Leadership in Sustainable Infrastructure

Leadership en Infrastructures Durables

Vancouver, Canada

May 31 – June 3, 2017/ *Mai 31 – Juin 3, 2017*

DEVELOPING A BIM MODEL FOR FM FROM HANDOVER DOCUMENTATION; A CASE STUDY

Soojung Kim[1,4], Erik A.Poirier[2,] and Sheryl Staub-French[3]

[1] Department of Civil Engineering, University of British Columbia, Canada

[2] Department of Civil Engineering, University of British Columbia, Canada

[3] Department of Civil Engineering, University of British Columbia, Canada

[4] soojungk417@gmail.com

Abstract: BIM is increasingly being used for design and construction (D&C) due to its emerging benefits. As the use of BIM for facility management (FM) remains limited in Canada, however, the D&C models end up losing their value post-construction. As the benefits of BIM for FM become better known through increasing research, there is a push to develop and extend the use of BIM for FM. However, there are still potential barriers of utilizing BIM for FM, which makes the owner hesitant about adopting BIM. To address these barriers, a detailed case study is done on a museum project which is initiated by a large public organization. A part of the existing BIM model of the project was developed into an operational model by populating the model data with handover documentation. This paper focuses on the information retrieval process and addresses the challenges of the process. The challenges include the massive amount of documents, unorganized templates, and the use of inconsistent units and terminologies by different suppliers. These problems caused the delay of information retrieval process. The paper informs the owners of the importance of handover documentation quality control to utilize BIM for FM purposes.

1 INTRODUCTION

It has been estimated that about 60 to 85 percent of the total life cycle costs occur in operation and maintenance phase of the building (Lewis et al. 2010). A major part of this operation cost is again caused by the inadequate access to the facility information and interoperability issues of the information (Newton 2004). Including the geometric and non-geometric information of the building, there is a massive amount of information that should be handed over to the owner after the construction is completed. Due to the difficulty of managing the quality of this information, AECOO industry has been increasingly adopting BIM for FM as a solution, which is used as a 'single source of truth' (Atkin and Brooks 2009, Sabol 2008). Despite the potential benefits of BIM, however, the owners and facility managers are being hesitant about adopting it due to the challenges of utilizing the model for FM. And one of the biggest challenges is the difficulty of populating operation model with a massive amount of handover information.

To investigate the barriers of utilizing BIM for FM purposes, a case study was carried out on a museum project initiated by a large public owner in Canada. The research team studied on the process of developing existing design model to an operation model to understand the challenges of the process. The model development was conducted in three steps, model assessment, information retrieval, and information embedment. This paper focuses on the information retrieval process, which is again divided into four detail steps. The challenges of each step related to the information quality of the handover documentation are addressed in the paper.

In the following section, the challenges of utilizing BIM for FM purposes are explained based on the previous studies, which is followed by the research methodologies. Then the research result section illustrates the process and challenges of the information retrieval process. Finally, the paper concludes with the lessons learned.

2 UTILIZING BIM FOR FM PURPOSES

Traditionally, the facility information is handed over to the owners by paper-based construction documents including drawings, specifications, and O&M manuals collected from various vendors. They are typically organized by the contractors in a format to align with their needs, which does not reflect the needs of facility managers (Goedert and Meadati 2008). Even when the information is provided in electronic formats, the information loses its value in most cases because of the lack of interoperability with the existing FM systems. Thus to update the systems, manual data entry is usually required, leading to duplication of efforts and high chances of error (Ghosh et al. 2015). It is estimated that each year $20 billion are lost in the US alone due to the inadequate information access and interoperability issues during the FM phase (Newton 2004). As a solution, it has been argued that utilizing BIM for FM will prevent these losses (Azhar et al. 2015).

The potential benefits of BIM for FM are addressed in many studies. First of all, BIM enables all physical and operational attributes of a building regarding spaces, equipment, systems, zones, and so on, to be modeled in a way that is universally recognized (Atkin and Brooks 2009). Those attributes are easily shared and reused by the project team (Sabol 2008), and the data does not have to be re-entered into a downstream FM system. This reduces the data entry cost and generates higher-quality data (IFMA 2013). Despite its benefits, however, it seems that owners and facility managers have not been motivated to implement BIM due to the barriers.

