GENERATING SCHEMATIC DIAGRAMS OF MEP SYSTEMS FROM 3D BUILDING INFORMATION MODELS FOR USE IN CONSERVATION

MICHIKO MATSUBAYASHI1 and SHUN WATANABE2
1, 2 University of Tsukuba, Tsukuba-shi, Ibaraki, JAPAN
{matsubayashi.michio, shun}@sk.tsukuba.ac.jp

Abstract. In this paper, we propose a method of generating schematic diagrams from 3D models of mechanical, electrical and plumbing (MEP) systems in order to represent this information in a more traditional, user-friendly format. It can be difficult to grasp the relationships between various MEP elements in building information models (BIM) because they are represented in a visually complex, three-dimensional manner. On the other hand, the relationships between building elements can be easily understood when using traditional schematic diagrams. First, sets of connected elements are extracted from a 3D model of MEP elements using their connection properties. Next, various elements of these systems are identified as nodes and their connections are represented as edges. Finally, these systems are displayed as a schematic diagram using element attribute information.

Keywords. BIM; Schematic Diagram; Attribute Information; Graph; Existing Buildings.

1. Introduction

The conservation of building stock constructed during Japan’s period of high economic growth, from the mid-1950s to early 1970s, is now an urgent problem in Japan. Many buildings were constructed during this period and the plans for these buildings, which were printed on paper, have deteriorated, rendering some of them unusable, while others have been lost. It is urgent that the remaining plans be converted into an electronic format so that they can be used to repair and maintain existing building stock. There are many ways of storing paper documents electronically, but in this study we propose a method which employs Building Information Modelling (BIM). In a previ-
ous case study, we converted old drawings for buildings at the University of Tsukuba into a BIM (Matsubayashi, 2014).

It is important for facility managers that building design documents be easy to use. When data is presented in the form of a 3D model, it can be difficult to grasp the connections between the various elements of mechanical, electrical, and plumbing (MEP) systems because these models are visually complex. In traditional architectural drawings, schematic diagrams are used to represent vertical connections between MEP elements which cannot be expressed in building plans. Although not drawn to scale, functional relationships are more important than exact locations when performing maintenance on MEP elements. It is important that new types of MEP diagrams be easy to interpret in order to allow effective facility management, since the traditional paper documents they are intended to replace are easy to use.

The actions to use BIM for new construction increase more and more. But, there have been few studies addressing the use of BIM with existing buildings. For example, a research study which evaluated the possibilities of BIM within renovation of historic buildings was conducted by Penttilä (2007). A BIM re-creation of a designated heritage building located in Toronto was carried out by using laser scans, drawings, and on-site inspections (Attar, 2010). In a few examples in Japan, An experiment using BIM for the purpose of life-cycle cost (LCC) calculation was performed by Chosokabe (2011).

And, standardization of the attribute information between different CAD systems was a major topic in the field of MEP engineering in Japan, and as a result BE-Bridge (CIDEC, 1999) was developed to allow the exchange of CAD data with attribute information between different CAD systems. These efforts have continued until today, and BIM has also begun to take this problem into consideration recently. For example, the creation of 3D component data is seen in MEP representations using Industry Foundation Classes (IFC) (Miki, 2014).

At present, there have been few other studies dealing with existing buildings, and none focused on simplifying 3D models of MEP elements.

2. Objectives

In this study, we converted the design documents of Building 5C at the University of Tsukuba in Tsukuba, Japan into a 3D model, as in our previous case study. Our goals were to then extract sets of elements from the 3D model using the connection attributes of the MEP elements, to identify these elements with nodes, and to represent the connections of these elements with
edges. This would allow us to express the MEP systems of the building as a schematic diagram, using nodes and edges to reflect attribute information.

3. Conversion into 3D model using BIM

3.1. BUILDING STOCK AT UNIVERSITY OF TSUKUBA

In this study, the design documents for major building projects on Building 5C at the University of Tsukuba, which was built in the mid-1970s, were converted into an electronic format.

The Tokyo University of Education moved from Tokyo to Tsukuba Science City and reopened as the University of Tsukuba in October 1973. Building 5C, designed by well-known Japanese architect Fumihiko Maki, has been in use since the opening of the University of Tsukuba forty years ago. It is a six-story, multi-purpose building, with laboratories and rooms for offices, meetings and classes. As shown in Figure 1, it is located in the southern part of the Tsukuba campus. Seismic reinforcement work on the building was carried out from 2006 to 2008, and the air conditioning, plumbing and electrical systems of the entire building were also renovated during this period.

Figure 1. Location (left) and exterior appearance (right) of Building 5C.

