INVESTIGATING THE TRANSITION TO BIM-ENABLED FACILITIES MANAGEMENT: A LARGE PUBLIC OWNER'S PERSPECTIVE

by

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF APPLIED SCIENCE

in

THE FACULTY OF GRADUATE AND POSTDOCTORAL STUDIES

(Civil Engineering)

THE UNIVERSITY OF BRITISH COLUMBIA

(Vancouver)

April 2017

Abstract

In the architecture, engineering, construction, owner, and operator (AECOO) industry, there is growing interest in the use of building information modeling (BIM) for facilities management (FM). BIM prevents facility information from being lost, eases the access to data, and automates data entry. Despite these advantages, however, the adoption of FM BIM is facing slow growth. To promote the use of FM BIM, we need to understand the challenges of transitioning to BIM for facility owners.

The objective of this research is to investigate the process and effort of developing and utilizing FM BIM. The research is based on a case study of a large public owner organization in Canada. The Owner recently completed the construction of an institutional facility that utilized BIM in design and construction. A pilot study was conducted to inform the owner of the effort to develop the handover BIM for FM purposes. The research was conducted in three phases: (1) the pre pilot study revealed the limitations of current FM processes, (2) the pilot study investigated the process to develop a FM BIM, and (3) the post pilot study identified the organizational barriers to utilizing the FM BIM.

The pre pilot study revealed the inefficiencies in the daily FM practice and FM information systems, which was due to the poor quality of handover documents, inaccuracy of facility data, and lack of interoperability among the systems. These inefficiencies motivated the owner to consider the opportunities that BIM could provide for efficient data management. The pilot study detailed the process of developing the FM BIM, which included numerous steps: analyzing handover model, obtaining data from handover documents, populating the model, and attaching the O&M files. A significant amount of effort was required due to the poor quality of

handover model, unorganized handover documents, and the absence of parameter template. Beyond these challenges, there were barriers to the utilization of the FM BIM, including the absence of BIM experts, lack of training, and lack of proper hardware and software, which emphasized the need for support from high-level management.

Preface

This paper is based on the author's work in Alberta Infrastructure under the direct supervision of Dr. Poirier and Dr. Staub-French. The author is responsible for the majority of data collection and research outcomes presented in this paper. The research project and method were approved by the University of British Columbia's Research Ethics Board [certificate # H12-03693].

This paper is intended to be submitted for possible future publications with some modifications.

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List of Abbreviations

AEC: Architecture, Engineering, and Construction

AECOO: Architecture, Engineering, Construction, Owner, and Operators

BIM: Building Information Modeling or Building Information Model

FM: Facility Management

FM BIM: FM intent BIM

O&M: Operation and Maintenance

AI: Alberta Infrastructure

RAM: Royal Alberta Museum

Acknowledgments

I would first like to express my sincere gratitude to my supervisor Dr. Sheryl Staub-French for the continuous support and guidance. She was always there for me when I felt lost and frustrated. Her patience, motivation, and consistent encouragement helped me in all the time of research and writing of this thesis.

I'm extremely thankful to Dr. Erik A. Poirier for sharing his vast knowledge and giving me valuable guidance. Without his support and encouragement, I would not have successfully overcome numerous obstacles I have been facing through my research.

I am also grateful to all my friends for their support and friendship. They motivated me, inspired me, and encouraged me throughout my grad life. I'm leaving UBC with great memories thanks to them. Also, I want to thank my colleagues from Alberta Infrastructure who supported my work and my life in Edmonton. I will never forget how much I loved working with them.

My sincere thanks go to Dr. Ghang Lee at Yonsei University who first led me to BIM and inspired me along the way. I could pursue my study thanks to his motivation and support.

Last but not the least, I must express my profound gratitude to my parents, my sister, my brothers, and my fiancé for providing me with unfailing support and continuous encouragement throughout my study and my life in general. This accomplishment would not have been possible without them.

Dedication

This thesis work is dedicated to my parents, who have always loved me unconditionally and whose good examples have taught me to work hard for the things that I love. I also dedicate my work to my sister, who is also my best friend, my mentor, and my inspiration.

Chapter 1: Introduction

1.1 Background

According to the National Institue of Building Sciences (NIBS), Building information modeling (BIM) is "a digital representation of a facility's physical and functional characteristics. As such, it serves as a shared knowledge resource for information about the facility, forming a reliable basis for making decisions during its life cycle from inception onward (NIBS, 2015)." Due to its benefits for the architecture, engineering, construction, owner, and operator (AECOO) industry, its adoption around the world has continuously grown over the last few decades. A market report published by Allied Market Research titled, "World Building Information Modeling Market: Opportunities and Forecasts, 2015-2022," forecasts that the world BIM market will garner a revenue of $11.7 billion by 2022 (Allied Market Research, 2016). Also, recognizing the declining productivity of the construction industry, governments around the world also have started recommending or mandating the use of BIM for public sector buildings (Kassem et al., 2015). Figure 1.1 shows governments that are moving toward BIM by mandating its use or developing national BIM guidelines and standards.

Applications of BIM include visualization, sustainability analyses, quantity surveying, cost estimation, site logistics, phasing and 4D scheduling, constructability analysis, building performance analysis, and building management (Azhar et al., 2015). These uses extend throughout a building's life cycle, including the design, build, and operations phases, as

Figure 1.2 indicates (NIBS, 2017).

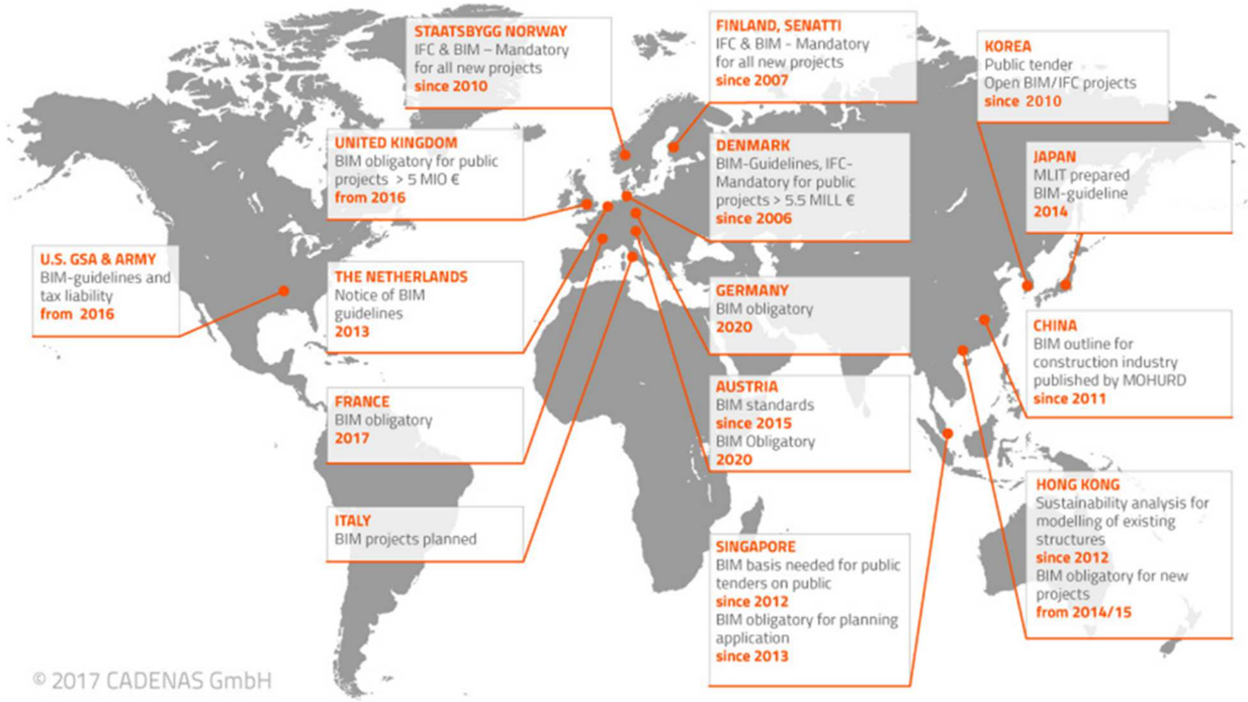


Figure 1.1 Governments around the world moving toward BIM (CADENAS, 2017)

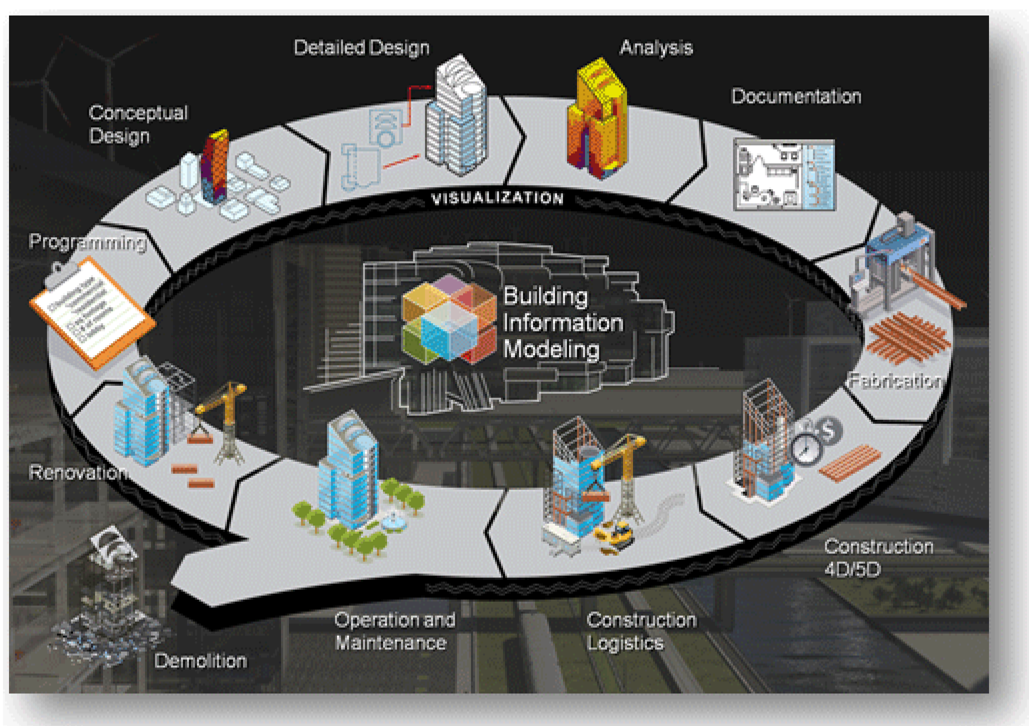


Figure 1.2 Applications of BIM throughout building's life cycle (Courtesy of Autodesk, Inc.)

The use of BIM during the design and construction phase has been widely accepted due to its benefits, which range from a reduction in design cycle time to a direct impact on construction cost (Wetzel & Thabet, 2015). According to McGraw-Hill Construction, the primary uses of BIM in the design phase are visualization, which helps designers better engage clients and align expectations, and performance analyses and simulations, which improve design solutions. Also, the contractors use BIM for the spatial coordination, which reduces costly rework, and digital fabrication, which increases speed and improves quality. These capabilities ultimately help owners deliver projects on time and within budget (McGraw-Hill Construction, 2014). Now the industry is showing a growing interest in the use of BIM in facilities management (FM) for coordinated, consistent, and computable building information/knowledge management throughout a building's life cycle (Becerik-Gerber et al., 2011). Many studies have addressed the potential benefits of using BIM for FM. BIM allows facility information to be collected and modeled in a way that is universally recognized and prevents the information from getting lost during project handover, from design to construction to operations teams (Atkin & Brooks, 2009). Furthermore, as BIM enables project teams to share and reuse the facility data easily, there is no need to re-enter the data into a downstream FM system manually. This reduces the data entry cost and generates high-quality data (IFMA, 2013; Sabol, 2008). Despite these benefits, however, the adoption of BIM for FM by owners is facing slow growth (Korpela et al., 2015). According to Wetzel and Thabet, with all the success that BIM has experienced during the design and construction phases, the effort of transferring the information to the facility management phase remains in its infancy (Wetzel & Thabet, 2015). Therefore, the model handed over to the owner often loses its value without being utilized further in FM. To promote the adoption of BIM for FM, there is a need to better understand what work and effort are required to use the handover BIM in FM.

1.2 Research objective and method

The overarching aim of this research is to to investigate the process and scale of the effort required to develop a BIM that can be utilized throughout facility management. To fulfill the objective, a case study was conducted on a large public owner organization in Canada. A new museum construction project, which was procured by the Owner, was recently completed and was in the process of being handed over to the Owner. During the design and construction phases of the project, a BIM model was developed by the project team for design and construction purposes. Thus, although the model was handed over to the owner after construction was completed, it was not developed specifically to support facility management purposes. As the Owner's interest in implementing BIM for its projects was growing, the Owner wanted to understand what work and effort were required to develop the project BIM model so that it could be utilized in the FM phase. Thus, a pilot study was conducted on part of the project model to investigate the possible effort needed to develop and utilize the handover BIM in FM.

The study was conducted in three phases. First, as a pre pilot study, the Owner's current FM processes were investigated. Then, as the pilot study, the project model was developed into a FM BIM to reveal the process and effort required for the modeling. Last, a post pilot study was conducted to identify the organizational barriers to utilizing the FM BIM. Table 1.1 shows the research activities (RAs) set for each phase of the study, and Figure 1.3 illustrates the roadmap of the research activities.

Table 1.1 Research activities

Objective: Investigate the process and effort required to develop a BIM for facility management.		
	Pre Pilot Study	
		RA 1. Investigate the facility FM practice to identify limitations
		RA 2. Investigate the FM information systems to identify limitations
	Pilot Study	
		RA 3. Examine the handover documentation to set out the model development
		RA 4. Analyze the handover model to identify gaps in modeling
		RA 5. Develop a FM BIM to demonstrate the proof of concept
		RA 6. Reflect on the effort of developing the FM BIM
	Post Pilot study	
		RA 7. Investigate the owner’s perceptions of the organizational barriers to BIM adoption

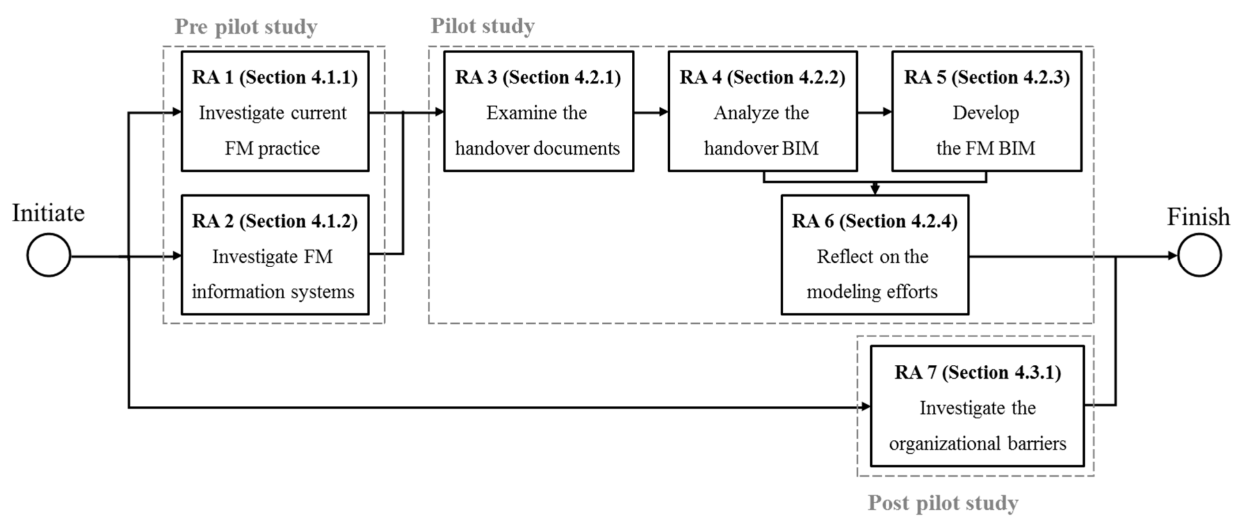


Figure 1.3 Research flow

(1) Pre pilot study: Prior to the pilot study, the limitations of the Owner’s current FM practices and FM information systems were investigated through interviews and

document analysis. The inefficient data management and poor quality of data found in their current practices demonstrated the need to investigate how BIM could be used as a single data source for FM.

(2) Pilot study: To implement the pilot study, the project model and handover documents were collected from the project team. The handover documentation contained an extensive amount of facility data, but the documents were not organized in a way to be imported into BIM model. In addition, the handover model contained significant amounts of inaccurate non-geometric data whereas the geometric data was somewhat accurate. Thus, the model was developed with the data extracted from the handover documents. A significant amount of time and effort were required to develop the FM BIM. Figure 1.4 illustrates the process and steps involved in the modeling process. In addition, we documented the timeline of the process as illustrated in Figure 1.5 . More detailed information is provided in Chapter 4 of the thesis.

(3) Post pilot study: Last, interviews were conducted to investigate the Owner's perceptions of the usefulness of the FM BIM to support facility management. We identified several barriers to BIM utilization in the FM phase, including the need for employee training, proper hardware and software, and dedicated BIM experts. These barriers reinforce the need for support from high-level management for owners considering the transition to BIM.

The method of each research activity is explained in Chapter 3 in detail.