The barriers of utilizing BIM for FM include the interoperability issues, difficulties of integration, and unclear responsibilities in the creation of models. One of the biggest barriers is the high level of effort to create BIM models or modify existing BIM models for FM purposes (Volk et al. 2014, McArthur 2015). To conduct either of the processes, the geometrical information of building has to be gathered, modeled, and the model should be complemented by the semantic property/attribute information, which exists in the handover documentation (Volk et al. 2014). While several technologies such as laser scanning and photogrammetry have been developed to capture the geometric data of the building, still there is no automatic way to import the non-geometric data from the documents to the model. Then how do we populate the BIM model with handover documentation? And what are the potential challenges we might confront during the process? To investigate these issues, a case study is conducted in this paper.

3 METHODOLOGIES

This paper documents a part of a case study done on a museum project initiated by a large public owner. One of the researchers was assigned to work in the owner's office for five months to conduct model development while interacting with the internal people. The whole model development process included assessing the existing model, retrieving the information, and embedding the information in the model. This paper focuses on the information retrieval part, which is again divided into four steps: 1) Sorting out the related document files, 2) extracting the information, 3) unifying terminologies and units, and 4) organizing the documentation files. The processes and challenges of these steps are documented in next section. Detail analysis of the handover documentation was carried out to address the poor quality of the handover documents.

The case study subject is a 37,810m^{2,} four-story museum building located in Alberta, Canada. The project was initiated in 2011 under a design- build contract, and construction was completed in August 2016. The only requirement for BIM from the owner was to produce a preliminary model for spatial validation, and no further BIM requirements were formally put in place by the owner. Therefore, BIM model was only used for the design and construction phases of the project. When the construction was almost completed, the owner expressed their willingness to use the model for FM, but there was no operation model nor as-built model to be delivered to the owner. As BIM has never been used in their previous projects, the owner had no knowledge of the processes or potential hurdles of developing operation model. As a result, the research team was involved in the process of developing the existing design model of the project to an operation model. 60 pieces of mechanical equipment located in the boiler room of the building were selected as the case study subjects (Figure1, Table 1). The information related to these components are retrieved from the handover documentation to populate the existing model.

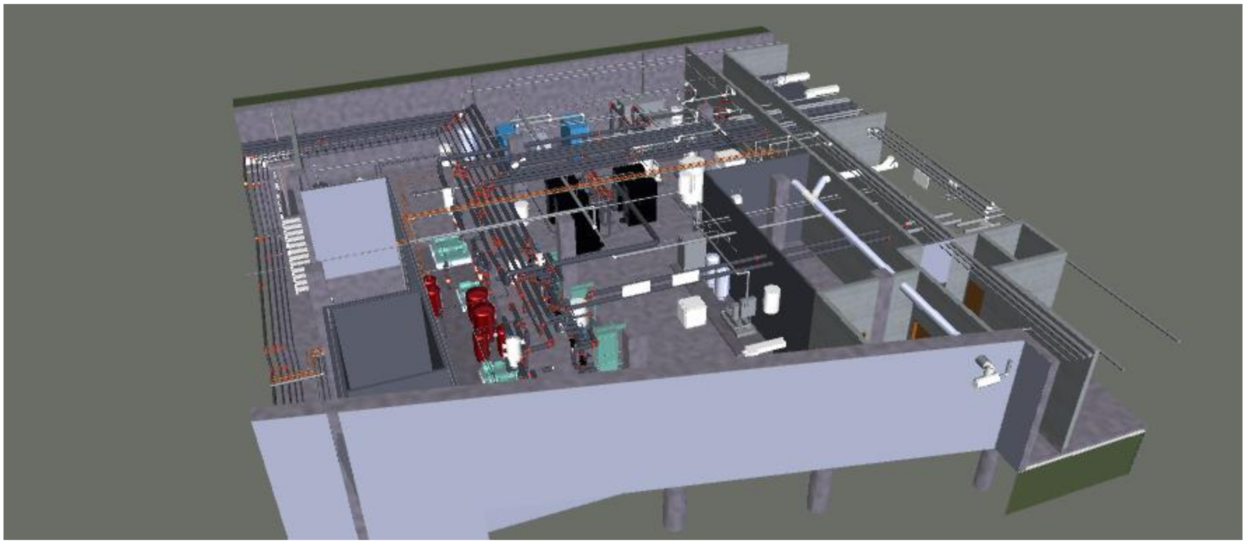

Figure 1: Design BIM model of the boiler room

Table 1: Mechanical equipment list

No.	Equipment Type	Quantity (pcs)
1	Pump	13
2	Heat Exchanger	3
3	Tank	5
4	Variable Frequency Drive	9
5	Expansion Tank	8
6	Domestic Water Heater	3
7	Compressor	1
8	Boiler	9
9	Reverse Osmosis	2
10	Boiler Feed	1
11	Water Softener	2
12	Carbon Filtration	2
13	Glycol System Feeder	1
14	Unit Heater	1
	Total	**60**

