Constructing a MEP BIM Model Under Different Maintenance Scenarios－A Case Study of Air Conditioning

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Abstract –

Facility managers usually need to make decisions under different types of MEP system breakdowns. They usually fight to find the information required to restore the system. However, the BIM model developed usually lacks information to satisfy the what-if analysis under various maintenance scenarios. This study first takes the air-conditioning system as the example to analyze the causes and the solutions of the common system breakdowns. Then an ontology is developed to determine the rules of developing BIM model to satisfy the information requirements for conducting simulation for different maintenance scenarios. In addition, a series of Dynamo modules are developed as the implementation to quickly develop the simulation-ready BIM model. Result shows, with this proposed approach, the BIM model can be used to help facility managers make decisions efficiently and effectively.

Keywords–

Building Information Modeling (BIM); Dynamo; Facility Management (FM); Ontology; Air Condition System

1 Introduction

Management of MEP (Mechanical, electrical, and plumbing) maintenance has gradually been valued and studied. Sullivan et al. [1] divide the general maintenance model into the routine maintenance and urgency maintenance. Routine maintenance has a large number of related documents, and the maintenance methods are easy to get and learn. There is no need for experience and emergency for managers. However, the breakdown maintenance has to be completed in the shortest time. It heavily depends on the professional judgment of maintenance engineers. But many data become more difficult to search with the complexity of the building. At the same time the important equipment shut down will affect the products delivery time. Therefore, experienced managers can finish the works with the best solution in the limited resources.

The professional field in buildings includes architecture, design, hydropower, air conditioning, etc. The overall fields lack an efficient system for management. Nowadays, more and more managers use the BIM model as a platform to coordinate or storage information. Wang et al. [2] mentioned that the most of the research focus on the design and construction rather than the operations and maintenance. The front-end design errors or unresolved problems often affect the maintenance management. The biggest difficulty is that the building of the model doesn't meet the back-end requirements. These problems lead to the maintenance staff must extra build the BIM model to meet the conditions in the breakdown maintenance. They also delay the maintenance works and increase the costs of resources. Even if the managers modify the existing model, they still have to spend a lot of time.

In recent years, many studies use different software and management methods to solve these problems. For example, Tserng et al. [3] produced a database of MEP components that based on real installation. They provide a framework of classification for components that includes installation, geometrical information, and other issues. The way improves the back-end asymmetry information, and indirectly provides manufacturers the components' rules for drawing plans. But there are thousands of MEP system components. How to balance the time of modeling and the data attributes, which can meet the requirements of maintenance, is still a major issue in the future.

In summary, a lot of the BIM models are not satisfied the back-end requirements and components' types, which make the managers hard to simulate the situation. Therefore, this study first uses the ontology to analyze the actual situation of the components. Then we analyze the maintenance data to obtain the appropriate detail of components in the BIM model. This study combines the BIM models and Dynamo modules to quickly create a model with maintenance information. Finally, we can enhance the maintenance efficiency and reduce the waste of resources through the simulation of maintenance processes.

2 Literature Review

2.1 Problem Statements

The frequency of breakdown maintenance is lower than routine maintenance. But, if the managers not complete the works in a limited time, it will result in a lot of problems. In particular, there are a large number of high-tech factories or financial buildings and each facility in the buildings are interrelated. The managers' primary purpose is to complete the maintenance work in the shortest time. According to the interviews, we can say that senior managers or engineers can efficiently use resources. Most of the new staff can only do secondary positions to indirectly learn about the professional knowledge of urgency maintenance.

At the same time, the study also pointed out what the experience gap is. The study found that the solutions are proposed by the experienced equipment managers are more comprehensive and consistent with the actual situation. Senior managers can sort out all the resources to make judgments and provide multiple solutions. However, although a small number of new staff can make the right decisions, the processes are relatively simple and direct. They don't take the other possibilities into account. In addition, the internal components of a large-scale equipment are very complex and even need to take into account the site construction conditions, parts disassembly sequence, mobile path, personnel activities, etc. In order to integrate the above problems before construction, the successes depend on the knowledge and experience of managers' judgment [4].

BIM is a unified platform for engineering information, but it cannot be effectively used in the operation and maintenance. We find that the reason is that the model usually only meets the current construction situation. The modeling phase doesn't consider the back-end requirements in detail and fail to effectively provide the appropriate model to the owners or maintenance staff. A lot of data is still passed with drawings, which lead to information loss and hard to search. All of these make the equipment managers more difficult to implement [5].