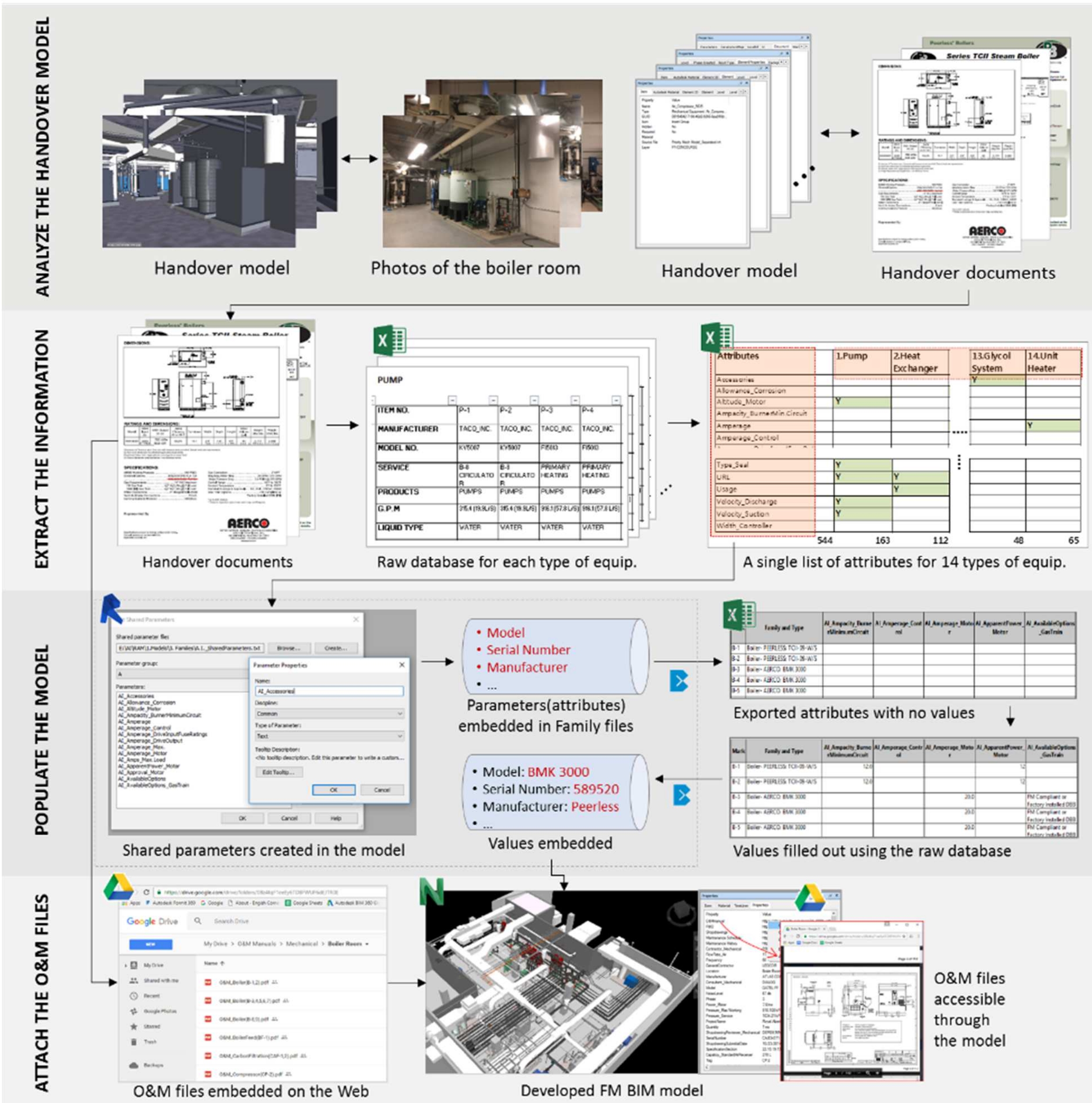


Figure 1.4 Process and information flows required to develop a FM BIM

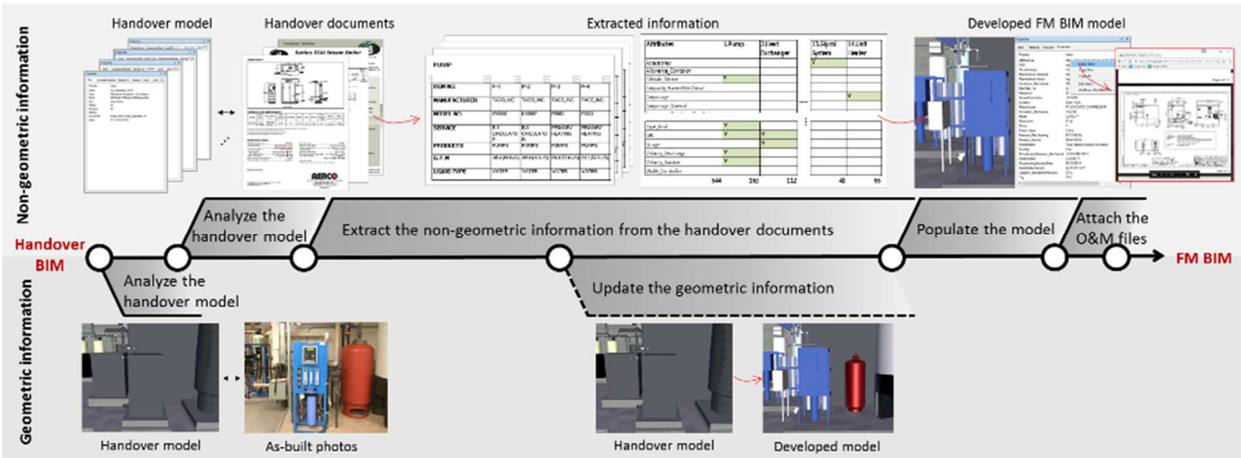


Figure 1.5 Timeline of the FM BIM development process

1.3 Thesis outline

This thesis consists of five chapters. Chapter 1 provides an overview of the industry problem, research objectives, and the research method. Chapter 2 reviews previous studies regarding traditional FM practices, BIM-enabled FM, and potential challenges of leveraging BIM in FM. Then we describe how this research addresses the limitations of existing studies. Chapter 3 illustrates the method of the research in detail. Information of the case study and pilot study are provided with detailed descriptions of the research activities and data collection methods. In Chapter 4, we illustrate the findings of the research activities in detail. The discussion is carried out for each phase of the study. Last, Chapter 5 concludes with the summary, limitations, and suggestions for further studies.

Chapter 2: Literature Review

2.1 Traditional FM

The British Standards Institute defined facility management (FM) as: “the integration of processes within an organization to maintain and develop the agreed services which support and improve the effectiveness of its primary activities” (BSI, 2007). It is a profession to ensure the functionality of facilities by integrating people, place, process and technology (IFMA, 2013). At a corporate level, it contributes to the delivery of strategic and operational objectives. On a day-to-day level, effective facilities management provides a safe and efficient working environment, which is essential to the performance of any business – whatever its size and scope (BIFM, 2017). Thus, inappropriate FM can have an impact on the performance of an organization because of equipment failure, the health of the organization’s staff, and the safety of building occupants. Conversely, a well-maintained facility can enhance an organization’s performance by contributing to the optimization of the working and business environment (Alsyouf, 2007; Atkin & Brooks, 2009; Roelofsen, 2002). However, the efficient utilization of facility information, its management, and its supporting technology in traditional FM practices have been somewhat problematic (Barrett & Baldry, 2003; Abel et al., 2006; Dettwiler et al., 2009).

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 to operate the building upon a project’s completion. Traditionally, facility information is handed over from the contractor to the owner through paper-based construction documents, which include drawings, specifications, product data sheets, warranties, O&M manuals, and so on. These documents are collected from various vendors and organized by the contractors in a format to align with their needs (Goedert

& Meadati, 2008). As the current process of information handover to FM phase is done manually, the information is often incomplete and inaccurate (Lucas et al., 2013). Even when the documents are available digitally, lack of interoperability of software platforms reduces the usefulness of the information. Rework and manual data entry are usually required to update FM systems, which leads to duplication of efforts and high chances of error (Ghosh et al., 2015). As a result, the industry is spending millions of dollars, and thousands of man-hours recreating such information and working with inefficient workflows (Keady, 2009). Due to these difficulties in managing the quality of facilities information, the AECOO industry has started to adopt BIM for FM purposes as the "single source of truth" (Atkin & Brooks, 2009; Sabol, 2008).

2.2 BIM-enabled FM

The use of BIM goes beyond the planning and design phase of a project, extending throughout the building lifecycle, supporting processes that include cost management, construction management, project management and facility operation (Eastman et al., 2008) (e.g. Eastman et al. 2011). BIM can bridge the information loss associated with handing a project from design team to construction team to building owner/operator, by allowing each group to add to and reference information they acquire during their period of contribution to the BIM process (Lucas et al., 2013). In addition, as the facility data in BIM can be easily shared and reused by the project team (Sabol, 2008), it does not have to be re-entered into a downstream FM system. This reduces data entry cost and generates higher-quality data (IFMA, 2013). The application areas of BIM in FM include locating components, facilitating real-time data access, checking maintainability, and automatically creating digital assets (Becerik-Gerber et al., 2012). Furthermore, to support the information handover process, efforts have been put forth to develop information exchange standards, such as Construction Operations Building Information Exchange (COBIE). COBie was also developed to create both a format and standardized template for information handover to operations and maintenance entities (Sabol, 2008). It is intended to simplify the work required to capture and record project handover data. The development of this standard signifies a push towards a life-cycle view of building information (Poirier, 2015).

Despite its benefits and multiple efforts by the industry to leverage BIM in FM, however, owners have been hesitant about adopting BIM for FM (Korpela et al., 2015).

2.3 Challenges of leveraging BIM in FM

In the last few years, several case studies have been carried out to develop a better understanding of the barriers to BIM adoption in FM. The identified challenges include the interoperability issues, difficulties of integration, and unclear responsibilities in the creation of models.

A case study of the USC School of Cinematic Arts project conducted by the University of Southern California investigated the progression of current BIM to BIM-enabled FM across three construction phases from the owner's perspective (Aspurez & Lewis, 2013). The study identified difficulties including the following: involving the stakeholders in the transition, understanding the requirements of FM team, determining who will manage the record BIM model after facility handover, and finding dedicated resources to make progress required to implement BIM FM.

Lavy and Jawadekar also investigated the use of BIM for FM in three projects at Texas A&M University (Lavy & Jawadekar, 2014). The project team identified challenges of integrating BIM with its maintenance system using COBie. First, there was a limitation on data sharing, which required a significant amount of data to be re-entered by the owner after the model was handed over. Also, the absence of a standardized data formulation process and the lack of internal BIM experts became a challenge. They also suggested initiating the data gathering and formulation process earlier in the project.

A similar approach was used in a study conducted by University of Washington (Asl, 2015). They investigated the value of using COBie with BIM in operations and maintenance. Interviews with facility services (FS) employees were conducted to understand the current work order process and how COBie can have an impact on it. As a result, the paper illustrated that COBie was not enough on its own to provide all the information needed for facility management. Also, it pointed out that COBie could ease the process of preventive maintenance (PM) work order planning by providing asset data, but it could not help with the PM management.

Korpela et al. also investigated the challenges and potential of utilizing BIM for FM through a case study of the Center for Properties and Facilities of the University of Helsinki (Korpela et al., 2015). Interviews were conducted with the designers and facility managers to understand their perceptions of the challenges of integrating BIM and FM information systems. They presumed that developing a useful FM model and keeping it update would require a significant amount of time and money. Also, hiring the experienced maintenance personnel with BIM skills was selected as a prerequisite for BIM adoption. Last, they suggested assigning the modeling task to the designers "up to the end."

2.4 Discussion

While adopting a similar approach to the previous case studies mentioned above, this research aimed to address the noted limitations of the studies.

First, existing studies are limited to the cases of adopting BIM from the early phase of the projects throughout the FM phase. However, as BIM sometimes is not used by all stakeholders in the building life cycle yet, some owners create isolated BIM solely for FM purposes (Volk et al., 2014). In addition, it is well known that existing facilities have a significant need for adopting BIM for efficient facility management, but still, there are very few studies that have addressed this issue (Godager, 2011). Therefore, there is a need to study the effort required to leverage BIM in FM after the facilities are handed over.

Second, previous studies are limited to small owner organizations, which typically involved universities. There is a need to investigate different types of owners with different nature to validate the results. To address this, this research studied focused on the perspective of a large public owner organization, specifically infrastructure department for the provincial government. This is also meaningful as large public building owners are considered as one of the most efficient drivers for BIM adoption by the industry (Newton et al., 2009).

Last, the data collection methods in the existing studies are limited to interviews, observations, or document analysis. In this research, one of the research members was directly involved in the owner organization to lead the pilot study of developing a FM BIM, while using interviews and document analysis as additional data collection methods. It allowed us to identify the challenges of the modeling process and acquire the owner’s perceptions in more detail.

Chapter 3: Research Objective and Method

3.1 Research objective

The overarching objective of this study is to understand the process and scale of effort required to develop and utilize a BIM for the FM phase. A case study was conducted on a large public owner organization, and a pilot study was carried out on its recently completed museum project. To meet the overarching objective, we conducted the study in three phases:

(1) Pre pilot study: Analyze the limitations of current FM processes;

(2) Pilot study: Investigate the process and effort required to develop a FM BIM; and

(3) Post pilot study: Identify the organizational barriers to developing and utilizing FM BIM

3.2 Case study

In this paper, the case study method was selected as the main research method. The case study method is known to be useful in research, as it helps a researcher to assess the data within a specific context at the micro-level (Zaidah & Zainal, 2007). It is known to be a practical solution when a researcher is unable to obtain enough sample subjects. Case studies also present data of real-life situations and provide better insights into the detailed behaviors of the subjects of interest (Zaidah & Zainal, 2007).

- **Alberta Infrastructure (AI)**

The case study was conducted in response to a request by the Government of Alberta's Infrastructure arm: Alberta Infrastructure (AI). AI is a large public owner organization that plans, builds, and manages government-owned infrastructure, including schools, hospitals, and other public facilities. AI manages approximately 1,900 government-owned and leased facilities. It has very little experience in BIM, but it recently noticed an increasing demand for BIM within its market segment. To meet the demand, AI and the research team carried out a four-year longitudinal collaboration research on adopting BIM in AI for use in future projects, which was initiated in 2013. The research was conducted in two phases of leveraging BIM in project delivery and leveraging BIM in facility management (Figure 3.1). This thesis documents the second phase, leveraging BIM in FM. As part of the data collection method, a pilot study was carried out on the Royal Alberta Museum (RAM) project, which was procured by AI.

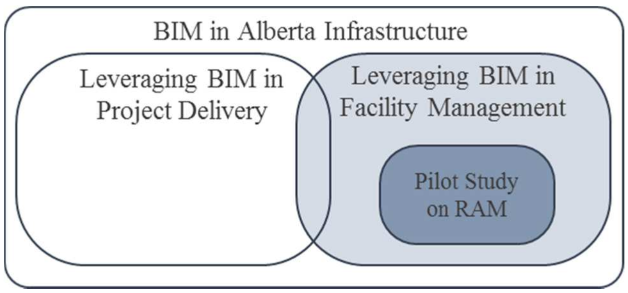


Figure 3.1 Research scope

- **Royal Alberta Museum (RAM) project**

The RAM is a four-story museum with a floor area of 37,810 m^2 that is located in Alberta, Canada (Figure 3.2). The project was initiated in 2011 under a design-build contract, and construction was completed in 2016. BIM was required by AI on this project, but the owner's only requirement for BIM was to produce a preliminary model for spatial validation, and there were no further formal BIM requirements imposed by the owner. However, the design-build team decided to develop the model further for design and construction purposes.

Figure 3.2 Royal Alberta Museum (Courtesy of Government of Alberta)

A ‘BIM Project Execution Guide (BIM PeG)’ was collaboratively developed by the project participants to develop and implement BIM successfully. It outlined the overall vision along with the implementation details for the team to follow throughout the project. The collaboration of the participants was the key to the success of BIM implementation since the architectural, structural, mechanical, and electrical models were developed by four individual companies (Figure 3.3).

The final level of development (LOD) of the construction model was aimed to be LOD 400. According to the guide, level 400 models *“include elements that are accurate in terms of size, shape, location, quantity and orientation with complete fabrication, assembly and detailing information At this Level, the Model may also have non-geometric (3D) information such as text, dimensions, notes, 2D details, etc.”* As a result, the BIM was used in the design and construction phases for various purposes such as visualization, detecting conflicts, estimating costs, and 4D scheduling (Figure 3.4). Furthermore, selected areas within the building were remodeled to a fabrication LOD by the project participants, if necessary, using the consultant models as reference.

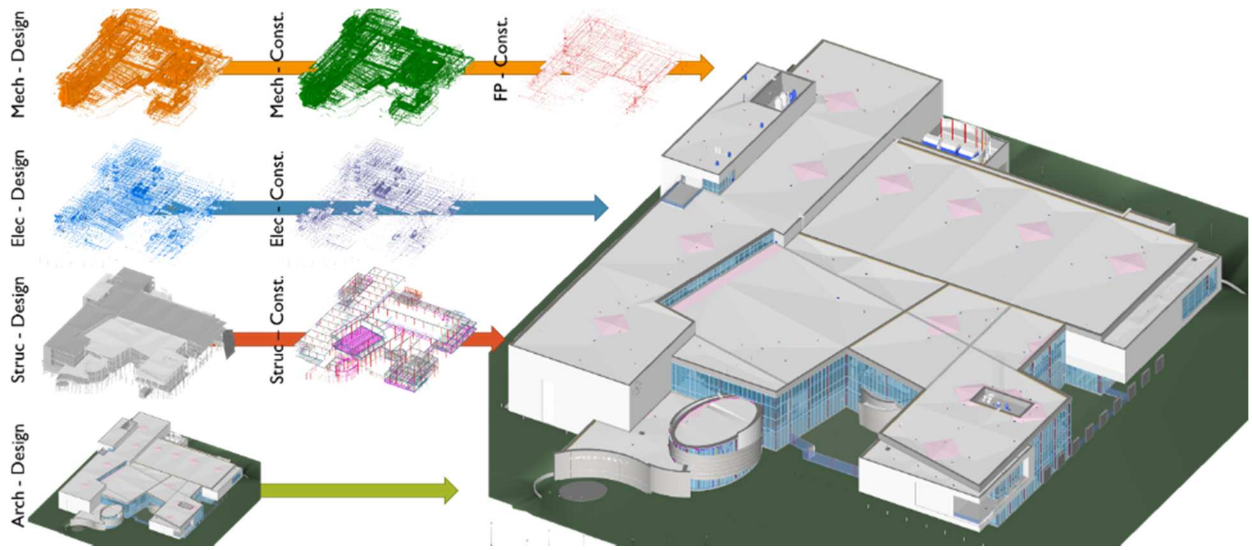


Figure 3.3 Developing BIM in four different disciplines (Courtesy of Ledcor Design-Build Inc.)