4 RESULTS

In this section, the process of information retrieval process and the challenges we identified during the process are explained in four steps. 1) Sorting out the related document files, 2) extracting the information, 3) unifying terminologies and units, and 4) organizing the documentation files.

4.1 Sorting out the related document files

The electronic copies of the handover documentation were received in June 2016, and the construction was completed in August 2016. The documents were still being updated when this study was carried out. See Table 2 below for the structure of the overall handover documentation. The handover documentation consists of 1442 files with 46741 pages (12.1 GB), and they are divided into nine folders. The mechanical O&M manuals, which we looked in detail for the case study, consist of 302 files with 11508 pages (954 MB).

Table 2: Structure of overall handover documentation

Folder Name	Discipline	Number of Files	Number of Pages	Folder Size (MB)	Summary of Contents	Format of Documents
O&M Documents	Architectural	70	22443	2930	Architectural O&M manual	Scanned or exported files (pdf)
VOL1	Architectural	198	198	1950	Architectural Drawings	Scanned files (pdf)
VOL2	Architectural	214	214	1840	Architectural drawings	Scanned files (pdf)
VOL3	Architectural	107	107	1030	Architectural	Scanned files (pdf)
VOL4	Structural	165	165	1330	Structural drawings	Scanned files (pdf)
Mechanical O&M	Mechanical	302	11508	954	Mechanical O&M manual	Scanned or exported files (pdf)
Mechanical Asbuilt	Mechanical	2	99	34	Mechanical drawings, Valve tag list & locations	Scanned files (pdf), Handwritten files
Electrical O&M	Electrical	118	11741	1870	Electrical O&M manual	Scanned or exported files (pdf)
Electrical Asbuilts	Electrical	266	266	161	Electrical drawings, Electrical panel schedules	Exported files (pdf)
	Total	**1442**	**46741**	**12099**		

In the 'Mechanical O&M' folder, we first located the files those contain information related to the 60 pieces of mechanical equipment we selected. First, we queried the equipment type from the folder (ex. Search 'Pump' in the folder). If the files showed up, we opened the files one by one and looked for the equipment tag number in the document (ex. Search P-3, the tag number of one of the pumps). We counted the number of pages that contained information related to the selected equipment.

Among 302 files with 11508 pages (954 MB) of mechanical O&M manuals, 49 files with 1270 pages (109.4 MB) were related to the 60 pieces of equipment we selected. We also found that many of the files contain information of two or more types of equipment. For example, when we found a file that contains ten pages of information related to the pump, which we were looking for, we realized that the file also contains the other 52 pages of information related to three other equipment types, which we don't need. In the same way, we ended up finding that only 982 pages from 1270 pages were directly related to the equipment we were looking for.

The challenges we identified during this process are listed below:

- Folder names are not organized. For example, the architectural O&M manuals are in 'O&M Documents' folder, and the mechanical O&M manuals are in 'Mechanical O&M.' This causes a delay in finding the right folder at once.

- The names of the files do not clearly reflect the information contained in the file. For example, when the user wants information of a compressor (tag number CP-2) and searches for 'compressor' in the O&M manual folder, total eight files show up as Figure 2. Only three of them are related to CP-2, which the user wants. Moreover, one of the files includes information related to another type of equipment which we do not need, and it is not indicated in the file name. File names should clearly reflect the contents of the file to avoid delay in finding information and misunderstanding of the users.