2.2 Facility Breakdown Maintenance

The equipment lifecycle can be classified into eight stages by the United States OSHA 29CFR 1910.119-PSR (Process Safety Management):

1. Requirement Description: Designers need to understand customer requirements.
2. Engineering Design: According to customer demand for equipment, designers set its industrial parameters.
3. Detailed Design: It's a more detail design than before.
4. Production: Designers send the draws to manufacturers and product the equipment.
5. Acceptance: The staff check equipment parameters and safety indicators that meet customers' requirements and regulatory restrictions.
6. Enabling: The staff transport the equipment to the destination and check the installation.
7. Operation and maintenance: It includes any maintenance work until demolition.
8. Demolition: Owners depend on equipment life, economic benefits, and other factors to change it.

We can find that the real equipment life is between the enabling and maintenance, as shown in figure 1. The enabled process is different because of the device itself, and the warranty will start on the same day. Therefore, the operation and maintenance phase belongs to the vast majority of equipment life. The good maintenance can extend the life of the machine and improve the efficiency.

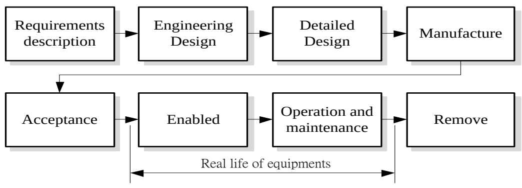


Figure 1. Life cycle of equipment

The International Facilities Management Association defined that the facilities management is: "Facility management is a profession that encompasses multiple disciplines to ensure functionality of the built environment by integrating people, place, process and technology." The American Parliament Library also defined it: "Facilities management is a systematic integration of the operating environment, the operator, and the operations. Its contents include management, architecture, equipment science and behavioral science integration." From the above, we can understand the maintenance works not only handle the equipment but also includes various fields of science. That is why maintenance is complicated and difficult to manage.

2.3 BIM for Facility Management

Nowadays, BIM becomes more and more popular and the public construction in Taiwan has gradually asked the contractor to have BIM technology. But according to Becerik-Gerber et al. [6], the study shows that the use of BIM stages can be divided into design, construction, and operation. The gray lines represent the people who already use BIM, and the percentage in gray lines mean their degree of using BIM at each stage. The black lines represent those people who have not yet used BIM and their percentage of interest in BIM development. We can find that BIM is mostly used in the design and construction, so most of the research also focused on these two stages. However, the operation has a great gap of 36%, as shown in figure 2.

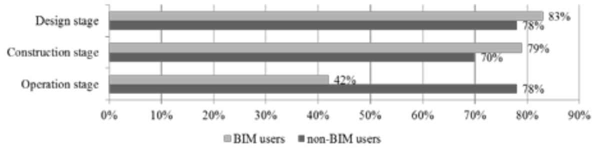


Figure 2. Project stages that BIM is currently used for or is planned to be used for [6]

The study integrated the difference and found that maintenance management has the following difficulties with using BIM:

1. Unclear and invalidated benefits of BIM in FM practices (for example, unclear productivity gains, or benefits gained from reduced equipment failure and better-automated building energy usage).
2. The amount of work that needs to be done to define the specific FM needs for which a model is necessary and how that model may need to be prepared to meet the needs.
3. Lack of interoperability among BIM solutions and between BIM solutions and FM systems.
4. Lack of demand for BIM deliverables by the owner community due to the uncertainty about what BIM might be used for.
5. Lack of clarity about responsibility for insurance and contracts.
6. Lack of standardized FM tools and processes.
7. Facilities management personnel have limited experience with BIM technology.

JJ McArthur et al. [7] also integrated four challenges related to the combination of BIM and maintenance management which must be overcome:

1. Identifying the critical information required for sustainable operations.
2. Managing information transfer between the BIM model and other FM tools.
3. Managing the level of effort to create the model.
4. Handling uncertainty where building documentation is incomplete.

Through the above research can realize that most of the model ignore the actual use of the back-end. In addition, some of the modelers are lack of the maintenance knowledge, which resulting information cannot feedback to the front.

2.4 Ontology Application on BIM

The ontology originated from the ancient Greek philosopher who defined it as “the science of the existence of objects.” It’s also the meaning of the existence of objects in nature. We can use conceptual models to describe the relationship between objects. The purpose of developing the ontology is to construct a platform to share special information among people and software. It can become more mature with the people using the ontology [8].