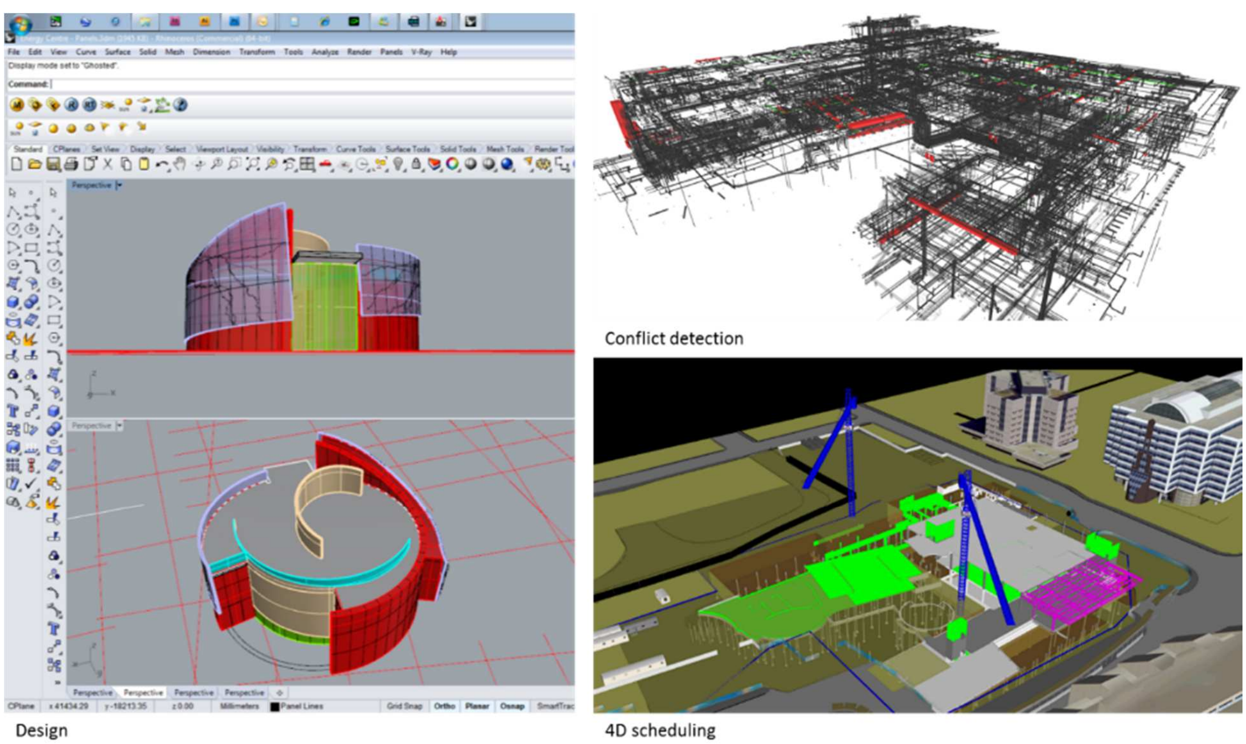


Figure 3.4 Use of BIM in design and construction phases (Courtesy of Ledcor Design-Build Inc.)

3.3 Pilot study

According to Hully et al., a pilot study is “a small-scale preliminary study conducted in order to evaluate feasibility, time, cost, adverse events, and effect size (statistical variability) in an attempt to predict an appropriate sample size and improve upon the study design prior to performance of a full-scale research project” (Hulley et al., 2013). A pilot study is considered an example of an exploratory case study. One of the advantages of conducting a pilot study is that it might give a warning about where the main research project could fail, where research protocols may not be followed, or whether proposed methods or instruments are inappropriate or too complicated (De Vaus, 2013).

For RAM project, AI had decided to execute FM with in-house staffs. As AI became aware of the benefits of BIM during the design and construction phases, it showed its interest in utilizing BIM for FM. However, the project model was not fully developed in a way to be used for FM purposes as it was developed for design and construction purposes. AI had no knowledge of developing the handover BIM to a FM BIM and had no intention to develop the entire model without acknowledging the time and money required for the process. Thus, the research team decided to carry out a pilot study on a selected area of the model to investigate the potential effort required to develop and utilize the handover BIM in FM.

For the pilot study, the construction model of RAM was handed over to the research team in both Revit and Navisworks formats. In addition, the electronic handover documents were collected as a reference to develop the model (Figure 3.5).

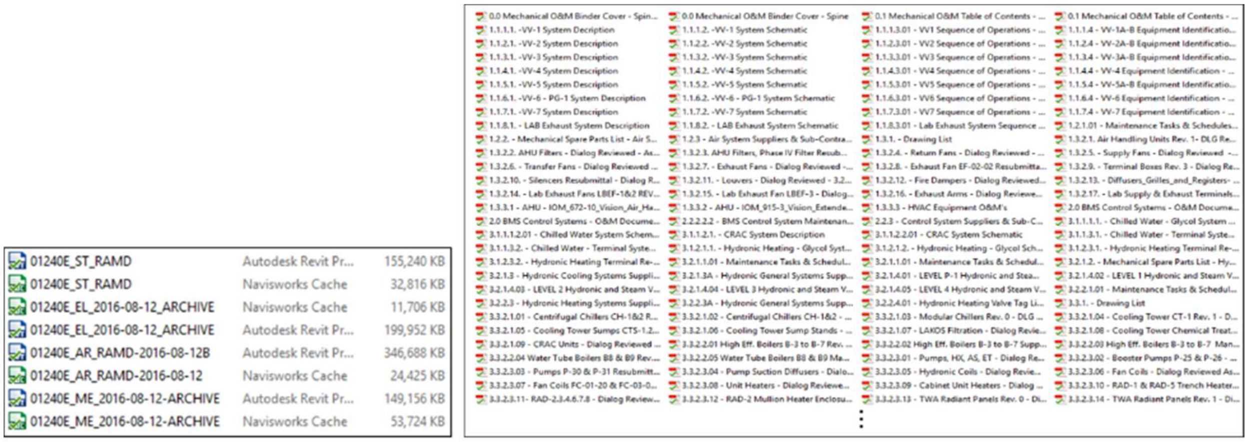
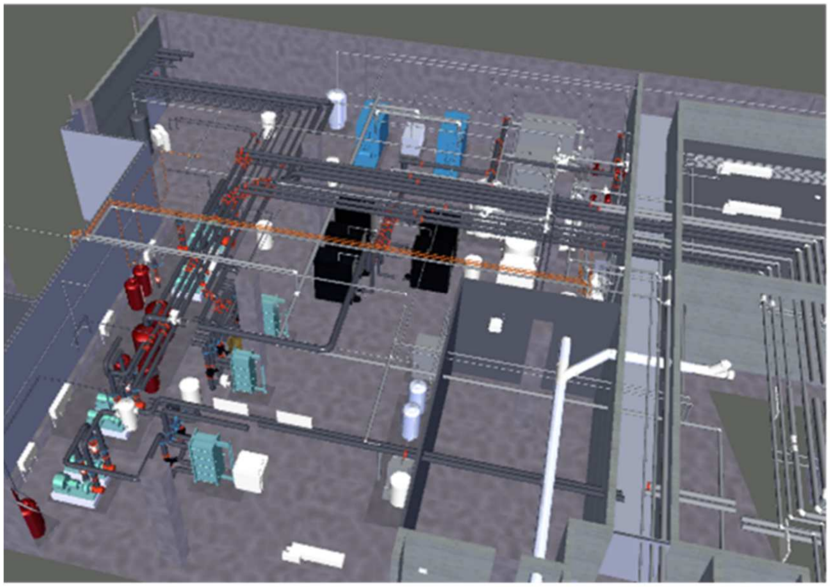


Figure 3.5 Handover models (Left) and handover documents (Right) of RAM

The subject of the pilot study is a boiler room with a floor area of 400m^2; it is one percent of the entire floor area of the building. Specifically, the boiler room contains 60 pieces of mechanical equipment that were investigated and developed for the FM BIM (Figure 3.6). There are mainly two reasons for considering only part of the model, particularly the boiler room. First, as the model was not developed to as-built condition, developing the entire model would require an enormous amount of effort. Since this research was done to inform the owner of the potential effort of developing a FM BIM and the pilot study was carried out to demonstrate the proof of concept, it was not reasonable to develop the entire model. Second, the facility manager of the RAM project suggested the boiler room for the pilot study as the room was one of his major concerns for operating the building. The room contains various types of complicated equipment that could cause serious issues in the event of a malfunction. Therefore, he wanted to see how the FM BIM would benefit him to operate the boiler room. As a result, the information related to these 60 pieces of equipment was assessed and developed for FM purposes.



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**

Figure 3.6 Model view of the boiler room and the mechanical equipment located in the room (Courtesy of Ledcor Design-Build Inc.)

3.4 Research activities

To fulfill the overall objective upon these organizational and project contexts, seven research activities (RAs) are set as shown in

Table 3.1. Figure 3.7 illustrates the flow of the research and Table 3.2 indicates the data collection method used for each research activity, which includes interview, document analysis, and pilot study.

Table 3.1 Research activities

Objective: Investigate the process and effort required to develop a BIM for facility management.
Pre Pilot Study
RA 1. Investigate the facility FM practice to identify limitations
RA 2. Investigate the FM information systems to identify limitations
Pilot Study
RA 3. Examine the handover documentation to set out the model development
RA 4. Analyze the handover model to identify gaps in modeling
RA 5. Develop a FM BIM to demonstrate the proof of concept
RA 6. Reflect on the effort of developing the FM BIM
Post Pilot study
RA 7. Investigate the owner's perceptions of the organizational barriers to BIM adoption

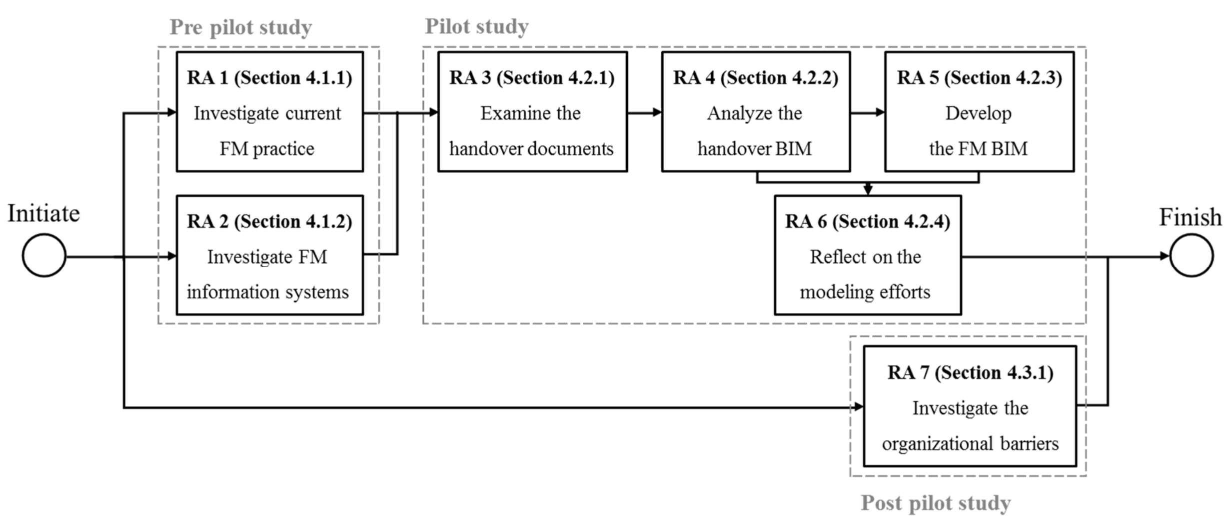


Figure 3.7 Research flow

Table 3.2 Data collection method used for each research activity

Data Collection Methods	Research Activities / Subjects	RA 1	RA 2	RA 3	RA 4	RA 5	RA 6	RA 7
Interview	Maintenance service worker (Facility A)	√						√
Interview	FM Information system managers		√					
Document analysis	FM Information systems data templates		√					
Document analysis	Handover documents (RAM)			√				
Document analysis	Handover model (RAM)				√			
Pilot study	FM BIM model development (RAM)					√	√	
Interview	Facility manager (RAM)							√

- **RA 1: Investigate the current FM practice to identify limitations**

The initial stage of any change involves understanding the current situation (Davenport, 2003). To leverage BIM in FM, the limitations of current FM practice in a facility were investigated through an in-depth interview. An in-depth interview is a qualitative research technique to explore the perspectives of a small number of respondents on a particular idea, program, or situation (Boyce & Neale, 2006). It is useful when we need detailed information about a person's opinions and behavior or want to explore new issues in depth.

As the RAM building was not being operated yet, the interview was conducted with a maintenance service worker of the FM team on another building, which will be referred to as "Facility A" in this paper. Facility A is located in Edmonton, Alberta, being owned and operated by AI. The building was re-commissioned in November 2014, and the occupancy commenced in February 2016. The interview was carried out on August 9, 2016. As we had no information on the current FM practice, we conducted the in-depth interview for two hours with open-ended questions. The FM team's daily operation process and its limitations were investigated.The interviewee was in charge of maintenance issues related to the HVAC system and general issues except for plumbing and electrical.

Originally, we had planned to conduct shadowing of the worker to investigate the daily operation process. However, most of the maintenance requests he received at that time had to be done within the office areas, and we were not allowed to access the areas due to security issues. Therefore, we decided to conduct an interview. Instead of showing the real maintenance work, the worker showed his typical workflow at the accessible parts of the building. In addition, we could have access to their O&M related documents including the O&M manuals, work log sheets, and work schedule boards (Figure 3.8).

Figure 3.8 O&M documents of Facility A

■ **RA 2: Investigate the FM information systems to identify limitations**

Ideally, the FM BIM needs to be integrated or compatible with the FM information systems (Becerik-Gerber et al., 2011). To adopt BIM as a data source for the existing FM systems in AI, we investigated the information systems deployed at AI to identify their limitations.

A total 52 information systems were being used at AI, whose purposes ranging from financial management, human resources management, capital planning, to facility management. In this research, we looked into one asset inventory management system and three facility management systems; these four systems were being deployed for FM purposes (Figure 3.9). Document analysis was conducted on the data templates of the systems, and three separate interviews were conducted with the system managers regarding the data requirements and data flow. Document analysis is a form of qualitative research in which documents are interpreted by the researcher to give voice and meaning around an assessment topic (Bowen, 2009). It is an efficient and effective way of gathering data because documents are manageable and practical resources.

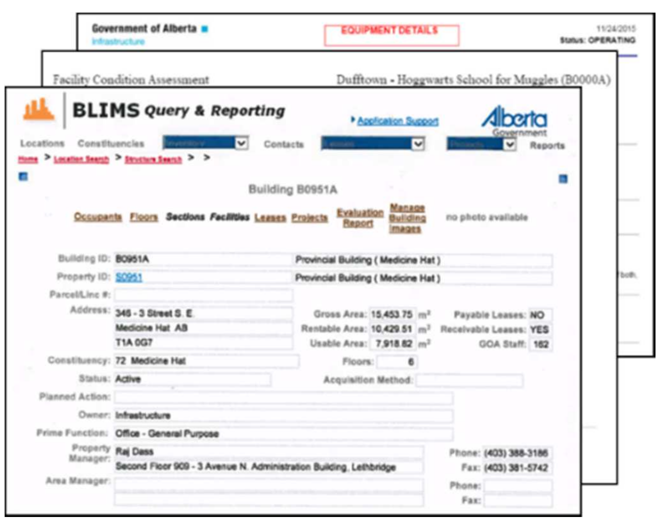


Figure 3.9 FM information systems deployed in AI (Courtesy of Alberta Infrastructure)

- **RA 3: Examine the handover documentation to set out the model development**

Project handover documentation, handover report, or handover information is the document delivered from the contractors to the facility owner when the facility is handed over. There was no clear academic definition of this term at the time this research was conducted. The handover documents usually include as-built drawings, commissioning documents, warranty documents, and O&M manuals. Therefore, the handover documents could be the largest source of facility data to develop a FM BIM in an existing building.

As the handover documents of RAM had been delivered to the owner at the time this study was commenced, we decided to use the documents as the source of facility data for the FM BIM (Figure 3.10). We assumed that the data is reliable as the documents were recently reviewed by the design-build team before they were handed over. Prior to developing the FM BIM model, we examined the overall handover documents to understand the quantity and quality of the documents and plan out the modeling process.

Figure 3.10 The handover documents of RAM

■ **RA 4: Analyze the handover model to identify gaps in modeling**

The BIM files of the project were handed over to the research team in August 2016. There were separate files for architectural, electrical, mechanical, and structural models. For successful utilization of BIM for facility management phase, the difference between the BIM and as-built condition should be reduced (Won & Lee, 2016). Thus, before developing the FM BIM, we assessed the information quality of the handover model to identify gaps in modeling.

We analyzed the subjects of the pilot study (60 pieces of equipment) in the model regarding the geometric data and non-geometric data. The geometric information was compared with the photographs of the as-built condition, and the non-geometric information was compared with the data in handover documents (Figure 3.11). This is done as a preliminary activity of the actual model development.

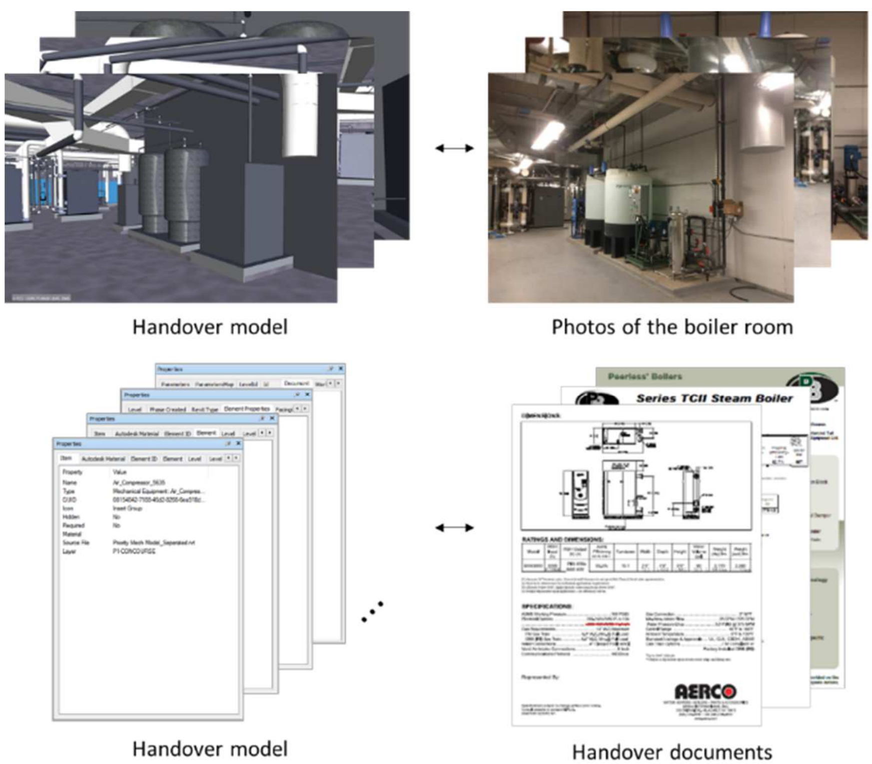


Figure 3.11 Analyzing the handover model

For this activity, document analysis was used to collect the data. Three different forms of documents were analyzed: digital model, photographs, and electronic documents. In document analysis, the ‘documents’ can take a variety of forms including papers, books, maps, photographs, and even television programs (Bowen, 2009). The main point is that the documents should be pre-produces ones, which are not generated by the researchers (O’Leary, 2004).