Table 1 lists the design documents for major building projects which have been carried out in Building 5C. Most of the new construction documents were printed on paper and are stored in the form of sheets or books. Over the years, many of these original documents have developed cracks, creases, folds and fading of line colours. On the other hand, design documents for renovation work performed in 2007 and 2008 were stored in an electronic format.
Table 1. List of design documents for major building projects on Building 5C.

<table>
<thead>
<tr>
<th>Year</th>
<th>Type of Work</th>
<th>Description</th>
<th>Number of Drawings</th>
<th>Stored on Paper</th>
<th>Stored on Electronic Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>1974</td>
<td>Architectural/Structural</td>
<td>New Construction</td>
<td>55</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>1974</td>
<td>Architectural/Structural</td>
<td>New Construction</td>
<td>119</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>2007</td>
<td>Architectural/Structural</td>
<td>Renovation</td>
<td>106</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>2008</td>
<td>Architectural/Structural</td>
<td>Renovation</td>
<td>79</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>1974</td>
<td>Air Conditioning/Plumbing</td>
<td>New Construction</td>
<td>48</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>1974</td>
<td>Air Conditioning/Plumbing</td>
<td>New Construction</td>
<td>11</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>2007</td>
<td>Air Conditioning/Plumbing</td>
<td>Renovation</td>
<td>87</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>2008</td>
<td>Air Conditioning/Plumbing</td>
<td>Renovation</td>
<td>94</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>1974</td>
<td>Electrical</td>
<td>New Construction</td>
<td>67</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>1974</td>
<td>Electrical</td>
<td>New Construction</td>
<td>17</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>2007</td>
<td>Electrical</td>
<td>Renovation</td>
<td>71</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>2008</td>
<td>Electrical</td>
<td>Renovation</td>
<td>68</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

The work done on the building has been classified into three categories: Architectural and Structural, Air Conditioning and Plumbing, and Electrical. For each type of work, the paper documents are stored on shelves, which are organized first by area of the campus, and then by building. In the aftermath of the Great Eastern Japan Earthquake in 2011, these documents were difficult to locate and could not be accessed immediately for restoration work because some shelves had fallen down and the drawings had become mixed up.

3.2. CREATION OF 3D MODEL

Using Autodesk’s Revit Building Design software, which is widely used in the Architecture, Engineering and Construction (AEC) industry, paper design documents for Building 5C were converted into a 3D model. This was done using the design documents from the most recent renovation projects done in 2007 and 2008. Documents from the building’s original construction were used as a reference when areas not described in the renovation documents were found. After architectural and structural elements were recorded, air conditioning, plumbing and electrical elements were placed. The 3D model of MEP elements which was created using this process is shown in Figure 2.
4. Comparison between 3D model and traditional drawings

4.1. CONVERSION INTO SCHEMATIC DIAGRAMS

In order to produce a schematic diagram, we needed to develop a method of converting this 3D model into a more traditional format.

A 3D model can be cut horizontally to produce floor plan drawings, or cut vertically to produce elevation and section drawings. Air conditioning, plumbing and electrical elements can be displayed separately so that the various MEP elements can be positioned in the model in the same locations as in the real building. By changing the viewpoint and limiting the display of elements, we were able to convert the 3D model into more traditional drawings that were easier to interpret.

In an interview with a staff member of the University’s Department of Facilities, we were told that it was important that the connections between the elements of building systems be clear and easy to understand in our representations. When performing construction work, for example, accurate locations and sizes of elements are important in order to determine whether different elements would interfere with each other. However, we were also told that when performing maintenance, functional relationships between elements are more important than physical locations. We were also told that they often use traditional paper drawings or CAD output in their operations,
and rarely use 3D models. They told us that they usually use a combination of plans and schematic diagrams to locate elements, and then go to the actual location to find them. Thus, it is necessary that BIM allows the generation of MEP diagrams that can be used by facility managers in a way similar to the way traditional diagrams are currently used.

4.2. TRADITIONAL SCHEMATIC DIAGRAMS

Traditionally, schematic diagrams have been used to represent air conditioning, plumbing and electrical systems in building plans. Figure 3 shows the schematic diagrams of the air conditioning ducts and air conditioning plumbing used for renovation work on Building 5C in 2007. Ducts, pipes and fittings are expressed as lines, and supply devices and terminals as symbols. Schematic diagrams are similar to a section and elevation view, but they are not identical. Schematic diagrams are not drawn to scale, for example. The values for floor height are shown, but their geometries are not represented to scale. Material flowing through ducts and pipes are represented as lines. In addition, different symbols are used to represent different kinds of elements, and labels are added to these symbols. It is important that schematic diagrams describe exactly what is connected to what, and clearly explain what each line represents.