Nowadays, the use of ontology has not been popularized in the MEP construction yet, but there is still lots literature about the ontology in different construction management. In 2014, Zhang et al. [9] proposed a platform to connect security managers and BIM software by using ontology model, as shown in figure 3. The study can automatically infer the potential risk factors between the works, and it presents the inferred results into the BIM model. Finally, they show the difference after the change through the 4D simulation. For example, when the high-rise building is in the process of assembling the templates, the possibility of waste or wood falling is higher than usual. Therefore, if the time allows, managers should try to avoid the renovation of the external walls. After inferring the results, the study demonstrates the time schedule in a 4D model to avoid the occurrence of the above items falling in advance. Finally, the BIM model has been improved the safety of object falling and expanded construction information.

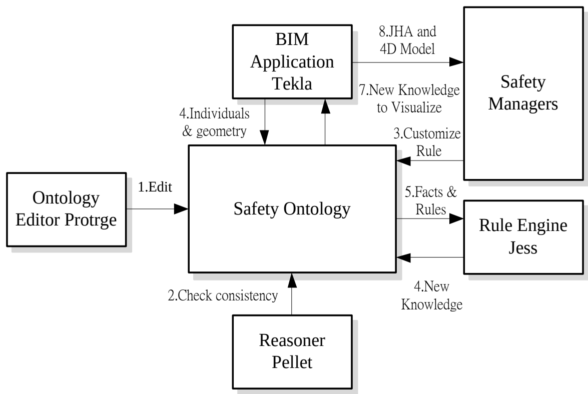


Figure 3. System architecture of the ontology-based hazard identification application in BIM [9]

3 Methodology and Results

3.1 Study Process

First, this study establishes an ontology model for breakdown maintenance to link with the BIM model. The entire workflow can be divided into three major parts. The first part is the development of ontology model, and it includes the A1, A2, and A3. The second part is a combination with BIM and Dynamo, and it includes the A4 and A5. The A6 part simulates the results and outputs the form to check.

In step A1, the real-world text descriptions are obtained by the laws and the equipment, and we need to analyze the maintenance requirements. A2 classifies the data and defines the scope of the ontology model, and it classifies the knowledge into the class. The data properties can express the relationship between classes and individuals which represent the components in the BIM model. A3 uses the degree of BIM modeling detail that come from the ontology model. The components should be cut or created to meet the maintenance simulation, and the classes also need to build in the same way. A4 creates a Dynamo module that can quickly modify or add maintenance information with the variable value. After building the maintenance information which is needed to be determined, it is suitable for delivery by COBie. If it is not suitable for COBie, A6 will show the conflicts that do not meet the requirements. Finally, these processes can automatically produce the results and reduce the human judgments. This study successfully improves the efficiency of back-end urgency maintenance and eases the burden on facility managers.

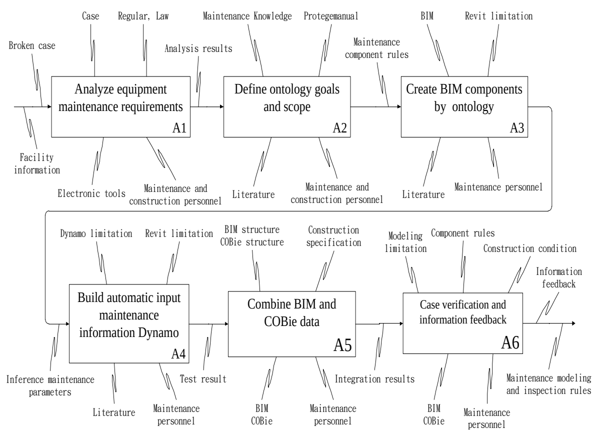


Figure 4. IDEF0 of urgency maintenance

3.2 Information Requirements of Maintenance

3.2.1 Breakdown of Components

Through the literature review and expert interviews, this study will use OmniClass table21 as the main structure of the air conditioning system classification. There are 7 classifications: transportation system, water supply system, drainage system, HVAC system, fire fighting system, communication system and security system. This study chooses the table because of the building services and the real situation of maintenance. In this study, we found that the classification is not detailed enough for some of the real maintenance situations. Therefore, the basic maintenance requirements come from the BIM model, COBie, and real situations requirements, and the fifth layer of the coding will be completed by them. Take the central cooling system for example, the classification will add the chilled water exchanger, warm water exchanger, compressor, motor, inlet and outlet, control panel, support frame, exhaust pipe, suction pipe and others under the OminiClass number 21-04 30 30 10, as shown in table 1. This framework can provide the BIM model for cutting or creation components, and the classes of the ontology also follow this rule.