- **RA 5: Develop a FM BIM to demonstrate the proof of concept**

After understanding the gaps in modeling, we developed the FM BIM to demonstrate the proof of concept. The geometric information was developed by an individual modeling contractor, who was previously involved in the RAM project as the BIM specialist for the mechanical subcontractor. In parallel, the non-geometric information was developed by the research team. The non-geometric modeling was conducted in three sub-steps: extracting information, populating model and attaching O&M files. The process and result of the modeling are documented in detail, and the methods to access the developed model are suggested. Pilot study method was used to collect the data.

The following list of software was used for the model development: Microsoft Excel, Google Drive, Autodesk Revit, Autodesk Navisworks, BIMlink, iConstruct, and Autodesk 360. The software logos are used in the body of this section to help readers understand the modeling process (Figure 3.12). More information about the software can be found in 0

Figure 3.12 List of software used for the model development

(Courtesy of Microsoft, Autodesk, Google, iConstruct, and BIMlink)

■ RA 6: Reflect on the efforts of developing a FM BIM

From analyzing the handover model to attaching the O&M files into the model, a considerable amount of time and effort was spent developing the FM BIM. To inform the efforts required to develop the FM BIM, the factors that required time and effort during the model development were identified (Figure 3.13). Last, the timeline of the process is illustrated to gain an understanding of time needed per a piece of equipment and unit area (Figure 3.14).

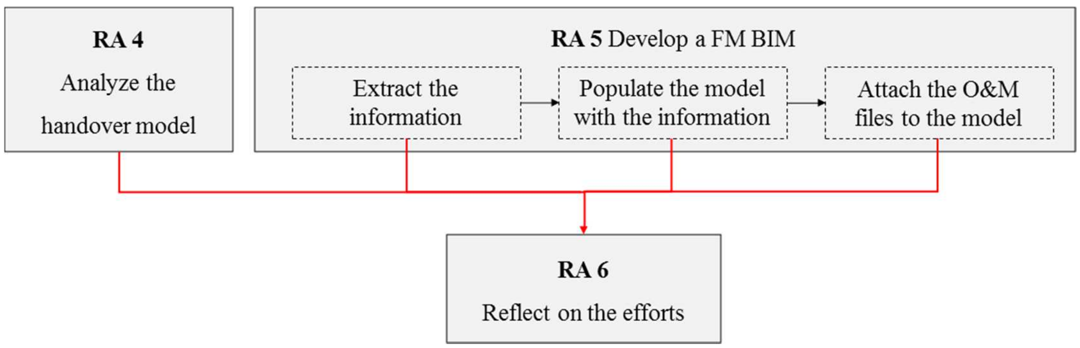


Figure 3.13 Reflecting on the efforts to develop the FM BIM

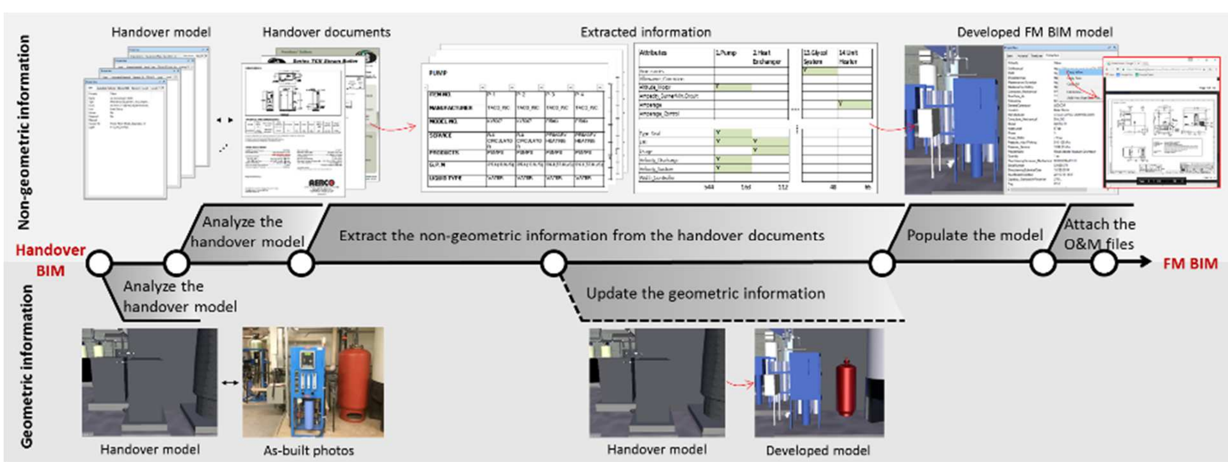


Figure 3.14 Timeline of the FM BIM development process

- **RA 7: Investigate the owner's perceptions of the organizational barriers to BIM adoption**

Even when the FM BIM is ready, there are potential organizational barriers to utilizing BIM for FM. To identify the barriers in AI, we interviewed two facility operators to hear the owner's perceptions of the barriers to adopting BIM. One of the interviews was conducted as part of the in-depth interview, which was done with the maintenance worker in Facility A. Another interview was done informally with the facility manager of RAM throughout several casual meetings. Informal conversational interviews are the least structured interview method. The wording of the questions and topics to be discussed were not predetermined (Moeller et al., 1980). These types of interviews often occur spontaneously. The research team also had several short conversations with the facility manager to discuss BIM utilization.

Chapter 4: Analysis Results

4.1 Pre pilot study

In this section, the findings from the investigation of the owner's current FM practice and FM information systems are discussed. We illustrate how these findings demonstrate the need and opportunity to introduce BIM for FM.

4.1.1 Investigate the current FM practice (RA 1)

Several limitations of current FM practice in Facility A were revealed through the interview conducted with a maintenance service worker. First, although the building was occupied for more than a year, the maintenance team had no as-built documents available. They only had construction drawings, which contained a significant amount of out-of-date information. The image of the drawing is not provided here due to security issues, but the drawings had out-of-date information with handwritten markings made by the FM team indicating the inaccurate information. As the documents had too many inconsistencies, whenever the workers get a maintenance request, they choose to locate the particular elements in the building manually, instead of looking into the drawings first. For example, once, two of the maintenance workers had to spend 40 minutes looking for a shut-off valve, as the drawings did not indicate the location of the valve. The interviewee said that much time is spent physically looking for elements due to the lack of quality as-built information.

Second, the team was not using the O&M manuals due to the poor quality of the documents. When the building was handed over to the owner, more than 70 binders of paper-based O&M manuals were delivered to the FM team. However, the manuals were not organized in a way that the FM team needed for their operation tasks, so the manuals ended up being stacked in storage (Figure 4.1). Each binder contains more than 500 pages, but each one had no useful label, index, or contents page to locate information. Therefore, whenever the workers need to find information about equipment, they must go through the documents page-by-page, which requires a significant amount of their time. Thus, instead of spending hours on the documents, they search online for the information they need. They were keeping their own O&M manual files printed out from online (Figure 4.1). The worker said, *"If we use these O&M manuals, we will end up wasting too much time locating the information we need. We do not have time for that. We find it much better to search online for the manuals when we need."*

Last, there was no online database or any information system where the workers could manage their work schedules or maintenance results. The schedules were being documented on the white board in the office for their records (Figure 4.1). In addition, whenever they make any change on equipment or complete a routine inspection, the results are recorded on paper-based work log sheets, where the workers should fill out manually (Figure 4.1). As the worksheets are only being kept for their record, no further update is made in the construction drawings or O&M manuals according to this data. Therefore, if equipment breaks down in the near future, it would be difficult to find out if the equipment was broken in the past, why it was broken, or how it was fixed. The worker said, *"If I leave this building, and new guys come, then there's no way they could find out what was happened in this building before they came."*

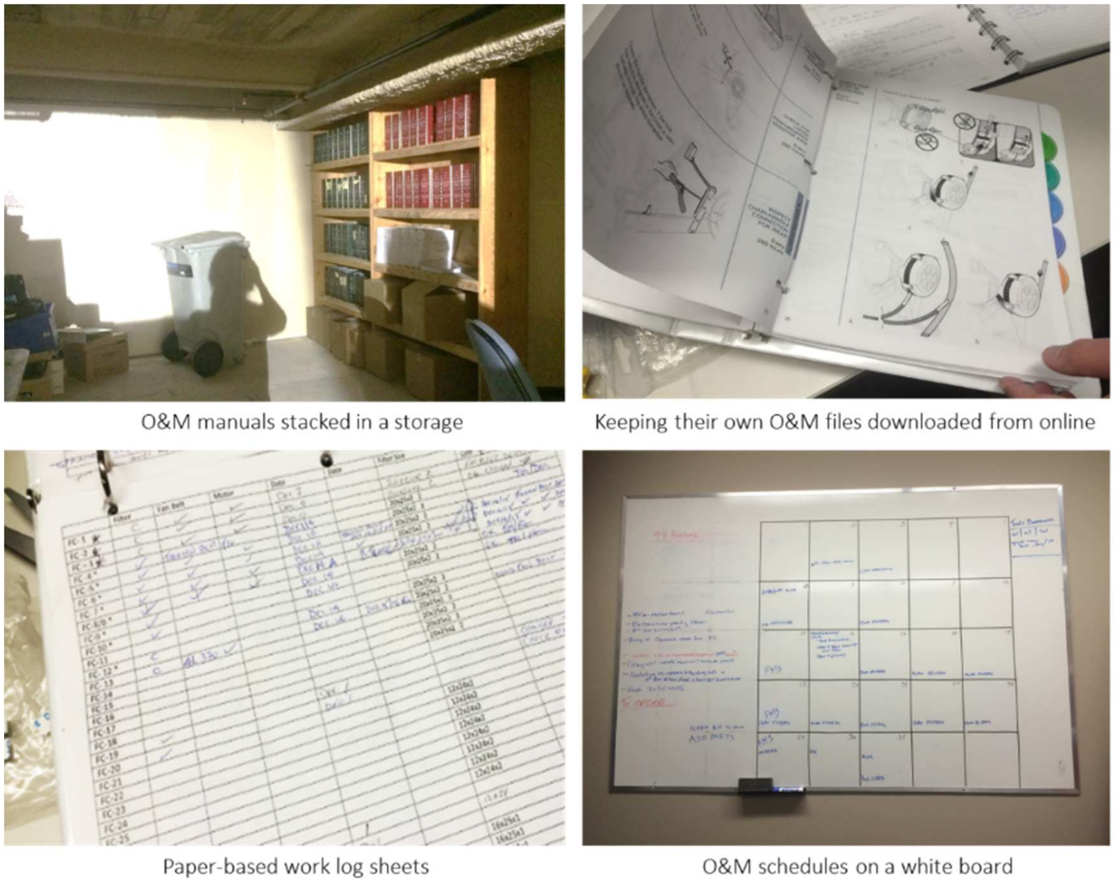


Figure 4.1 Poor quality of O&M documents

4.1.2 Investigate the FM information systems (RA 2)

Next, we investigated four FM information systems deployed at AI to identify their limitations. Document analysis was conducted on the data templates of the systems, and three interviews were conducted with the system managers (Figure 4.2). We looked into one asset inventory management system, which will be referred to as “System A,” and three facility management systems, which will be referred to as “System B,” System C,” and “System D.”

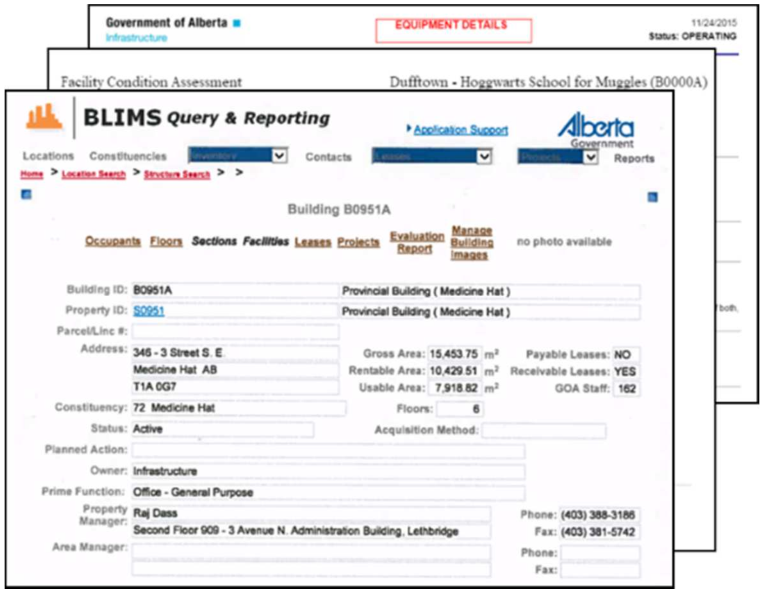


Figure 4.2 Data templates of existing FM information systems (Courtesy of Alberta Infrastructure)

Although the four systems were all intended for FM, each system contained a different type of facility information for different uses. System A is a central database where the basic facility data, such as “Property ID,” “Building ID,” “Building name,” and “Address” are originally generated. System B is in which the basic equipment properties and maintenance tasks information are contained. It contains data such as “Equipment ID,” “Serial Number,” “Maintenance task number,” and “Service cost.” It is the main system used by the facility managers residing in facilities. System C is used for the facility condition assessment, collecting the information required to optimize long-term facilities investments. It includes data such as “Maintenance needs for next 5 years,” Current 5 years facility condition index,” Prime audit firm,” and “Inspection date.” System D carries information regarding the maintenance work order, which includes “Work title,” “Priority of work,” “Approved date,” and “Labour cost.”

Figure 4.3 shows the concept of the data flow between these four systems. System A was intended to serve as a central database where the other sub-databases can retrieve facility data. However, we learned that only a little information such as “Building ID,” “Address,” and “Gross

Area" could be exported from System A to other databases. The majority of the data required by the other systems had to be entered manually into the databases by the authorized users. Moreover, the other three databases cannot share the data with each other, even though they have common attributes required. Therefore, if any change occurs in a facility and the data in the systems has to be updated, each system is filled out manually and separately by different users. This often causes information loss and inconsistency of information throughout the systems, which might eventually lead to an inadequate FM.

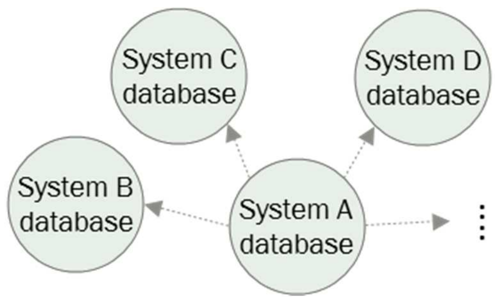


Figure 4.3 Data flow among the information systems

Moreover, we identified inconsistencies in terminologies used by the different systems. The databases investigated here required a different number of attributes which ranged from 20 to 53. Among them, there were several common attributes that were required by two or more systems. These include the building name, building location, equipment name, and gross area (Table 4.1). However, different terms were used by different systems for most of these common attributes. For example, for the building name (second attribute in Table 4.1), System A and B used the term "Building name," whereas System C used "Asset Name" and System D used "Facility Name." Also, for the address of the building (third attribute in Table 4.1), System A used "Address," System B used "Location," and System C had both "Address" and "Location." These inconsistencies occurred due to the fact that the systems were designed by different suppliers and data was entered manually by different users. This can not only cause interoperability issues between the systems but also confuse the users who might retrieve information from several systems.

Table 4.1 Data requirements of the information systems

	SYSTEM A	SYSTEM B	SYSTEM C	SYSTEM D
1	Building ID	Site/BID	Asset Number	Facility ID
2	Building Name	Building Name	Asset Name	Facility Name
3	Address	Location	Address/Location	Client Area
4	Gross Area	-	Gross Area	-
5	Floors	-	Floors	-
6	-	-	Year Constructed	-
7	-	-	Replacement Cost	-
8	-	-	Prime Audit Firm	-
9	-	-	Audit Date	-
10	-	-	Auditor Name	-
11	-	-	Audit FCR	-
12	Building Status	-	-	-
⋮				
TOTAL	20	53	33	25

4.1.3 Discussion

To understand the owner's needs for FM BIM, the limitations of current FM practice and FM information systems were investigated. We identified that the facility information is being managed inefficiently in current FM practices. The FM team has difficulty in conducting daily operations tasks due to the poor quality of handover information, and they lacked databases where they could keep their work records and schedules. We also identified that the facility information is being managed poorly in the information systems due to the lack of single repository and the lack of interoperability between the systems. These issues could cause considerable information loss, poor information quality, and inadequate facility management, which would lead to considerable losses in time and money (Keady, 2009; Parsanezhad & Dimyadi, 2014). Thus, to prevent this loss and support the owner in operating the facilities successfully, there is a need for more efficient facility information management. BIM can be a solution to this as a single repository of data, which would not only improve the data entry process but also provide a high quality of information to the FM team (Atkin & Brooks, 2009; Sabol, 2008).

While interviewing the FM worker in Facility A, there was a possibility that the researcher had influenced the interviewee's response, which is called "Response bias." It is a cognitive bias that influences the responses of participants away from an accurate or truthful response, which is most prevalent in interviews or surveys (Furnham, 1986). Response biases can have a large impact on the validity of questionnaires or surveys. To overcome this, the FM documents were also examined during the interview to confirm the fact of the interview results. According to Denzin, the use of two or more data collection methods can enhance the validation of the research outcomes by avoiding the personal bias of the investigator and overcoming the deficiencies inherent to a single-investigator. This is called *methods triangulation* (Denzin, 1978). This theory could also be applied to the second research activity, where we investigated the information systems through interviews and document analysis. This enhances the validity of the result. In the same way, the results of two research activities can again strengthen the validation of the high-level outcome: the need for adopting BIM for FM.

When we investigated the existing FM information systems, we intended to reflect the data requirements of the systems to develop the FM BIM. However, at the same time, the owner was also planning a huge transformation of its entire information systems including those described above. Three of the four systems we looked into were to be eliminated in the near future. Therefore, we decided to exclude consideration of the information systems when we developed the FM BIM. For future projects, however, the same investigation should be conducted on the new information systems after the system transformation is done. The data required by each system should be considered when the FM BIM is developed, and the model should be interoperable with the new systems. Also, we suggest consolidating the terms used by different systems to avoid interoperability issues among the systems.