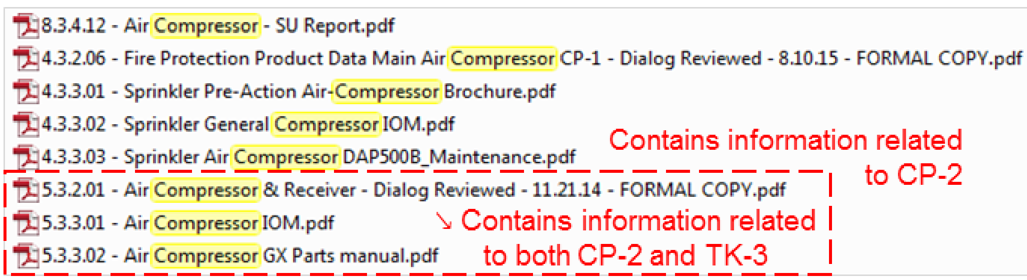

Figure 2: Unclear file names

- Also, some of the file names contain acronyms of the equipment types, which can't be searched unless the user knows which acronyms are used in the project. For example, we searched for 'heat' from the folder as we wanted to find information of a heat exchanger, but nothing showed up. As the 'HX' was used as the acronym of the heat exchanger in this project, the information of heat exchanger was included in *'3.3.2.3.01 - Pumps, HX, AS, ET - XXX Reviewed - 12.08.14 - FORMAL COPY'.* This causes confusion and also a delay in finding the information.

- Some of the files contain too small or too large amount of information. The smallest file includes one page of information, and the largest file contains 2845 pages of information, which makes readers waste time to find a particular information.

4.2 Extracting the information

After sorting out the files we need, we read through the documents in detail and extracted the necessary information into the excel sheets manually. The data is exported to excel format as it is interoperable with several BIM tools including Revit. Then we listed the attributes and values in one table for the same type of equipment to compare the attribute types from different suppliers. For example, we compared the information of A, B, and C boilers provided by supplier A, B, and C (Table 3). By comparing the list, some of the attributes were found to be in common among three different models, and some were not. This happens as different suppliers use different formats of documents, which each contains different types of attributes. A total of 120 attributes were extracted, and 19 of them were in common from three documents. 30 attributes were in common from two of the documents, and other 71 attributes were included in only one document. This implies that a part of the necessary data is missing in some documents and some of the unnecessary information exists in some documents.

Table 3: Information gap between different documents from various suppliers

Attributes	Values		
	Model A	Model B	Model C
Tag	B-1	B-3	B-8
Manufacturer	PeerlessBoilers	Aerco	Unilux
Full Load Amperage	10	10	5.4
Voltage_Motor (V)	120	208-230	
OperationMode_Burner	Modulation		Modulation
Pressure_Norm.InletGas (kPa)	1.39		27.58
Temperature_Max.Working (C)		98.8889	121.11
NationalBuildingNo.		67617	1687
Input_Oil (kW)	771		
Power_Steam (kW)	511		
Material_LowerTubeheet		Stainless Steel, SA-240 Ty 439	
Pressure_Operating (C)			82.22-93.33
Material_DownComer			SA 53-B

** Grey cell means that particular information isn't contained in the documents.*

The challenges we identified during this process are listed below:

- One manual contains too much information. Also, the information is not in the order of the tag numbers. For example, the file *'7.3.2.2.05 - VFD's - XXX Reviewed - 2.26.15 - FORMAL COPY'* has total 196 pages of information related to 48 pieces of variable frequency drives. However, the information is not in the order of the tag numbers, so we had to scroll up and down to find the data related to a particular piece of equipment.

- Some of the files are scanned from printed documents. Because of the low resolution, it is hard to read the drawings (Figure 3). An enormous time and effort were wasted confirming the information from project managers or the contractor.