![Figure 3. Schematic diagram of 2007 renovation work: Air conditioning ducts (left) and air conditioning piping (right).](image)

5. Development of conversion system

5.1. EXPORTING ATTRIBUTE INFORMATION

In order to clearly identify each element of a building’s systems and describe the attributes of these elements, we developed a process for generating schematic diagrams of MEP elements using Autodesk’s Revit software and Cytoscape, a program which visualizes networks with attribute data.
After confirming that a group of elements were connected, the attribute information for each element of a given network was extracted from a 3D model of MEP elements. The processes involved were performed within the Revit platform, and were implemented using the Revit Application Programming Interface (API) with C#.

All of the elements that formed a given network were collected. Only categories that were components of the selected system were then listed. For example, in the case of the duct system, all of the categories that belong to the duct system were selected, which included ducts, duct fittings, ventilation machinery, and air terminals. Then, all the elements belonging to each of these categories were selected in turn. Figure 4 shows the procedure for exporting the identification and attribute information for each element.

![Procedure for extracting attribute information for each element.](image)

The connection of each element to the system was confirmed in the first step of the process, by checking whether the connection status of the item was “True”. The existence of a connection is important in order to assign the same attribute information (such as the kind of duct or pipe, its size, etc.) to elements drawn continuously. Information about a connection is not revealed as part of a normal operation. If an element’s connection status were “True”, then all of the elements connected to it would be accessed, and the
attribute information for each of these elements would be obtained. Connected elements were linked by confirming a selected item’s reference information. When it was connected to another element, the identification and attribute information for both elements were written together in a line. In this study, the category name, floor position, and name of the applied MEP system were extracted as attribute information. A line was added to a text file for every pair of elements, and they were exported as one file.

5.2. LAYOUT OF ELEMENTS

The elements listed in the text data were then placed within the diagram. For this step, we used the open source software platform Cytoscape to construct the diagram since it provides various ways of assigning attributes to nodes and edges. For nodes, an attribute is assigned a shape, fill colour, size, border colour, border width and a label. For edges, an attribute is assigned a line type, colour and label. Which attribute to assign to each element was decided by observing the symbols in the existing design drawings.

First, the text files were imported and the ID of each element was placed as a node, with the connections between IDs expressed as edges. It is difficult to distinguish which node is which type of element in this state, however. Next, attributes were assigned to nodes and edges in order to more closely approximate the traditional layout of schematic diagrams. Nodes expressed floor positions, element categories, while edges contained information about which of the systems were being represented.

The schematic diagram shown in Figure 5 was then created based on these assigned attributes. The top of Figure 5 is the entire diagram. Nodes were repositioned by assigning floor positions of the height direction and the longitudinal direction. In order to prevent the overlap of nodes, the value of the short direction was added to the value of each direction. As one way to show exactly where elements were located, the image of the schematic diagram was placed upon the one of the section view. In the software, when the entire diagram is displayed, only nodes & edges are shown, but node & edge labels appear when the user zooms in, as shown at the bottom of Figure 5.
6. Conclusion

In this paper, we proposed a method of extracting MEP elements from 3D models created with BIM software, representing elements as nodes and connections between these nodes as edges, in order to create schematic diagrams using Cytoscape. Floor positions were assigned to each node, and the shape of each node was used to represent the identity of the element being represented. Similarly, edges were distinguished by their association with a particular system, and the name of the associated system was assigned to each edge label. Additionally, colour was used to associate edges with different functions. In this manner, a complicated, 3D model of MEP elements was simplified into an easily interpreted schematic diagram.

A method to place a schematic diagram upon a section view was carried out in this paper. Future work involves revising a method to precisely link generated schematic diagrams to spaces within a building, because it is important for building diagrams to show exactly where elements are located, i.e., within particular spaces or rooms.

The conversion of paper design documents into an electronic format is necessary in order to ensure that facilities managers have a durable, accessi-
ble and efficient means of maintaining records on their building stock. 3D models created using BIM features which maintain accurate placement and size information for MEP elements is one method of converting these records into an electronic format. Because these 3D models can be difficult to use, and because traditional paper drawings are still the most common method of building record management, a 3D model of MEP elements that can produce familiar schematic drawings is an attractive option. These diagrams not only increase the usefulness of BIM software, but can also improve the management of existing building stock.

Endnotes

1. Two kinds of connections exist: physical connections and logical connections. In this study, only physical connections are considered.

Acknowledgements

We would like to acknowledge the assistance of the Department of Facilities of the University of Tsukuba. The present study was supported by the "Theory and Experimental Study of Selecting, Consolidating, and Overhauling Aged Urban Infrastructures" Grants-in-Aid for Scientific Research (KAKENHI) in Japan.

References