4.2 Pilot study

Realizing the limitations of current FM processes and the need for leveraging BIM in FM, we initiated the pilot study on RAM to investigate what is involved in developing the FM BIM from the handover project model. First, the handover documentation was examined to set out the model development. Then, we identified the modeling gaps in the handover model. Following these assessments, the handover model was developed into a FM BIM. We documented the time and effort required for each step of the modeling in detail.

4.2.1 Examine the handover documentation (RA 3)

First, we assessed the handover documentation to set out the model development. The handover documents of RAM were delivered to the owner from the design-build team in pdf files (Figure 4.4). The overall structure of the documents is shown in Table 4.2. The documents consisted of O&M manuals and drawings of architectural, structural, mechanical, and electrical disciplines. There was a total of 1,442 files with 46,741 pages (12.1 GB). If we print out these documents, we would end up having 70 binders with 670 pages of papers in each binder.

Figure 4.4 Part of the handover documentation files

Table 4.2 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 As-built	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 As-builts	Electrical	266	266	161	Electrical drawings, electrical panel schedules	Exported files (pdf)
	Total	**1442**	**46741**	**12099**		

The mechanical O&M manuals, which we used as the data source for the FM BIM, consisted of 302 files with 11,508 pages (954 MB). We noticed that some of the files contained documents of poor quality. Several documents were difficult to read because of the low resolution as shown in Figure 4.5, and some of them contained handwritten documents (Figure 4.6). Furthermore, there was a large amount of descriptive information that could not be automatically exported (Figure 4.7). In addition, since part of the pdf files were scanned from the paper-based documents, the data were recognized as images, not as texts This made it difficult to locate data by searching the particular text in the file. Due to these reasons, we decided to extract the data manually for the FM BIM by going through the documents from page-to-page.

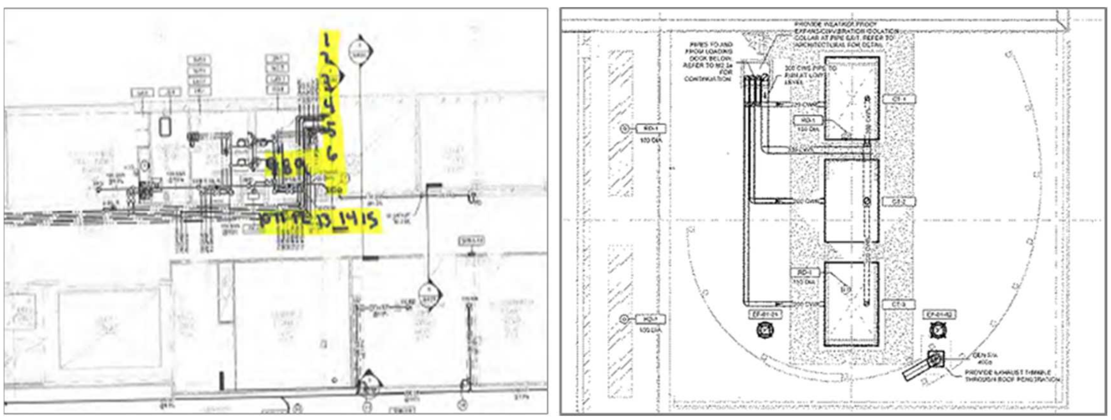
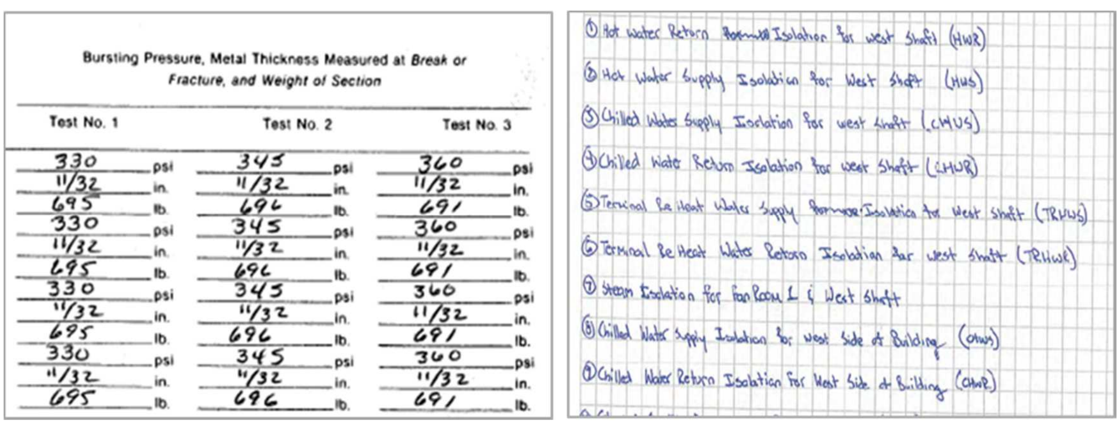


Figure 4.5 Illegible documents with low resolution (Courtesy of Alberta Infrastructure)



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 [illegible] 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 [illegible] 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 (CHWS)
⑨ Chilled Water Return Isolation For West Side of Building (CHWR)

Figure 4.6 Handwritten documents (Courtesy of Alberta Infrastructure)

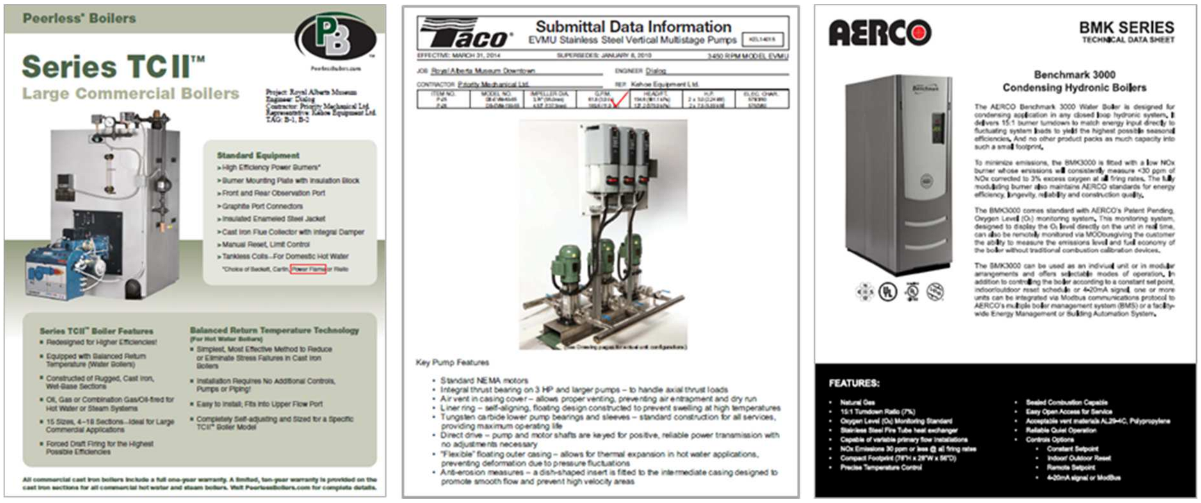


Figure 4.7 Descriptive data in the handover documents (Courtesy of Alberta Infrastructure)

The poor quality of this handover documentation highlights the potential challenges of FM in RAM, as these documents had similar quality to the handover documents in Facility A. They both have extensive amount of data but there were no proper contents pages, and it is impossible to update the data in the documents as they are not editable. Thus, the FM team at RAM may have difficulties in managing the quality of these documents. This also further demonstrates the need and opportunity for using BIM for RAM project.

4.2.2 Analyze the handover model (RA 4)

The BIM files of the project were handed over to the research team in August 2016. Prior to developing the FM BIM, we analyzed the handover model to identify gaps in modeling. The gaps in geometric modeling were identified by comparing the handover model with the photos of the boiler room, and the model was again compared with the handover documents to identify the gaps in non-geometric data (Figure 4.8).

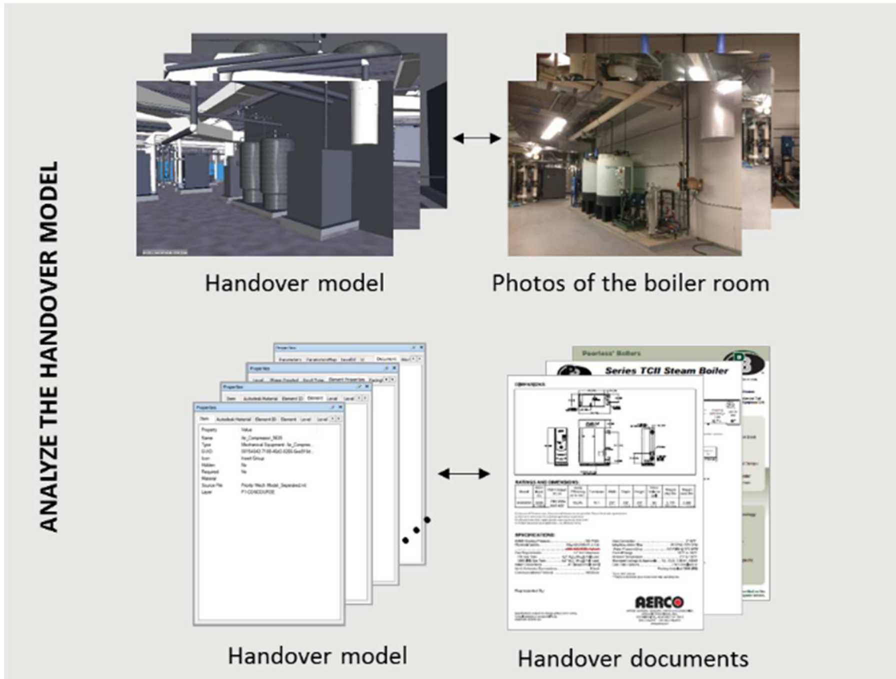


Figure 4.8 Analyzing the handover model

■ Geometric information

Some of the components in the model had a different appearance and location from the as-built, and a few of them were missing. The following examples show the gaps in the geometric modeling.

- Inaccurate shape and size (Figure 4.9): The form and size of the equipment in the model do not represent the reality, so it is hard to figure out what type of equipment it is until we look into the properties. Among the 60 assets in the pilot study, four of them had different appearances from the as-built condition.

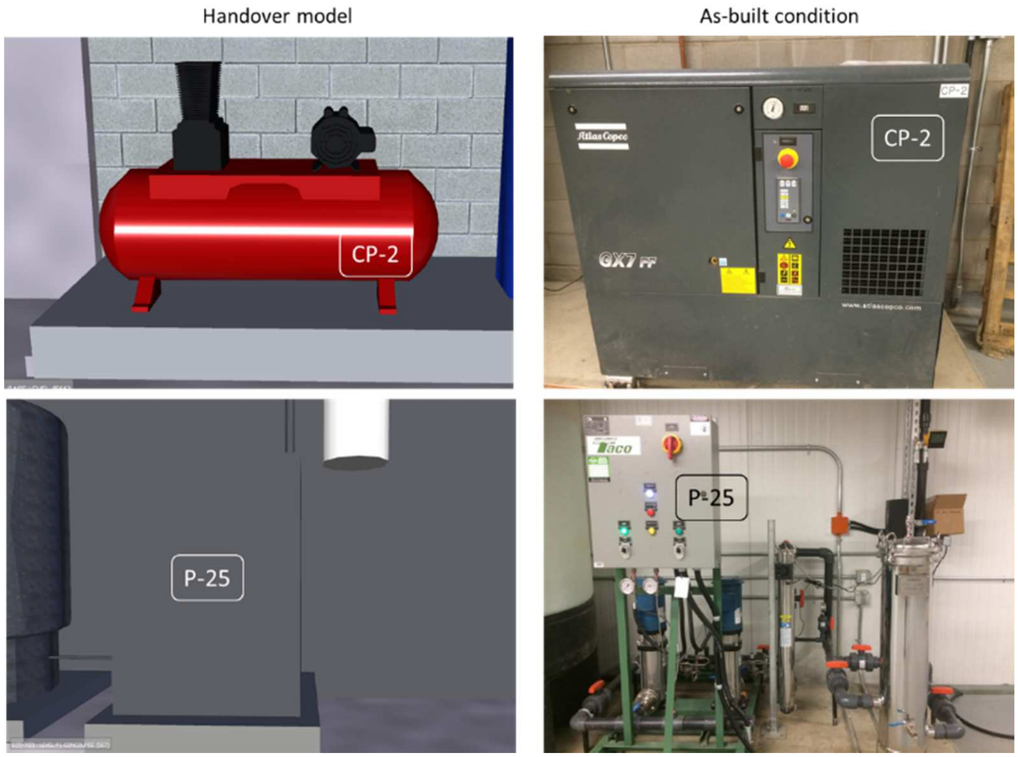


Figure 4.9 Inaccurate shape and size of the components (Courtesy of Ledcor Design-Build Inc.)

- Missing components (Figure 4.10): Some of the elements are missing in the model. This is mostly due to the change of design made after the model was created. Among the 60 pieces of equipment, three were missing in the model.

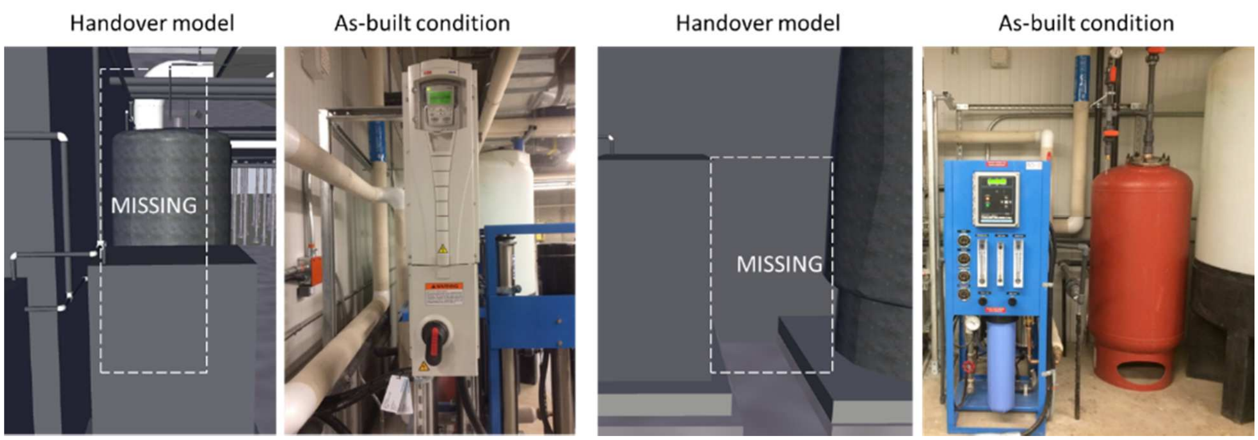


Figure 4.10 Missing components (Courtesy of Ledcor Design-Build Inc.)

- Inaccurate location (Figure 4.11): The locations of some of the equipment differ from the as-built condition. Eight pieces of the equipment were not in the actual locations.

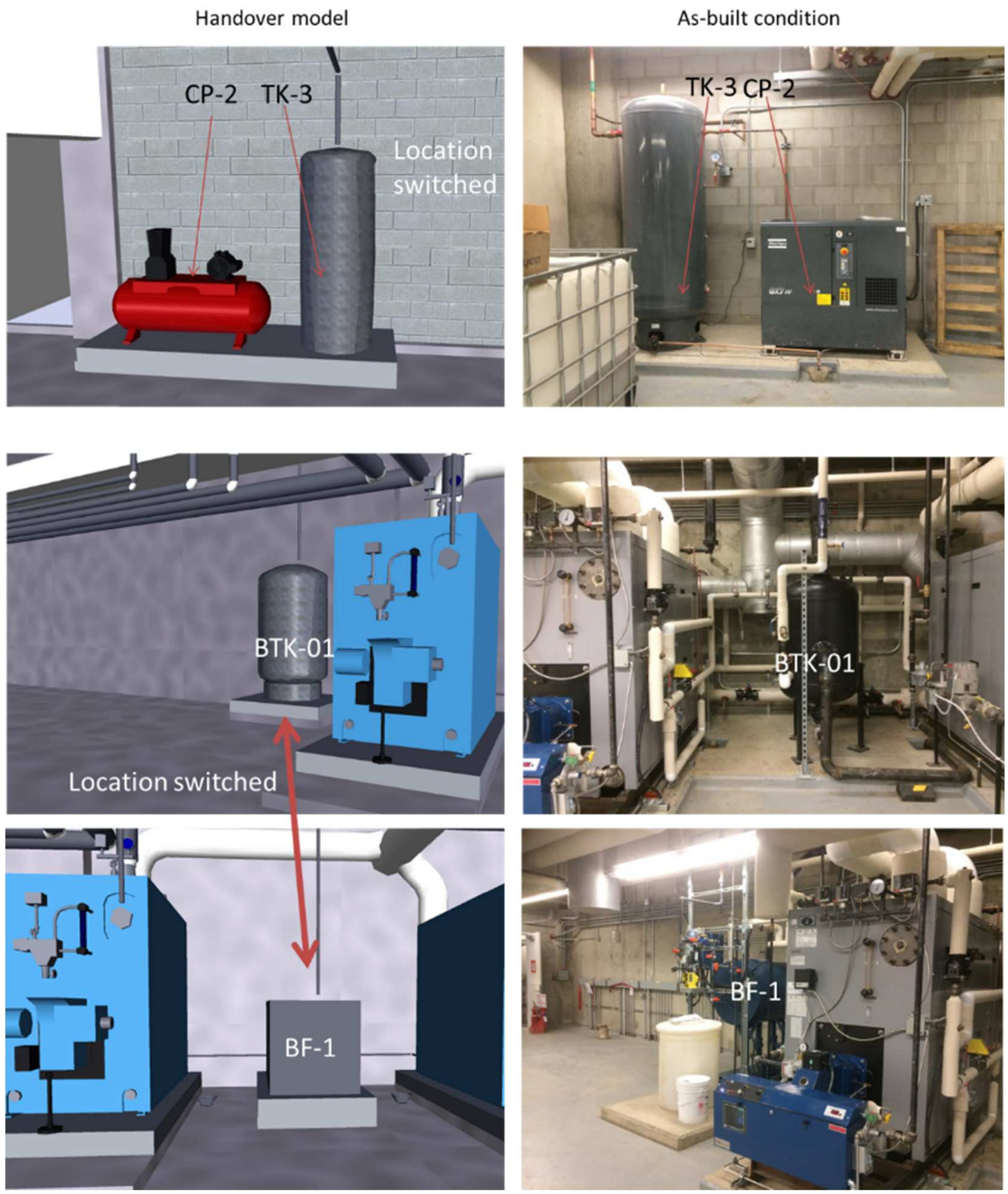


Figure 4.11 Inaccurate location of the components (Courtesy of Ledcor Design-Build Inc.)