Table 1. OmniClass classification of HVAC

OmniClass	Level 1	Level 2	Level 3	Level 4	Level 5
21-04 00 00	Service				
21-04 30		HVAC			
21-04 30 30			Cooling system		
21-04 30 30 10				Central cooling	
21-04 30 30 10 10					Chilled water exchanger
21-04 30 30 10 11					Warm water exchanger
21-04 30 30 10 12					Compressor
21-04 30 30 10 13					Motor
21-04 30 30 10 14					Inlet and outlet
21-04 30 30 10 15					Control panel
21-04 30 30 10 16					Support frame
21-04 30 30 10 17					Exhaust pipe
21-04 30 30 10 18					Suction pipe
21-04 30 30 10 19					Other componets

3.2.2 Maintenance Ontology Model

In practice, maintenance methods rely on the past experiences of maintenance staff. However, this kind of information has a lack of uniformity and standardization, and it will indirectly cause missing of data in the transmission and difficulty of learning.

In this study, the semantic information will be transferred into a classified knowledge which is used by the Protégé. First, maintenance staff will get the statement from the clients: “Chiller does not work”. In the classification, the “chiller” is from the chiller system, and its category also includes compressor, control panel, suction pipe, exhaust pipe, chilled water exchanger and other components. The “not work” is the failure situation which may be “compressor failure” or “host setting abnormal” and so on. According to the broken situation, it will be associated with the HVAC components, but the “broken situation” and “components” do not belong to the same class. Therefore, we must establish a new relationship “relating to” between the “broken situation” and “components” to meet the description of the facility managers' semantics.

This study uses the way, which is mentioned above, to analyze the statement and divide the ontology into two parts, as shown in figure 5. The upper part is the BIM model and the lower part is the maintenance ontology model, and then we connect the two parts through the "individual". Therefore, the carriers are the components in the BIM model and "individual" in the ontology model. In order to increase searching speed and object independence, we connect two models by coding system of BIM model. According to interviews and literature review, if the model wants to meet the real situations, it must completely consider overall maintenance events. First, the "broken system" has "broken situation", and "air conditioning system" has "air conditioning components". The "broken situation " will have their own associated "HVAC components" in each class. In addition, some of the situations that the facility managers will provide a suggested method for broken components. The facility managers choose the appropriate "maintenance method" to handle the "HVAC component" based on the broken situations. The relationship between the two is generated by the object property "has method".

Finally, the broken situation and other factors will determine the "maintenance resources" that the "HVAC component" needs. The maintenance resources are divided into "component information", "maintenance path", "maintenance people", "maintenance tool", "transport devices" and "warranty date". There is a real statement: "The size of the compressor is so large that it cannot pass through a part of the doors and elevators". The "Compressor Size" and "Doors and elevators size" are maintenance resources in the class of "component information". We can get the size data from the BIM model, but some of them must use the Dynamo to obtain.

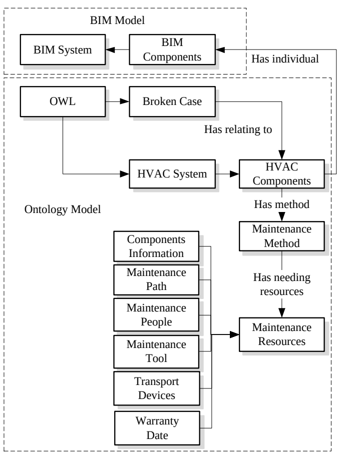


Figure 5. Ontology model framework

3.2.3 Maintainability Inferences

This study uses the SWRL language to infer six outcomes and uses the BIM and COBie forms to store information based on their data application. The six indicators include "space maintainability", "path maintainability", "people maintainability", "tool maintainability", "transport device maintainability" and "warranty maintainability", as shown in figure 6.

Figure 6. Class of maintainability

Taking spatial maintenance indicators for example: "ChillerSystem_Box_Compressor(?x)^ VacuumPump_Tool(Tool_VacuumPump_1)^ has_ToolWorkSpace(Tool_VacuumPump_1,?TWS)^ swrlb:greaterThanOrEqual(?TWS,0)^ swrlb:lessThan(?TWS,100)-> MaintenanceSpace_0_100(Tool_VacuumPump_1)". The "ChillerSystem_Box_Compressor" is a class in the ontology model, and "?x" is an individual of the class. The "VacuumPump_Tool" is also a class in the model, and the rule will automatically find an individual named "Tool_VacuumPump_1". Then the individual has a data property of "has_ToolWorkSpace" and is named as "TWS". The SWRL language "greaterThanOrEqual" and "lessThan" limit values range from 0 to 100. When the conditions are met, the engine will automatically judge the true, and the "Tool_VacuumPump_1" is classified into the class "MaintenanceSpace_0_100". After the inference, facility managers can realize that the maintenance event requires at least 0 to 100 of the space, and it is also controlled by several components. Other SWRL rules of maintainability indicators can be seen in figure 7.