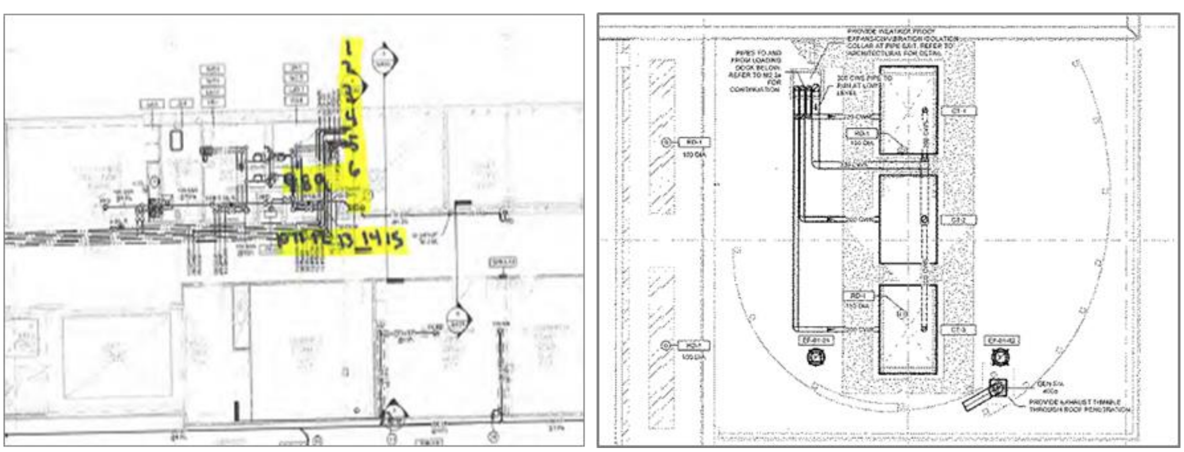

Figure 3: Illegible documents with low resolution

- Some of the scanned files contain handwritten information (Figure 4). As it is recognized as an image, it is unable to query information from those documents. This delays the time of locating the information. Also, as the text can't be copied, the data should be exported manually.

Bursting Pressure, Metal Thickness Measured at *Break or Fracture, and Weight of Section*

Test No. 1		Test No. 2		Test No. 3	
330	psi	345	psi	360	psi
11/32	in.	11/32	in.	11/32	in.
695	lb.	696	lb.	691	lb.
330	psi	345	psi	360	psi
11/32	in.	11/32	in.	11/32	in.
695	lb.	696	lb.	691	lb.
330	psi	345	psi	360	psi
11/32	in.	11/32	in.	11/32	in.
695	lb.	696	lb.	691	lb.
330	psi	345	psi	360	psi
11/32	in.	11/32	in.	11/32	in.
695	lb.	696	lb.	691	lb.

1 Hot water Return Isolation for west shaft (HWR)
2 Hot Water Supply Isolation for West shaft (HWS)
3 Chilled Water Supply Isolation for west shaft (CHWS)
4 Chilled Water Return Isolation for west shaft (CHWR)
5 Terminal Re Heat Water Supply Isolation for West shaft (TRHWS)
6 Terminal Re Heat Water Return Isolation for west shaft (TRHWR)
7 Steam Isolation for Fan Room 1 & West shaft
8 Chilled Water Supply Isolation for West Side of Building (CWS)
9 Chilled Water Return Isolation for West Side of Building (CWR)

Figure 4: Handwritten documents

- Various templates are provided from different suppliers for the same type of equipment (Figure 5). Therefore, the amount of information, orders of the information, and the representation of the information were all different. This causes a delay of understanding the document and finding information.

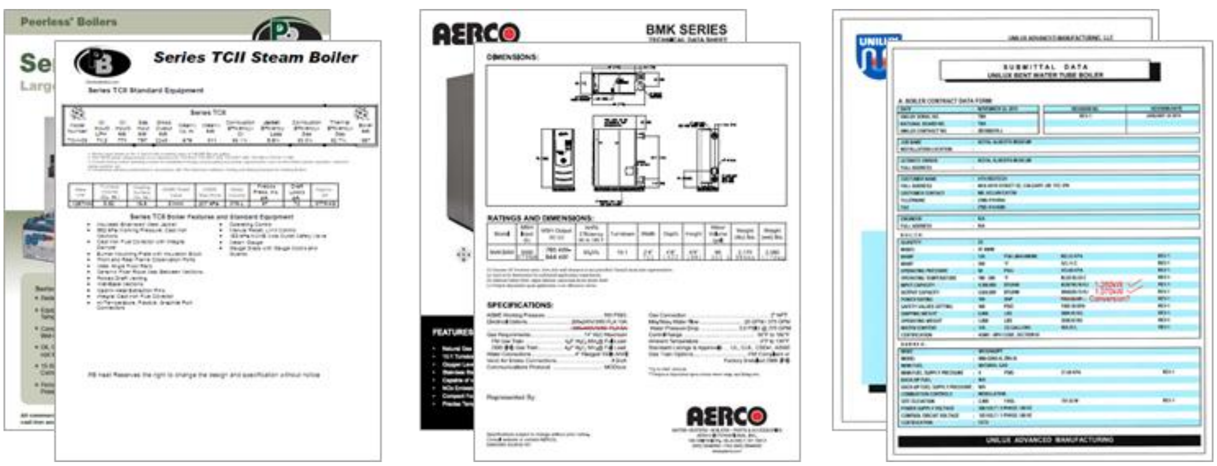

Figure 5: Different templates from various suppliers

- Different types and a different number of attributes are provided for the same type of equipment. This might cause the waste of time creating shared parameters for the massive amount of attributes in the model.