- Inaccurate connection of piping and ducts (Figure 4.12): The location, connection, and length of piping or ducts was incorrect.

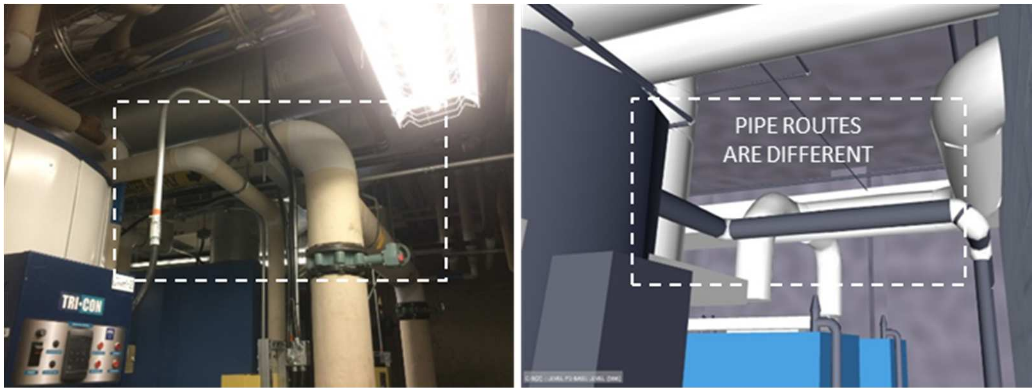


Figure 4.12 Inaccurate connections of piping and ducts (Courtesy of Ledcor Design-Build Inc.)

Although it had some inconsistencies, the geometric data was mostly similar to the as-built condition as the model was developed to be used for construction purposes. Most of the inconsistencies were due to changes made during construction, according to the mechanical subcontractor. Figure 4.13 shows the high level of accuracy of the geometric data in the handover model. Thus, we decided to keep the geometric data as it is and modify the parts that had inconsistencies.

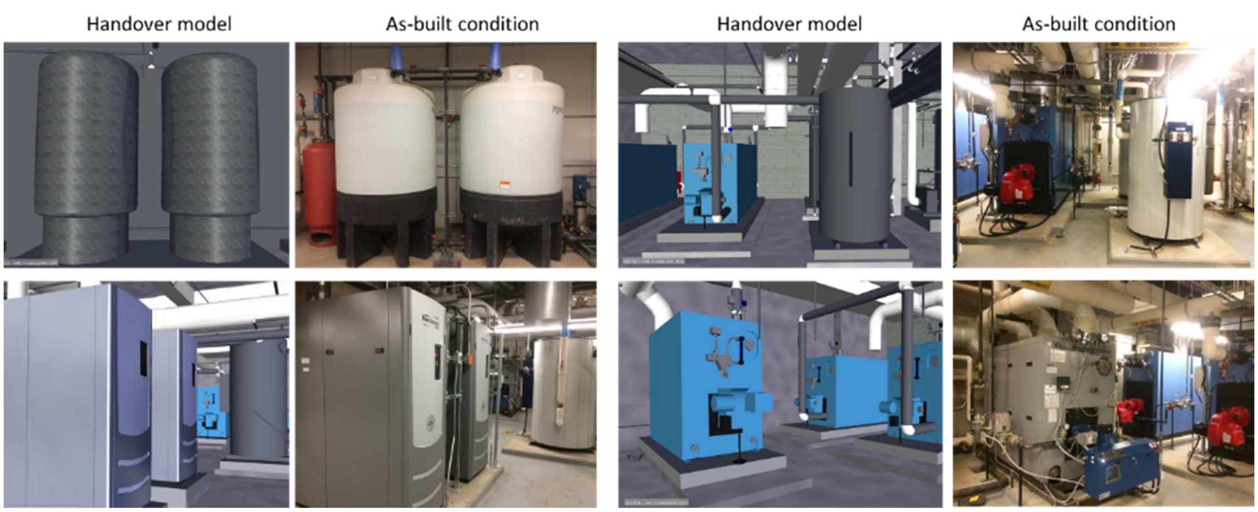
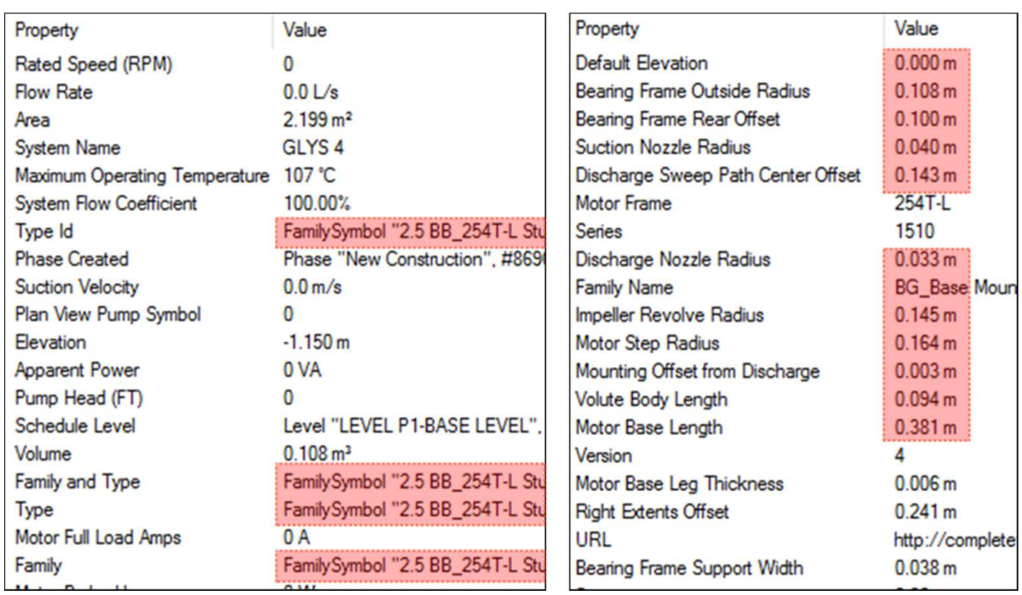


Figure 4.13 Accuracy of the geometric information (Courtesy of Ledcor Design-Build Inc.)

■ Non-geometric information

We revealed that the amount of information included in the model was massive, but the semantic data was quite inaccurate. The gaps in non-geometric information include following:

- Duplicate attributes (Figure 4.14): There were many duplicate attributes created in the model. This can not only increase the size of the file but also confuse the potential users. For example, there were 47 attributes associated with the Domestic water heaters and 8 of them were redundant ones that could be eliminated.
- Unnecessary attributes (Figure 4.14): There were unnecessary attributes, such as detailed dimensions, which are not necessary for the operations task. Moreover, the facility manager of RAM said that they would not look up BIM for the detailed dimensions. If they need the dimensions, particularly for the replacement, they would measure the equipment directly, to avoid mistakes in ordering new parts. For example, 12 of 29 attributes of the Tank were related to the dimensions.



Property	Value
Rated Speed (RPM)	0
Flow Rate	0.0 L/s
Area	2.199 m²
System Name	GLYS 4
Maximum Operating Temperature	107 °C
System Flow Coefficient	100.00%
Type Id	FamilySymbol "2.5 BB_254T-L Stu
Phase Created	Phase "New Construction", #869
Suction Velocity	0.0 m/s
Plan View Pump Symbol	0
Elevation	-1.150 m
Apparent Power	0 VA
Pump Head (FT)	0
Schedule Level	Level "LEVEL P1-BASE LEVEL",
Volume	0.108 m³
Family and Type	FamilySymbol "2.5 BB_254T-L Stu
Type	FamilySymbol "2.5 BB_254T-L Stu
Motor Full Load Amps	0 A
Family	FamilySymbol "2.5 BB_254T-L Stu

Property	Value
Default Elevation	0.000 m
Bearing Frame Outside Radius	0.108 m
Bearing Frame Rear Offset	0.100 m
Suction Nozzle Radius	0.040 m
Discharge Sweep Path Center Offset	0.143 m
Motor Frame	254T-L
Series	1510
Discharge Nozzle Radius	0.033 m
Family Name	BG_Base Moun
Impeller Revolve Radius	0.145 m
Motor Step Radius	0.164 m
Mounting Offset from Discharge	0.003 m
Volute Body Length	0.094 m
Motor Base Length	0.381 m
Version	4
Motor Base Leg Thickness	0.006 m
Right Extents Offset	0.241 m
URL	http://complete
Bearing Frame Support Width	0.038 m

Figure 4.14 Duplicate attributes (Left) and unnecessary information (Right) contained in the handover model (Courtesy of Ledcor Design-Build Inc.)

- Inaccurate values (Figure 4.15): Most of the values in the model are different from those in the handover documents, which means the values in the model are inaccurate. For example, there were 13 pumps installed in the boiler room. From the handover model, we could identify 572 values associated with these pumps, but only 56 of them were consistent with the handover documents. The accurate attributes included "tag number," "fluid type," "frequency," and "suction size." However, we need to note that the default values of the "fluid type" and "frequency" in Revit were same with the actual values, which is "water" and "60 HZ". Therefore, these values might not have been entered by the modeler, but just automatically created. The inaccurate attributes included "manufacturer," "pump model," "pump type," "flow rate," and "motor power."

HANDOVER MODEL

Mark	P-1	P-2	P-3
Manufacturer	Bell & Gossett	Bell & Gossett	Bell & Gossett
Model	5x5x7	5x5x7	5 E
Description	In-Line Mounted Pump	In-Line Mounted Pump	Base Mounted End Suction
Flow Rate	0.0 L/s	0.0 L/s	0.0 L/s
Fluid Type	Water	Water	Water
Pump Head (FT)	0	0	0
Power_Motor			0 W
Rated Speed (RPM)	0	0	0
Motor Frame	184	184	254T-L
Count	1	1	1

HANDOVER DOCUMENTS

ITEM NO.	P-1	P-2	P-3
MANUFACTURER	TACO_INC.	TACO_INC.	TACO_INC.
MODEL NO.	KV5007	KV5007	FI5013
PRODUCTS	PUMPS	PUMPS	PUMPS
G.P.M	315.4 (19.9L/S)	315.4 (19.9L/S)	916.1 (57.8 L/S)
LIQUID TYPE	WATER	WATER	WATER
HEAD/FT.	12.4 (37KPA)	12.4 (37KPA)	115.4 (344.6KPA)
H.P	1.5 (1.12KW)	1.5 (1.12KW)	40 (30KW)
RPM_Motor	1160	1160	1760
MOTOR FRAME	182JM	182JM	324T
QUANTITY	1	1	1

Figure 4.15 Inaccurate values in the handover model

- Missing attributes (Figure 4.16): There were many missing attributes in the model compared with the handover documents. For example, we could extract 63 attributes of the Heat exchanger from the handover documents, but only 34 of them were identified in the model. Moreover, only three of the 34 attributes had correct values.

HANDOVER MODEL

TAG	HX-1	HX-3	HX-4
MANUFACTURER	TACO	TACO	TACO
-			
-			
-			
-			
-			
-			
-			

HANDOVER DOCUMENTS

TAG	HX-1	HX-3	HX-4
MANUFACTURER	TACO	TACO	TACO
HEAT DUTY (KW)	1049	2264.53	2264.53
HOT SIDE FLUID	WATER	WATER	WATER
HOT SIDE MASS FLOW RATE (KG/S)	33.41	23.07	23.07
HOT SIDE VOLUME FLOW RATE (L/S)	33.75	23.5	23.5
HOT SIDE PRESSURE LOSS (KPA)	34.584	28.677	28.677
HOT SIDE INLET TEMPERATURE (C)	44.8	71	71
HOT SIDE OUTLET TEMPERATURE (C)	37.28	48	48
COLD SIDE FLUID	WATER	PROPLYENE GLYCOL/WATER 40/60	PROPLYENE GLYCOL/WATER 40/60

Figure 4.16 Missing attributes in the handover model

- Missing values (Figure 4.17): Even when there are attributes in the model, the values associated with the attributes are sometimes missing. For example, 32 attributes were found in Expansion tank component, but 5 of them did not have values associated. Moreover, among 27 other attributes, only three had accurate values.

HANDOVER MODEL

Mark	ET-1	ET-2	ET-3
Manufacturer	TACO	TACO	TACO
Model	CA	CA	CA
Type	ET-3,4,5,8_CA500_79-132gal	ET-3,4,5,8_CA500_79-132gal	ET-3,4,5,8_CA500_79-132gal
Tank Volume			
Maximum Working Pressure			
Relief NPT			
Piping Radius	19	25	13

HANDOVER DOCUMENTS

TAG	ET-1	ET-2	ET-3
MANUFACTURER	TACO	TACO	TACO
MODEL NO.	CBX600-125	CBX600-125	CBX300-125
CONSTRUCTION	SEAMLESS BLADDER TYPE	SEAMLESS BLADDER TYPE	DIAPHRAGM TYPE
TANK VOLUME (L)	600	600	300
WORKING PRESSURE (KPA)	862	862	862
NPT (MM)	13	13	-
SYSTEM CONNECTION NPT (MM)	19	19	26

Figure 4.17 Missing values in the handover model

Considering these inconsistencies, we decided to clean all the non-geometric data except the tag numbers. The incorrect information in the model is not only unnecessary, but also interrupts embedding new information and increases the model size.

4.2.3 Developing the FM BIM (RA 5)

After realizing the gaps in modeling, we developed the model to a FM BIM to demonstrate the proof of concept. The geometric information and non-geometric information were developed in parallel.

- **Geometric information**

The process of developing the geometric information is not illustrated in detail in this report as it was out of our research scope. There were two reasons why we left out this part from our research. First, according to the analysis of the handover model, there were relatively little inconsistencies in the geometric information. The geometry was well developed as it was used for the construction phase. For FM purposes, the level of detail did not need to be developed further as the appearance and location were similar to the as-built condition. This was also verified by the facility manager of RAM. Second, there are many existing studies focused on developing the geometric data. There are many technologies developed to capture the geometric data, such as laser scanning and photogrammetry (Jung et al., 2014; Tzedaki & Kamara, 2013). On the other hand, there are relatively little studies on capturing non-geometric information. Therefore, we assigned the geometric modeling task to a modeling contractor.

The updates conducted for the geometric information include the location and appearance of the equipment, the routes of piping and ducts, and the connections between the equipment. They were developed according to the as-built conditions, as shown in Figure 4.18. While updating the geometric information, the non-geometric information was cleaned out to create a clean model with no unverified data embedded in it.

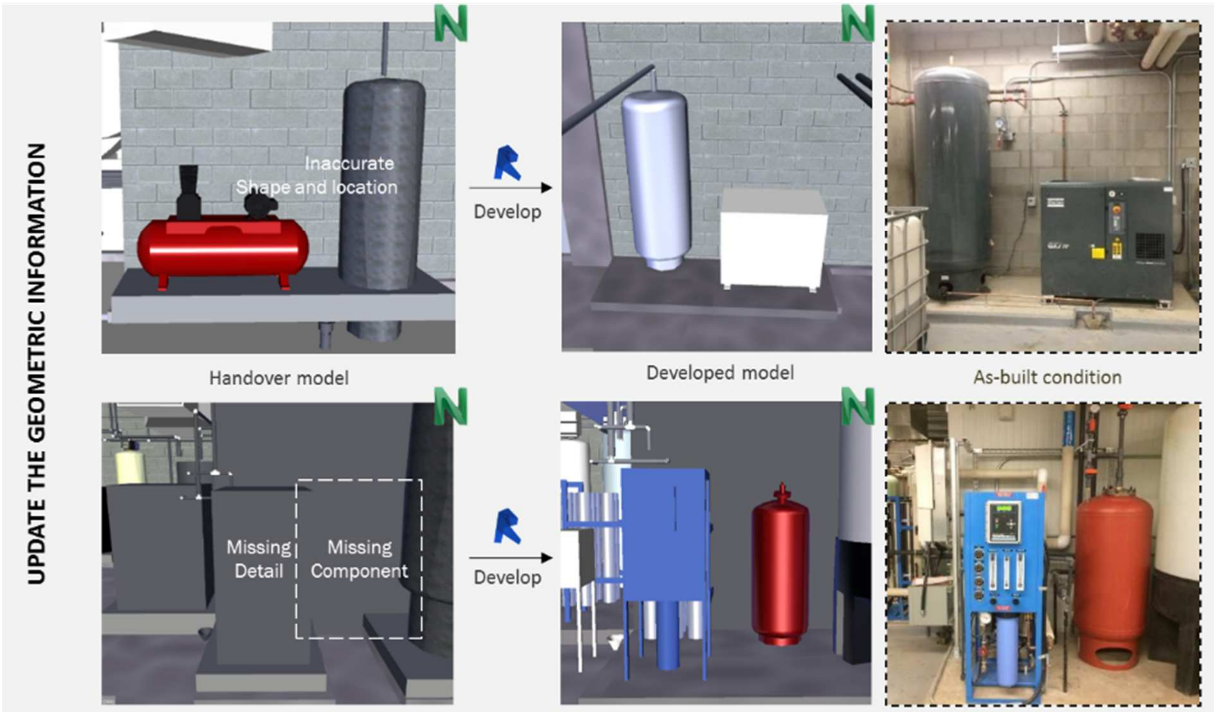


Figure 4.18 Developing the geometric information (Courtesy of Ledcor Design-Build Inc.)

■ **Non-geometric information**

The non-geometric information was developed in three steps: (1) Extract information from the handover documents, (2) populate the model with the information, and (3) attach the O&M manuals to the model. The entire process is illustrated in Figure 4.19.