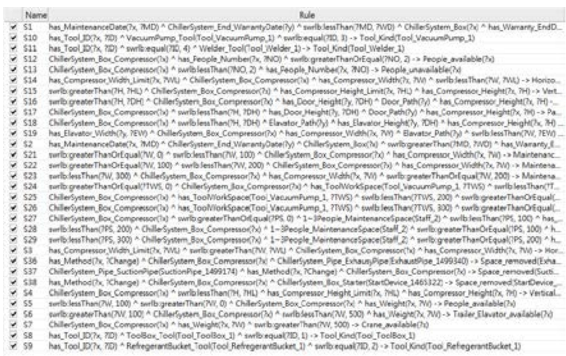


Figure 7. SWRL rules

3.3 BIM Model and COBie Form

In this study, the BIM model was developed in

LOD350. The model has a total nine floors of the reinforced concrete buildings, and it uses HVAC system for the case analysis. The HVAC host room is located on the 8th floor as shown in figure 8, which consists of two cooling towers, two chillers, four switchboards, two pumps, four kinds of pipelines and other valves. Pipelines are classified as green cooling tower backwater, blue cooling tower supplement, red chilled water for chiller and orange chilled water back to the chiller. According to the actual pipeline installation, it is mostly connected by welding and uses the valves in the joints for strengthening. Both the cooling towers and chillers have one group that used as a backup when the facilities break down.

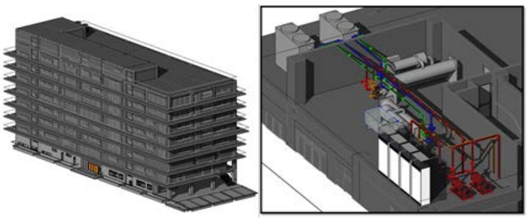


Figure 8. BIM and MEP model

Then we use COBie software to expand the maintenance information. Most of the modeling staff are manually placing maintenance information into the COBie expansion field. But if the model is very large or has a complex classification of components, it will lead to an excessive number of components. Therefore, this study uses Dynamo's special node "Element.SetParameterByName" to automatically input information in the correct fields, such as "CreatedBy", "CreatedOn", "Component.Name", as shown in figure 9. The node needs to be input the component information, the property name and the value which we manually input. Take centrifugal compressor of the chiller for example, after picking the component, the module grabs the field name "COBie.Component.Description" and enter the custom information "Pingtung Administration HVAC host room" into this field. The other fields are filled in the same way as described above, and then we only need to select a large number of components at once.

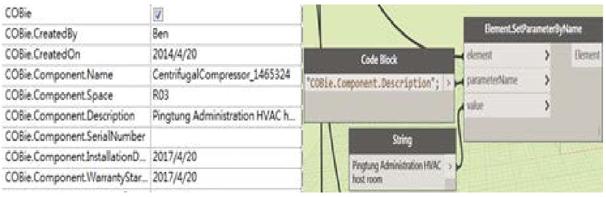
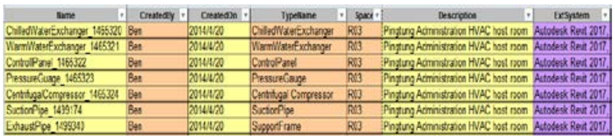


Figure 9. Extended COBie and Dynamo nodes

Figure 10 shows the output of COBie forms about the chiller components. When the COBie forms are produced, it will give every element an independent "ExtIdentifier". Although the purpose is to solve the repeatability of components, the text composition is too long and mix with English and number. The biggest problem is that it cannot be found in the BIM model by ExtIdentifier. So on the basis of naming components still uses BIM coding system. The number behind of the components name will be input like "CentrifugalCompressor_1465324", and it can help us to select the correct components to check or change in the BIM model. This method can also successfully output very small components which are hard to choose.