4.3 Unifying the terminologies and units

In the existing model, there were many duplicate attributes named with different terms. For example, there were 'Flow,' 'Flow Rate,' 'Flowrate,' and 'Air Flow,' which meant the same property. This happened because the modeler downloaded the model components from various suppliers' websites and did not unify the terms. This increases file size and causes confusion when the information is exported to another information system. Therefore, we need to set the standard terminologies that can be used in the model, documents, and information systems. As we do not have a universal standard for the terms, we selected the one that was used most frequently in the organization's information system and documents. We also unified the units into the metric system, which is the official system of Canada, and converted the values to match the units. As a result, we could have a single list of attributes that can be used for all types of equipment (Figure 6).

Attributes	1.Pump	2.Heat Exchanger	3.Tank	4.VSD	5. Expansion Tank	6. Domestic Water Heater	7.Compressor	8.Boiler	9.Reverse Osmosis	10.Boiler Feed	11.Water Softener	12.Carbon Filtration	13.Glycol System Feeder	14.Unit Heater
Accessories													Y	
Allowance_Corrosion			Y											
Altitude_Motor	Y													
Ampacity_BurnerMin.Circuit								Y						
Amperage			Y						Y	Y				Y
Amperage_Control								Y						
Amperage_DriveInputFuseRatings				Y										
Amperage_DriveOutput				Y										
Amperage_Max.				Y										
Amperage_Motor								Y						
Amps_Max.Load									Y	Y				
ApparentPower_Motor								Y						
Approval_Motor									Y					
AvailableOptions				Y			Y							
AvailableOptions_GasTrain								Y						
Bypass				Y										
Capacity_Burner								Y						
Capacity_Exchange											Y			
Capacity_Min.Relief&SafetyValve								Y						

⋮

** Y means the attribute is used in that particular equipment type*

Figure 6: Unified attribute terminologies

The challenges we identified during this process are listed below:

- Various terminologies and units are used for the same type of attributes of different types of equipment. For example, for the weight of the equipment, the Heat Exchanger uses Weight Dry/Wet (Kg), the Expansion Tank uses Shipping Weight (Kg), and the Pump uses Weight (LBS). This should be unified, or duplicate parameters will be created in the model, which will cause the increase of file size and unorganized model information.

- As the different suppliers used different terms, sometimes abbreviations, it took an enormous amount of time to organize the terminologies.

- Some of the units were missing in the documents. This is critical as it will confuse the users and cause miscommunication.

- Soft conversion can cause an error. For example, if we convert 0.75 inches to 1.905mm to use the metric system and round up to 1.9mm to embed in the model, later when the user needs imperial measurement, it will be converted to 0.748031inch. So the hard conversion should be used when we unify the units to eliminate the error.

- The terminologies we selected are not universally standardized ones, so if the information needs to be exported to other information systems, it will not be automatically converted.

4.4 Organizing the O&M manual files

In the O&M manuals, there is descriptive information that can't be embedded in the model. Therefore the manual itself should also be linked to the model so that the users can access the document when they need. As it is addressed in the previous section, the manual files had problems such as one file containing information of multiple equipment types or file name not reflecting the contents.

We reorganized the files by splitting the pages and merging the ones related to the particular type of model of equipment. Unrelated ones could be eliminated. Contents page was also added to help the readers locate the information. Then we renamed the files to be recognizable and searchable. As a result, we reduced from 49 files with 1270 pages to 30 files with 862 pages (Figure 7).