Here, we should note that no BIM data standards were adopted for this process. As it is briefly reviewed in Chapter 2, there are existing data exchange standards, such as COBie, developed to help to build BIM for FM. COBie is increasingly being used by the industry to manage the data for facility management, and there is an agreement that it is useful for structuring data (OPEN BIM Network, 2012). However, many studies identified the limitations of COBie, including the lack of details on what information is to be provided, when and by whom (East & Carrasquillo-Mangual, 2012). It is also argued that facility managers need to

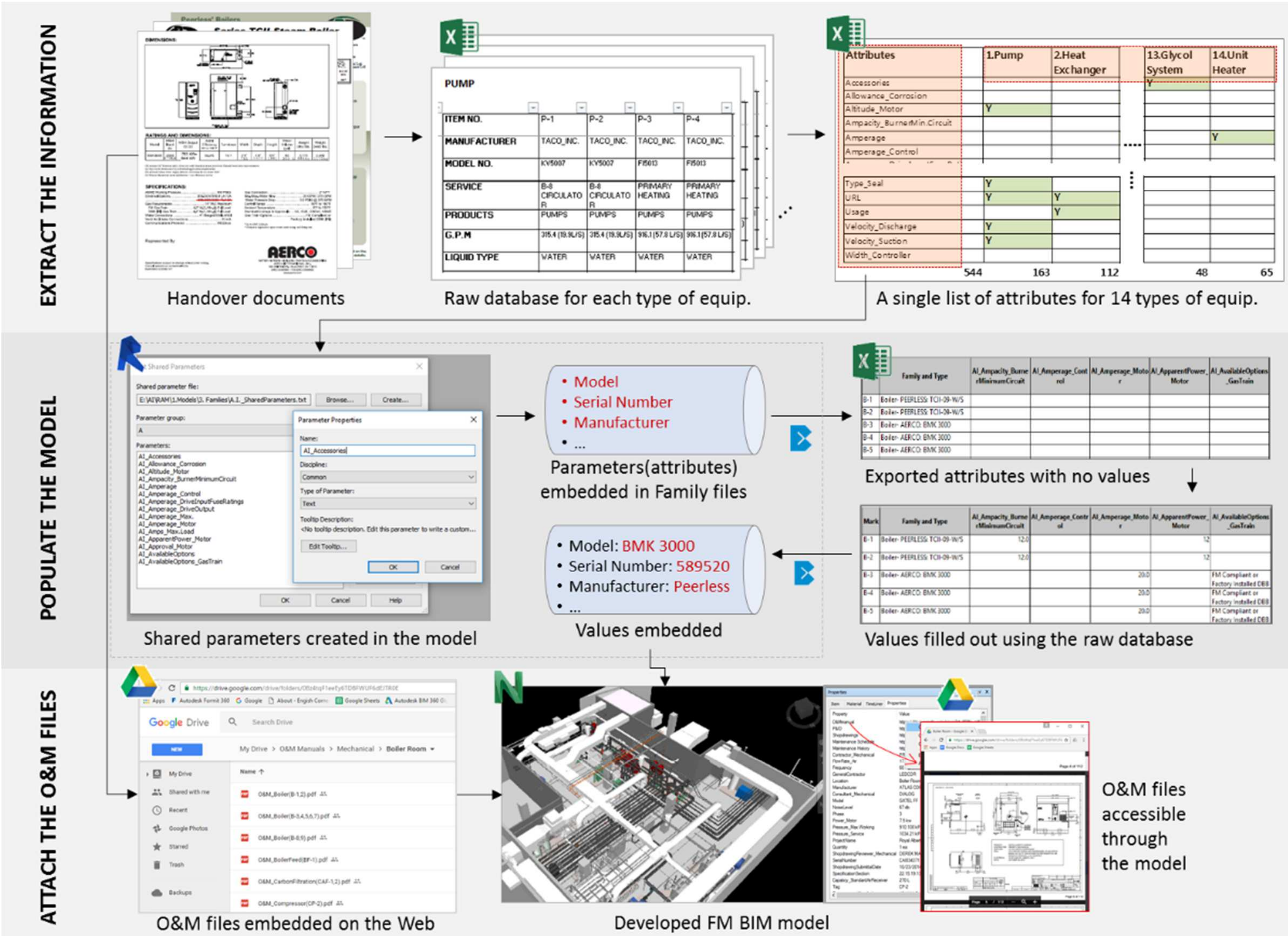


Figure 4.19 Developing the non-geometric information

detail and prioritize their information requirements (IFMA, 2013). One of the case studies reviewed in Chapter 2, also concluded that COBie is not enough on its own to provide all the information needed for facility management. Based on these limitations and the fact that we are developing the FM BIM after construction was completed, we determine that utilizing COBie offered little value for our research purposes. Also, as the data required by COBie was already contained in the handover documents, it was unreasonable to use its data requirement list.

- **Extract information from the handover documents:**

  First, the non-geometric information related to the 60 pieces of equipment was extracted from the handover documents. A raw database for each type of equipment was created, which contained both attributes and values of the equipment. This step was necessary to support the process of embedding the values in the model. Then, the attribute lists for 14 types of the equipment were merged into a single list. This was necessary to avoid duplicates when creating the Shared parameters in the model in the next step; the Shared parameter is a definition of a container for information that can be used in multiple families or projects (Autodesk, 2017b). As a result, a single list of 544 attributes was created.

- **Populate the model with the information:**

  Using the attributes list created in the previous step, 544 Shared parameters were set up in the model. This process is about creating the empty parameter (attribute) slots to be filled out with the values. From the 544 Shared parameters, we selected the ones related to each type of equipment and linked them to the family file; A family is a group of elements with a common set of properties, called parameters, and a related graphical representation (Autodesk, 2017a). Then, the family's attributes were exported to a spreadsheet with no values associated. Last, the spreadsheet was filled out with the values using the raw database created in the previous step and imported back to the model. As a result, the model was populated with the proper attributes and values.

- **Attach the O&M Manual files to the model:**

In the O&M manuals, there is descriptive information that cannot be entered in the model. Therefore, the manual itself also should be linked to the model so that users can access the document when they need. This function was also requested by the facility manager at RAM. First, the O&M files were embedded on the Web to make them accessible from anywhere without the files being saved on the users' devices. Then, the links of the files were attached to the related components in the model. As a result, all the related O&M files were embedded in the model through the links, which can be accessed through any device, even with mobile devices in the field. Beyond the O&M manuals, any other documents the user wants can be embedded in the model using the same method.

Through these processes, the handover model was developed for FM purposes with accurate geometric and non-geometric data. It also provides access to the original O&M manuals. This will reduce the time of the FM team in searching for information on equipment, which was traditionally done with the paper-based O&M manuals. In addition, the model can be used as a central database of the information systems deployed in AI, providing reliable and consistent information.

■ **Uses of the developed FM BIM model**

There are many ways to access the model and associated information. The method can be selected depending on the user's need and capability. Here we suggest using Navisworks, A360, and barcode/QR code. The methods are appropriate for facility managers or maintenance workers to view the information but not to modify the model. To update the information, the users need to use the central Revit file.

- Through Navisworks (Figure 4.20): This is appropriate when the Navisworks software is installed on the users' devices. However, the file has to be saved on their devices. The users also can export the model into various file formats (dwf, 3ds, asc, etc.) if necessary. In addition, the user can directly add comments on the model and share with others.

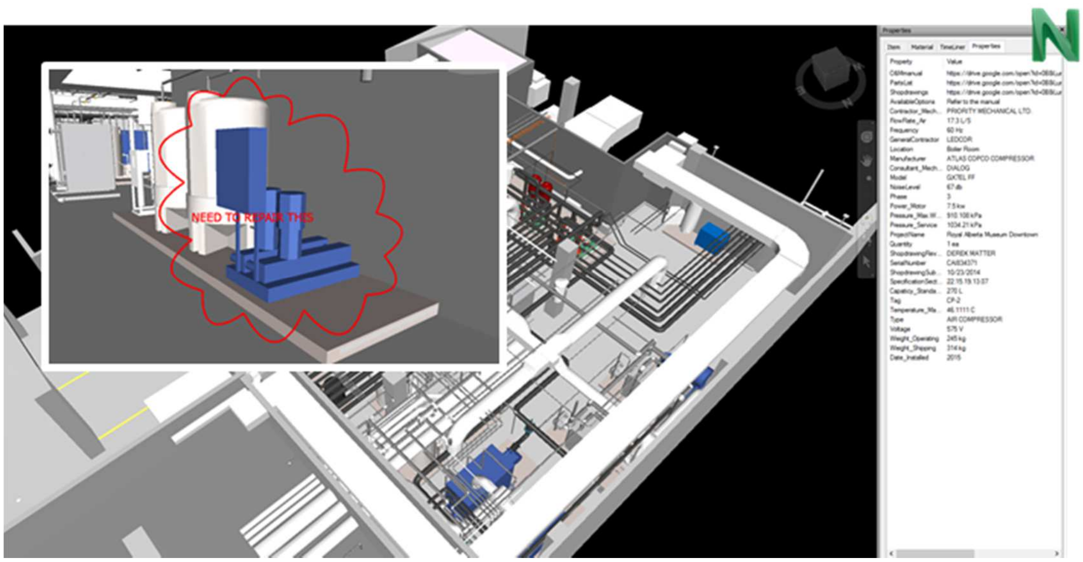


Figure 4.20 Accessing the FM model through the original file (Navisworks)

- Through A360 (Figure 4.21): If the model file is uploaded on A360, the users can access the model without any software installed on their devices but require a subscription. Also, anyone can have access to the model if he or she has the URL of the model. There is no need to save the file on the devices. In addition, the model file can be updated through the same URL, so the users can have access to the latest model without receiving the new file.

Figure 4.21 Accessing the FM model through the website (A360)

- Through barcode/QR-code (Figure 4.22): Users can embed the URL of A360 into a barcode or QR-code and attach them to the equipment on the site. Anyone can have access to the model and information if he or she has a barcode reader application on his or her devices. It is a quick and easy way to get the information on the site. It is also useful when the user needs to access the model on the site. As the model can be updated with the same URL, facility managers can have access to the latest information when necessary.

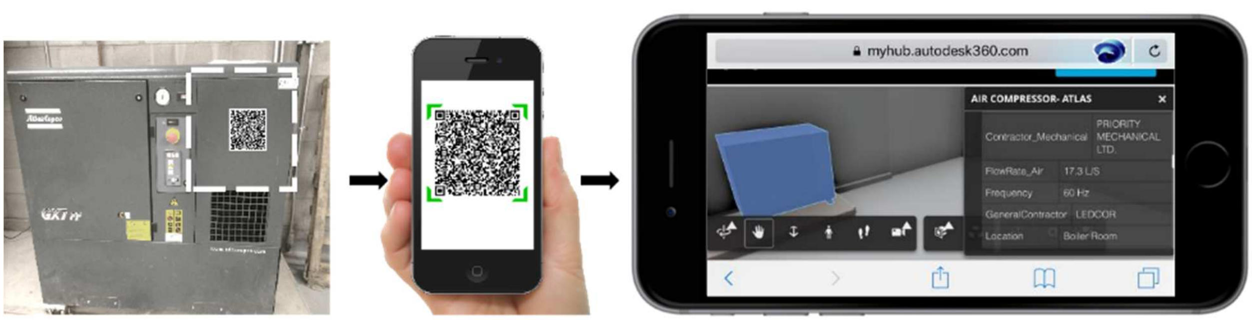


Figure 4.22 Accessing the FM model through barcode or QR code

4.2.4 Reflect on the efforts to develop the FM BIM (RA 6)

In this section, the challenges of each step that required much time and effort are explained in more detail steps (Figure 4.23). Last, the total amount of time spent on the process is illustrated to gain an understanding of time needed per a piece of equipment and unit area.

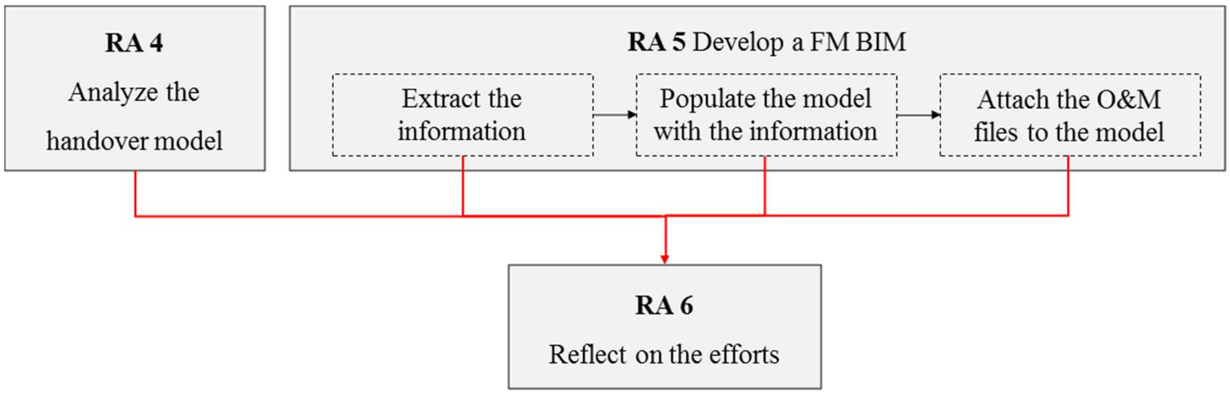


Figure 4.23 Reflecting on the efforts to develop the FM BIM

■ **The effort required to analyze the handover model:**

- Step A: To identify the gaps in geometric information modeling, we had to visit the site to capture the as-built condition of the boiler room. As the room contained various types of equipment with complex connections, we had to spend much time locating the equipment and taking photographs of the as-built status in detail. A total of 479 photos were taken during two site visits (Figure 4.24).
- Step B: Then, we compared the model with each photo manually to identify the modeling gaps. As a result, 15 hours were spent capturing the as-built status and comparing with the model.

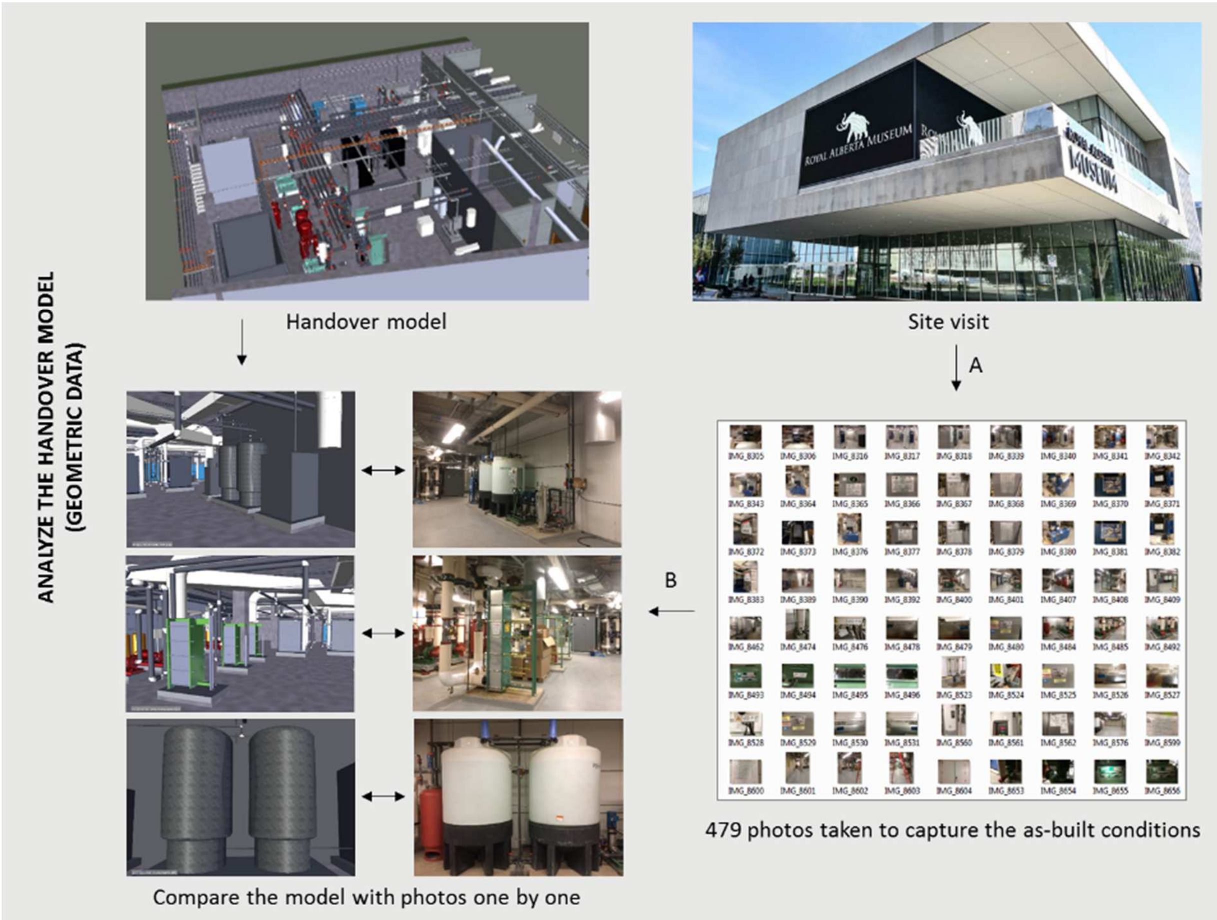


Figure 4.24 Analyzing the handover model (geometric data)

- Step C: In addition, due to the extensive amount of non-geometric data contained in the handover model and the handover documents, much time was required to compare these two (Figure 4.25). For example, for just one piece of the pump with the tag number P-5, we had identified a total of 200 attributes from the model, and 70 of those from the handover documents. As there were 60 pieces of equipment, which we needed to compare, a total of 21 hours were spent identifying the non-geometric modeling gaps.