Name	CreatedBy	CreatedOn	TypeName	Space	Description	ExtSystem
ChilledWaterExchanger_1465320	Ben	2014/4/20	ChilledWaterExchanger	R03	Pingtung Administration HVAC host room	Autodesk Revit 2017,
WarmWaterExchanger_1465321	Ben	2014/4/20	WarmWaterExchanger	R03	Pingtung Administration HVAC host room	Autodesk Revit 2017,
ControllPanel_1465322	Ben	2014/4/20	ControlPanel	R03	Pingtung Administration HVAC host room	Autodesk Revit 2017,
PressureGuage_1465323	Ben	2014/4/20	PressureGauge	R03	Pingtung Administration HVAC host room	Autodesk Revit 2017,
CentrifugalCompressor_1465324	Ben	2014/4/20	Centrifugal Compressor	R03	Pingtung Administration HVAC host room	Autodesk Revit 2017,
SuctionPipe_1499174	Ben	2014/4/20	SuctionPipe	R03	Pingtung Administration HVAC host room	Autodesk Revit 2017,
ExhaustPipe_1499340	Ben	2014/4/20	SupportFrame	R03	Pingtung Administration HVAC host room	Autodesk Revit 2017,

Figure 10. Components of chiller output results

3.4 BIM Modeling Rules

If the BIM model wants to meet the back-end maintenance simulation and application, it must comply with certain specific modeling rules. There are 6 rules during the creation of the model:

1. The model should be drawn in LOD350 because model under the LOD350 does not contain the adapters which are often needed to check and maintain.
2. The internal components of the large machine should be placed in the same position as the design because we need to know the maintenance space of the facility.
3. The components size must be the same with the drawing. The correct size can help managers to assign works.
4. The model needs to take the joints into account.
5. The model must meet the requirements of the existing regulations such as large equipment reserved distance of at least 50 cm. The detailed specifications are listed in the "Building Technical Rules – Construction" which ensure the maintenance operations at the lowest standards.
6. The components should be cut or create in OmniClass classification. Some components only need to be cut to the fourth layer, and some need to be divided into the fifth layer.

There are also some contents that don't need to be the same:

1. The component internal structure does not need to be drawn because it belongs to component design manufacturers' works. If we draw in the BIM model, it will greatly increase the capacity of the

model.

2. The energy efficiency of the machine and the watts are not used directly in this study, so the attribute data can be replaced by other value.

3.5 Integration of Information and Inference Results

This study uses different software to infer and storage maintenance information, so we must integrate transmission methods to reduce the loss of data. All of the software use components to carry maintenance information, and they can be divided into three purposes by software and application, as shown in figure 11. The first one is the components in the BIM model. The second one is based on individuals as the carrier of the maintenance ontology. The third is the maintenance information of COBie forms. In these three surfaces, the BIM model ID code will be used as a connection. When a facility manager searches for relevant maintenance information, it still can use the same ID to find information that he needs even they have different data type. The ID not only retains the unity of the components but also make the search simpler.

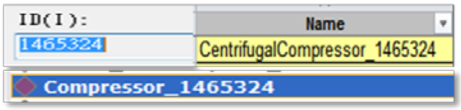


Figure 11. ID in the different interfaces

Before running the SWRL rules, the real world parameters must be entered into the ontology model by data property. According to the broken situation, figure 12 shows the data contents of "CentrifugalCompressor_1465324". This information indicates that the maintenance method is replacement, and it has 80 cm in width and height, and two staff do the maintenance, and maintenance date is 2017-10-10 and its weight 300 kg.

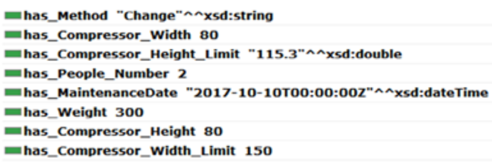


Figure 12. Data properties of compressor

In the above data properties, the height limit and the width limit of the compressor must be personally measured by staff or through the drawing to calculate the value. If an unpredictable error happens, this kind of approach will lose a lot of times and resources. Another way is to use the BIM model to get the limit value of the parameters, but it can only accurately calculate the 2D distance in the Revit software. If we want to calculate the shortest distance in the three-dimensional space, we must find the coordinates of the two objects and calculate the distance by the trigonometric function. The above approaches are too complex, so this study uses Dynamo's special node "Geometry.DistanceTo" to calculate the shortest distance between the components. Take replacement of the compressor for example, we first mark the compressor in number one, and other components are number two. Then the module automatically grabs these two types of components and divides them into list one and list two. All pairs of comparison results are related to the "compressor_1465324" because the component in list 1 is single. We can find that the shortest distance between the "compressor_1465324" and the other components is 152 cm in the horizontal, and the shortest element is "column_316090", as shown in figure 13. Finally, the information will be input in the ontology model.

