materials were used in this study, but in practice, there are various types of fitting.
3. Dynamo module still has room to improve its function and effect.

Acknowledgement

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