Number of files	Number of pages	File size (MB)
49	1270	106.4

3.1.2.1.1. - Hydronic Heating - Glycol Syst...	3.1.2.1.2. - Hydronic Heating - Glycol Sch...
3.3.2.2.01 High Eff. Boilers B-3 to B-7 Rev. ...	3.3.2.2.02 High Eff. Boilers B-3 to B-7 Supp...
3.3.2.2.03 High Eff. Boilers B-3 to B-7 Man...	3.3.2.2.04 Water Tube Boilers B8 & B9 Rev....
3.3.2.2.05 Water Tube Boilers B8 & B9 Ma...	3.3.2.3.01 - Pumps, HX, AS, ET - Dialog Re...
3.3.2.3.02 - Booster Pumps P-25 & P-26 - ...	3.3.2.3.03 - Pumps P-30 & P-31 Resubmitt...
3.3.2.3.04 - Pump Suction Diffusers - Dialo...	3.3.2.3.08 - Unit Heaters - Dialog Reviewe...
3.3.2.3.24 - Hydronics, Glycol System Feed...	3.3.2.3.27 - Hydronics, Glycol Product Dat...
3.3.3.2.01 - B3 to B-7 AERCO Boilers O&M's	3.3.3.2.02 - B3 to B7 AERCO Boiler Venting...
3.3.3.2.03 - B8 & B9 Unilux Water Tube Boi...	3.3.3.2.04 - B8 & B9 Unilux Pressure Drop ...
3.3.3.3.01 - Pumps - Taco IOM 302-012 - F...	3.3.3.3.02 - Pumps - Taco IOM 302-015 - 1...
3.3.3.3.03 - Pumps - Taco IOM 302-031 - K...	3.3.3.3.04 - Heat Exchangers - Taco IOM P...
3.3.3.3.11 - Hydronic Unit Heaters - Modi...	5.1.1.1.01 - Domestic & Process Water Sys...
5.1.1.2.01 - Domestic & Process Water Sys...	5.1.1.2.02 - Domestic Hot Water System S...
5.1.1.2.03 - Process Domestic Hot Water S...	5.1.5.1. - RO Water System Description
5.1.5.2. - RO Water System Schematic	5.3.2.01 - Air Compressor & Receiver - Dia...
5.3.2.11 - RO System, CAF, TK-1.2 - Dialog...	5.3.2.13 - RO Water Softeners - Dialog Rev...
5.3.2.14 - Water Heaters - Dialog Reviewe...	5.3.3.01 - Air Compressor IOM
5.3.3.02 - Air Compressor GX Parts manual	5.3.3.04 - Water Heaters - PV500-45U IOM
5.3.3.05 - Booster Pump RL IOM	5.3.3.07 - RO - L Series Operating Manual ...
5.3.3.08 - CAF - 2850 Control Valve Service...	5.3.3.10 - Water Softener - 3200NXT Servic...
6.3.2.01 - Steam Boilers B1 & B2 Rev. 2 - D...	6.3.2.02 - Steam Boilers B1 & B2 SteamMa...
6.3.2.09 - Boiler Feed Package Revised - Di...	6.3.3.01 - Steam Boiler - TC_IOM
6.3.3.02 - Boiler Feed - G Series Pump IMI ...	6.3.3.03 - Boiler Feed - SB Control Valve
6.3.3.03 - Boiler Feed Sparge Valve - Not S...	6.3.3.04 - Boiler Feed - Self-acting_Temper...
7.3.2.2.05 - VFD's - Dialog Reviewed - 2.26....	

→

Number of files	Number of pages	File size (MB)
30	862	100

O&M_Boiler(B-1,2)	O&M_Boiler(B-3,4,5,6,7)
O&M_Boiler(B-8,9)	O&M_BoilerFeed(BF-1)
O&M_CarbonFiltration(CAF-1,2)	O&M_Compressor(CP-2)
O&M_DomesticWaterHeater(DWH-1,2,PD...	O&M_ExpansionTank(ET-1,2)
O&M_ExpansionTank(ET-3,4,10,11)	O&M_ExpansionTank(ET-7,8,12)
O&M_GlycolSystemFeeder(GFS-1)	O&M_HeatExchanger(HX-1)
O&M_HeatExchanger(HX-3,4)	O&M_Pump(P-1,2)
O&M_Pump(P-3,4)	O&M_Pump(P-5,6)
O&M_Pump(P-15,16)	O&M_Pump(P-17,18)
O&M_Pump(P-25,26)	O&M_Pump(P-30,31)
O&M_ReverseOsmosis(RO-1,2)	O&M_Tank(BTK-1)
O&M_Tank(TK-1,2)	O&M_Tank(TK-3)
O&M_UnitHeater(UH-P1-02)	O&M_VariableFrequencyDrive(VSD-P-3,4)
O&M_VariableFrequencyDrive(VSD-P-5,6)	O&M_VariableFrequencyDrive(VSD-P-15,1...
O&M_VariableFrequencyDrive(VSD-P-17,1...	O&M_WaterSoftener(WS-1,2)

Figure 7: Organized O&M manuals (left: before, right: after)

The challenges we identified during this process are listed below:

- As the information was not in the order of the tag number, it took much time to extract the related pages and merge in the right order. Also, the data for several pieces of equipment were in the same file, not separated. For example, one of the files included information on pumps, heat exchangers, expansion tanks, and air separators. And the order of the information had no rule (P-15, 16, 17, 18, 19, 20, 21, 22, 28, 29, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 23, 24, 27, HX-1, 2, 3, 4, ET-1, 2, 3, 4, 10, 11, 5, 6, 7, 8, 12, 9, Air Separators.)