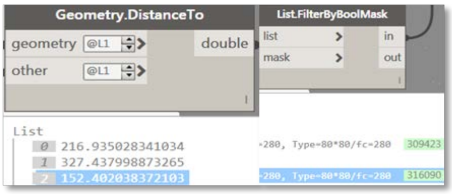


Figure 13. Dynamo calculation results

In the inference process, the Protégé engine compares the managers' resources of maintenance and related constraints. The Protégé engine automatically classifies the maintenance components into the maintainability class, as shown in figure 14. As a result of the light yellow derivation, it is known that the compressor element is sufficient in the horizontal and vertical movement space. In the movement of other components, we can find that "ExhaustPipe_1556568", "StartDevice_1465322" and "SuctionPipe_1499174" are in the "Space_removed". The inferred result is also supported by the shortest distance calculation. Then we set the limitation of distance in the Dynamo program and screen out the too close components which distance is less than 10 cm between each other. Finally, the program will highlight the components in other colors to increase the discrimination.

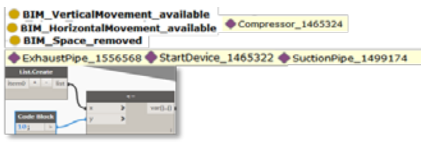


Figure 14. Spatial maintainability

The maintenance space indicators need to infer the key parameters that control the size of the space. The intervals which are "BIM_Maintenance_0_100", "100_200" and "200_300" will be placed the key parameters of maintenance space. The components that control the "0_100" interval are "Compressor_1465324" and "Tool_VacuumPump_1". The "100_200" interval is controlled by the "Staff_2", and the maintenance space is 100 cm. There is no key parameter in the "200_300" interval.

After we get the control factors, the Dynamo can quickly build the maintenance space in the BIM model. First, we establish the component boundary by the six-sided cube to solve the problem of irregular surface shape. Then we analyze the parameters from boundary to create the maintenance surface and extrude the space which the distance is 100 cm. Finally, the space symbol is converted into a spatial volume in order to import and give it meaning in the BIM model. It can also expand fields by COBie forms. After the creation is completed, figure 15 shows a gray transparent block. When the model changes to the 2D plan, the distance between the maintenance space and the column still has 50 cm which is very abundant.

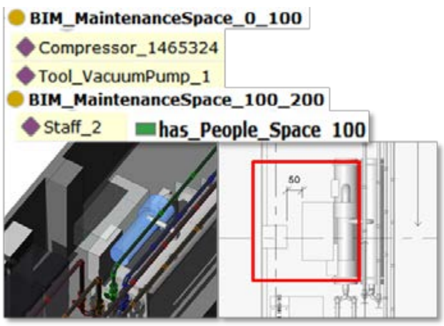


Figure 15. Maintenance space location

In figure 16, we can see that "Compressor_1465324" is classified into the class of available with the warranty date, the transport device choice and whether the maintenance staff enough. After comparing the weight of the compressor and reasonable range, it is recommended that the maintenance staff should carry it by trailers or elevators. Finally, the two of staff assigned to maintain are also in the "People_avaible".

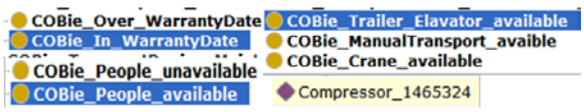


Figure 16. People, transport and warranty maintainability

If the compressor is replaced by different methods, it will affect the inference of the tool choice. Therefore, the Protégé engine infers "Tool_RefregerantBucket_1", "Tool_ToolBox_1", "Tool_VacuumPump_1" and "Tool_Welder_1" to the class of "Tool_Kind", as shown in figure 17. Facility managers can use the information to quickly know that replacement of the compressor should need which special tool. In the "ToolBox" class also contains a large number of small tools, such as needle-nose pliers, waterproof tape and screwdrivers, and they have been built in the ontology model. The feasibility of the path is inferred by the size of the components and the size space which includes doors, elevators and others in the BIM model. Finally, it will automatically classify the space which can pass into "Path_Through_available" and cannot pass into "Path_Through_unavailable". The managers can determine the proper transport path from the inference results, and whether there is a conflict in the expected route. Users also can find the conflicts in the BIM model by its ID code.

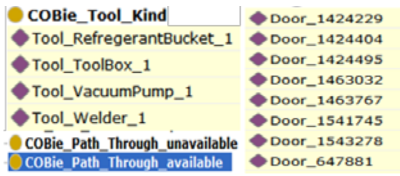


Figure 17. Tool and path maintainability

3.6 Maintenance Information Application and Storage

The inferred results and maintenance information are not suitable for directly using or delivery because the users must have a certain degree of learning on the BIM model and other software. There is also no extra time to do a complex pre-operation when urgency maintenance happens. Therefore, this study stores the maintenance information on the document page which can be used to store different kinds files for external data in COBie forms. But it cannot be completed in the BIM model. We must first export the COBie forms and manually add data in it. In the COBie.Document we still use the BIM model ID code to name the contents. According to the above maintenance, indicators are divided into six class "People", "Transport", "Path", "Warranty", "Tool" and "Space", as shown in figure 18. The first five indicators can be stored in the format of text, but the spatial indicator cannot use the same way to convey. Therefore, we use Navisworks to export videos as a carrier of maintenance information.