- Some of the equipment accessories information pages did not indicate which equipment they are related. It took some time to figure out. For example, one of the files included information related to the boiler feed, tank, and some valves. We had difficulty dividing the manuals as the information of valve did not indicate its parent equipment.

5 LESSONS LEARNED

A case study was carried out on developing BIM model for FM by populating information from handover documentation. The paper illustrates the processes and challenges of extracting and organizing the information. The main reason that required a huge amount of effort of the research team to proceed the model development was the poor quality of handover documents. The handover documentations had qualitative problems including:

- The massive amount of information randomly listed in the file.

- Single file including too much information of various types of equipment.

- Illegible documents with low resolution.

- Image files scanned from the handwritten document. Information cannot be queried.
- File names including acronyms and not reflecting the contents.
- Various templates provided from different suppliers with different amount of information.
- Different type and different amount of attributes provided for the same type of equipment.
- Various terminologies and units used for the same type of attributes.

As a result, these factors caused a delay of retrieving and organizing the information. This addresses the importance of the quality management of handover documentation for utilizing BIM for FM purposes. The impact of these problems would have been reduced if there was a deliverable guideline for the handover documentation in the first place. The guideline should contain information such as the folder and file naming conventions, standard terminologies and units of attributes, and format of the delivered files. And this should not only be used for the handover documents but also the related information systems. However, as the amount of information that should be handled in the operation model is massive, there is no single solution to solve the problems. Further studies should be carried out on finding the efficient methods to populate the facility information in existing BIM model, and to manage the quality of the handover information.

References

Atkin, Brian, and Adrian Brooks. 2009. *Total Facilities Management*. *A John Wiley & Sons, Ltd., Publication*. Third Edit. doi:10.1007/978-3-540-89230-4.

Azhar, Salman, Malik Khalfan, and Tayyab Maqsood. 2015. “Building Information Modelling (BIM): Now and beyond.” *Construction Economics and Building* 12 (4): 15–28. doi:10.5130/ajceb.v12i4.3032.

Ghosh, Arundhati M., Allan D. Chasey, and Mark Mergenschroer. 2015. “Building Information Modeling for Facilities Management: Current Practices and Future Prospects.” In *Building Information Modeling : Applications and Practices in the AECO Industry*, edited by Svetlana Raja R. A. Issa; Olbina. American Society of Civil Engineers (ASCE).

Goedert, James D, and Pavan Meadati. 2008. “Integrating Construction Process Documentation into Building Information Modeling.” *Journal of Construction Engineering and Management* 134 (7): 509–16. doi:10.1002/9780470432846.

IFMA. 2013. *BIM for Facility Managers*. Edited by Paul Teicholz. John Wiley & Sons.

Lewis, Angela, David Riley, and Abbas Elmualim. 2010. “Defining High Performance Buildings for Operations and Maintenance.” *International Journal of Facility Management* 1 (2): 16.

McArthur, J. J. 2015. “A Building Information Management (BIM) Framework and Supporting Case Study for Existing Building Operations, Maintenance and Sustainability.” *Procedia Engineering* 118. Elsevier B.V.: 1104–11. doi:10.1016/j.proeng.2015.08.450.

Newton, Randall S. 2004. “Inadequate Interoperability in Construction Wastes 415.8 Billion.” *AECNews. Com*.

Sabol, Louise. 2008. “Building Information Modeling & Facility Management.” *Design + Construction Strategies*, 1–13. http://www.dcstrategies.net/files/2_sabol_bim_facility.pdf.

Volk, Rebekka, Julian Stengel, and Frank Schultmann. 2014. “Building Information Modeling (BIM) for Existing Buildings - Literature Review and Future Needs.” *Automation in Construction*. doi:10.1016/j.autcon.2013.10.023.