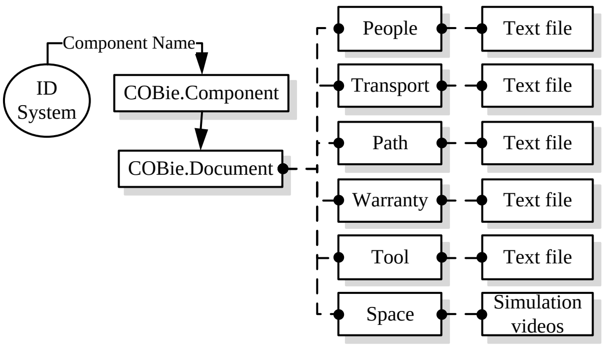


Figure 18. COBie application mode

Figure 19 shows the results of the "COBie.Document" information that are related to the urgency maintenance of the "compressor_1465324". The facility managers don't need to do additional simulation and operation when the breakdown happens. They can directly use the "Document.COBie" to search by ID and get the relevant maintenance information. This approach can significantly correct the back-end operational phase which lacks the maintenance information, as well as provides a lot of data to assist the judgment of maintenance. The "Document.COBie" contains the type and introduction of the tool, the company's internal maintenance staff expertise, the contract manufacturer's warranty certificate, the application transport device information and the size of the components in BIM model. The above information can be in a hyperlinked exists in the "Document.COBie", and users can click on them to connect to external data. Space maintenance indicators can be provided by additional pre-recorded videos, and they support maintenance staff to simulate or strengthen problems before start off. The videos contain the entire replacement process, the site maintenance without replacement, possible conflict location and other precautions. Through the videos, they can combine resources and the experience of maintenance staff they have. So that the overall efficiency of the urgency maintenance work can be improved even reducing the waste of resources.

Name	Created	Category	RowName	Director	File
Tool Information	Ben	21-04 30 30 10 12	CentrifugalCompressor_1465324	.pdf	Tool types and catalogs.pdf
Staff needs	Ben	21-04 30 30 10 12	CentrifugalCompressor_1465324	.pdf	Employee information.pdf
Warranty information	Ben	21-04 30 30 10 12	CentrifugalCompressor_1465324	.pdf	Warranty certification.pdf
Transport information	Ben	21-04 30 30 10 12	CentrifugalCompressor_1465324	.pdf	Transportation catalog.pdf
Path information	Ben	21-04 30 30 10 12	CentrifugalCompressor_1465324	.pdf	Path size table.pdf
Name	Created	Category	RowName	Director	File
Replacement process	Ben	21-04 30 30 10 12	CentrifugalCompressor_1465324	.avi	Replace film.avi
Site maintenance process	Ben	21-04 30 30 10 12	CentrifugalCompressor_1465324	.avi	Site repair film.avi
Conflict presentation	Ben	21-04 30 30 10 12	CentrifugalCompressor_1465324	.avi	Conflict film.avi
Other precautions	Ben	21-04 30 30 10 12	CentrifugalCompressor_1465324	.avi	Other Considerations Video.avi

Figure 19. External link maintenance data

4 Conclusions

This study constructs an ontology model based on facility maintenance and connects the results with BIM model. The ontology model is based on the actual maintenance work, and it also changes the BIM modeling which lacks the maintenance procedures from the inference results. This study develops maintenance information requirements and applies to the BIM model, and it significantly reduces the burden on facility managers. All of the semantic information has been categorized in the model, and it can reduce the experience gap between the facility managers and staff.

The senior managers can add new maintenance scenarios to the ontology model in the future; update the field of knowledge for maintenance. New employees can not only learn from the work site but also use the BIM model as a learning platform. Dynamo modules can be more directly observed about the maintenance situation that may encounter and reflect the advantages of BIM visualization and logical calculus. Finally, the BIM model helps managers to reduce the threshold of maintenance with the COBie drawing, and it speeds up the overall maintenance efficiency.

5 Acknowledgement

This research was supported by the Ministry of Science and Technology, Taiwan under Grant MOST 105-2221-E-006-047-MY2.

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