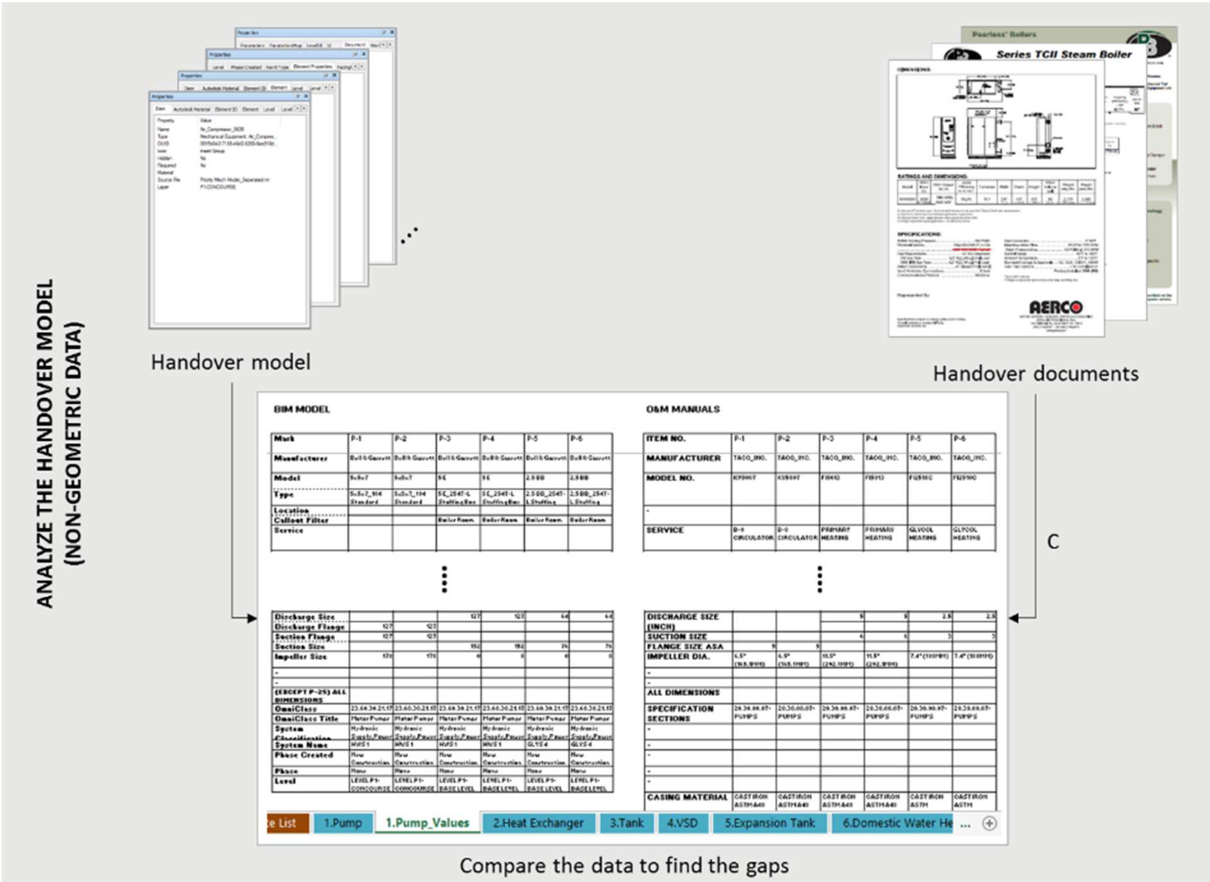


Figure 4.25 Analyzing the handover model (non-geometric data)

In total, 36 hours were spent analyzing the handover model to determine the modeling gaps. The time spent capturing the as-built conditions could have been reduced if we had used laser scanning or photogrammetry. These tools are known to offer faster and less error-prone creation of as-built BIM models compared with the traditional methods of surveying (Jung et al., 2014; Tzedaki & Kamara, 2013). However, it was not available for this pilot study due to the time and cost required for hiring the subcontractor. Moreover, from analyzing the non-geometric information, we had identified that most of the information embedded in the handover model was inaccurate and unnecessary. We could have reduced the amount of time analyzing the non-geometric data if the handover model had not contained this unreliable data.

■ **The effort required to extract information from handover documents:**

To extract the information from handover documents, we had to go through five sub-steps as indicated in Figure 4.26. Each step required much time and effort due to the poor quality of the documents.

- Step A: We started by locating the files related to the 60 selected pieces of mechanical equipment from the "Mechanical O&M" folder. Among 304 files of mechanical O&M files with 11,607 pages, we sorted out 49 files with 1,270 pages. However, as the file names did not clearly reflect the information contained in the file, we had to waste time locating the necessary files (Figure 4.27). For example, to locate the file related to a compressor with the tag number CP-2, we searched for "compressor" in the O&M manual folder. Eight files were identified, as shown in Figure 4.1, but only three were related to CP-2. Moreover, some of the file names contained acronyms of the equipment types, which cannot be searched unless the user is familiar with the abbreviations used in the project. For example, we searched for "heat" to find information on a heat exchanger, but no files were identified. We discovered that the acronym "HX" was used for the heat exchanger in this project, and the information regarding this heat exchanger was in a file labeled "3.3.2.3.01 - Pumps, HX, AS, ET - XXX Reviewed - 12.08.14 - FORMAL COPY." This type of improper labeling causes confusion and delay in locating desired information.

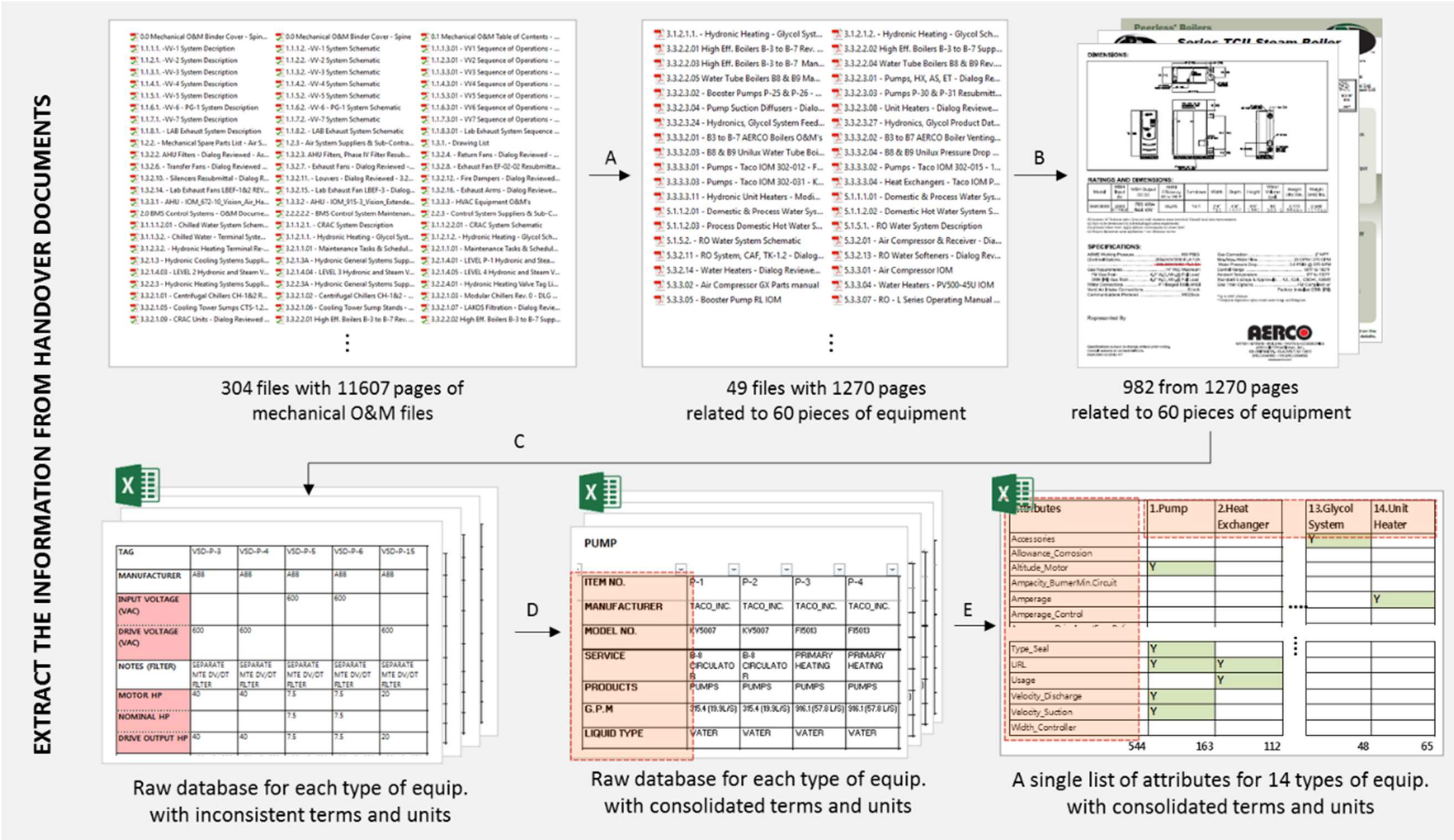


Figure 4.26 The effort required to extracting the information from handover documents

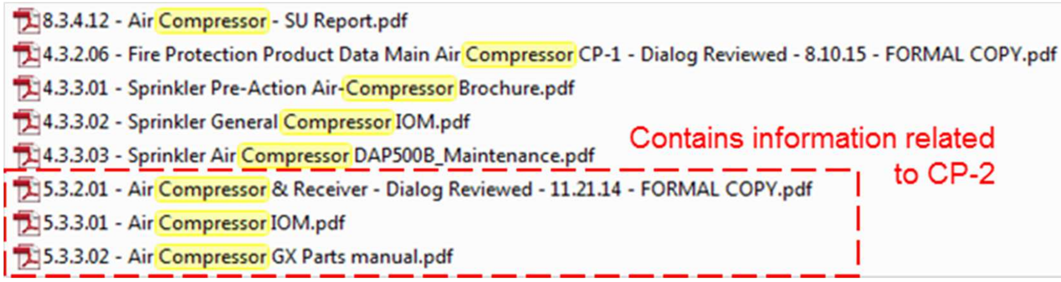


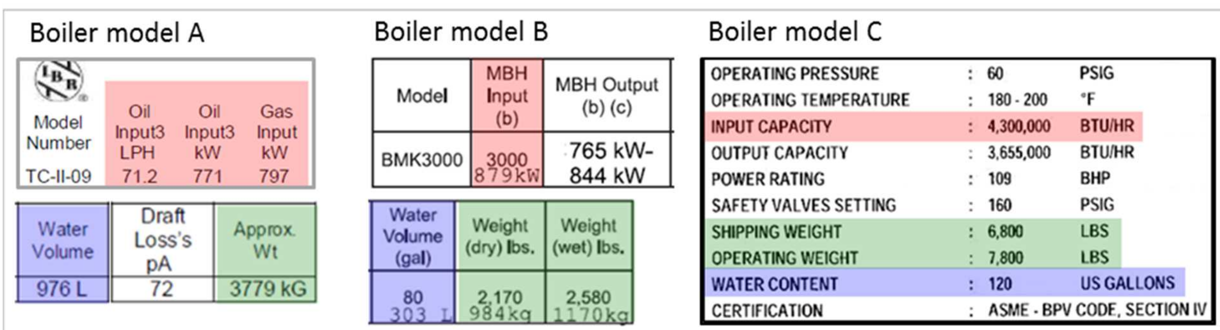
Figure 4.27 Unclear file names

- Step B: Due to the situation wherein many of the files contained information for two or more types of equipment, particular pages were sorted out again from the 49 files, which exclusively contain data of the 60 pieces of equipment. As a result, we found 982 pages out of the total 1,270 pages to be directly related to the equipment of interest to us. However, the unorganized order of the information contained in the files required a large amount of time to sort out the pages. For example, one of the files included information on pumps, heat exchangers, expansion tanks, and air separators in the following order.: Pump (tag number 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, Heat Exchanger (tag number HX-1, 2, 3, 4,) Expansion Tank (tag number ET-1, 2, 3, 4, 10, 11, 5, 6, 7, 8, 12, 9,) and Air Separators. As not all the data in the files were needed, nor they were in a certain order, a significant amount of time was spent scrolling through the pages to find the data we needed.
- Step C: Last, we read the 982 pages in detail to obtain the data to be embedded in the FM BIM. However, because the documents had been collected from different suppliers, they were provided with various templates. Therefore, the amount, order, and representation of the information were all different. For example, the number of attributes extracted from 60 pieces of equipment ranged from 27 to 118. Also, much of the information was

in descriptive format, which caused a delay in understanding the documents and finding relevant information. This process took a lot of time and effort.

- Step D: Moreover, as the documents were provided by different suppliers, the raw databases contained many attributes with different terminologies and units. As such, before populating the model, we had to consolidate the terms and units. Among the various terms, we decided to choose the terms that appeared most often in AI's information system and documents. We also decided to use the metric system units, which is the standard system in Canada.

As different terms and units were used even for the same type of equipment as shown in Figure 4.28, first, we consolidated the terms and units for the same types of equipment. The number of attributes of each equipment type ranged from 48 to 207 attributes, implying that we had to compare the terms of 48 to 207 attributes manually.


Boiler model A

Model Number	Oil Input3 LPH	Oil Input3 kW	Gas Input kW
TC-II-09	71.2	771	797

Water Volume	Draft Loss's pA	Approx. Wt
976 L	72	3779 kG

Boiler model B

Model	MBH Input (b)	MBH Output (b) (c)
BMK3000	3000 879kW	765 kW-844 kW

Water Volume (gal)	Weight (dry) lbs.	Weight (wet) lbs.
80 303 L	2,170 984kg	2,580 1170kg

Boiler model C

OPERATING PRESSURE	:	60	PSIG
OPERATING TEMPERATURE	:	180 - 200	°F
INPUT CAPACITY	:	4,300,000	BTU/HR
OUTPUT CAPACITY	:	3,655,000	BTU/HR
POWER RATING	:	109	BHP
SAFETY VALVES SETTING	:	160	PSIG
SHIPPING WEIGHT	:	6,800	LBS
OPERATING WEIGHT	:	7,800	LBS
WATER CONTENT	:	120	US GALLONS
CERTIFICATION	:	ASME - BPV CODE, SECTION IV	

Figure 4.28 Different terms and units used for the same type of equipment (captured from each document)

- Step E: Then, we created a single list of attributes for use with all 14 types of equipment. The resulting list comprised a total of 544 attributes. This, we had to compare the terms of 544 attributes manually to eliminate the duplicates and select the terms we will use.

As a result, we spent a total of 87 hours to extract information from the handover documents, starting from sorting out the related files to consolidating the terms and units. 48 of 87 hours were solely spent consolidating the terms and units. The fundamental reason was the unorganized handover documents with various templates collected from various suppliers. If there was a guideline or template provided to the subcontractors in the early phase of the project, these challenges could have been reduced and a huge amount of time could have been saved. The guideline or template should indicate not only the data requirements, but also the particular order, format (descriptive or non-descriptive), terms, and units of the data the owner needs.

- **The effort required to populate the model with the information:**

The process of populating the model contained five sub-steps as indicated in Figure 4.29. Each step required much time and effort mostly due to the technical challenges.

- Step A: After extracting the information, we had to create shared parameters in the model to populate the model. As we had cleaned out the non-geometric information from the model and since there was no shared parameter file available, we had to create the shared parameters manually. This step again included a series of small tasks including typing the parameter name, selecting the proper "Discipline" and "Type of Parameter," and selecting the parameter "Group." These were done for each of 544 parameters.
- Step B: Then, among the 544 parameters, we associated the related ones to each family file. As the shared parameter file contains entire attributes required for 60 pieces of equipment, we had to select the particular attributes required by each equipment by referring to the raw database. We had to go through this step 33 times as there were 33 different family files.

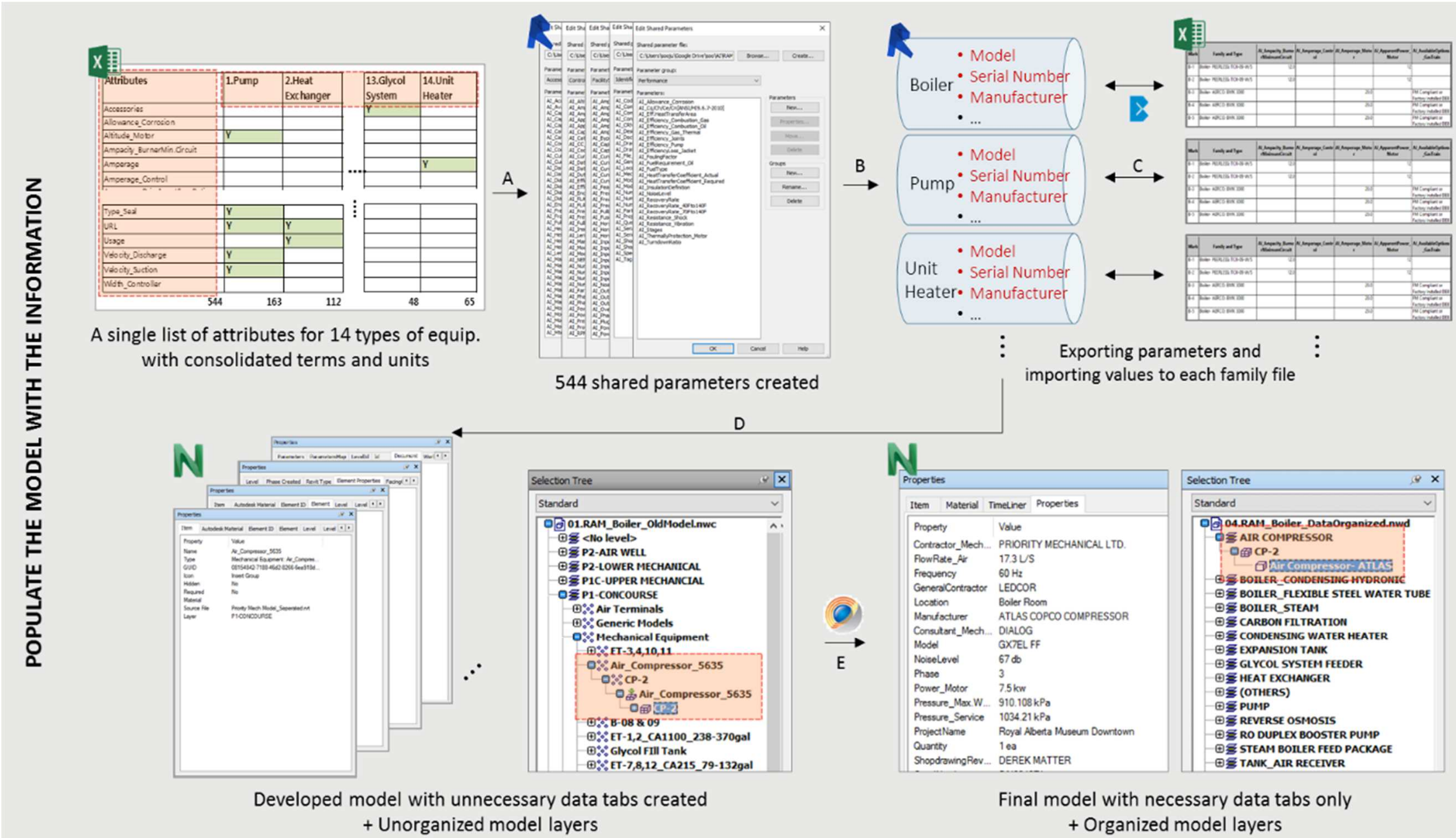


Figure 4.29 The effort required to populate the model

- Step C: After the parameters had been set, we imported the values into the model for each family. The process itself was not complicated, but there were several interoperability issues we identified during the process, which caused delay. They included the following:
  - Several types of parameters cannot have a null value. For example, the parameters those need units such as “mm,” “F,” and “V” can’t have null values. When the null values are imported back to the model, the model automatically recognizes the value as “0,” not null. Also, for the “Phase” parameter, both null and “0” values are not allowed. It recognizes them as “1”. Moreover, the “Temperature” parameter recognizes null as “-273 C.” Since these can cause huge misinterpretation, the values should not be remained as null. However, as we were not aware of this issue until it was recognized, we had to review all the attributes again to make sure there was no inaccurate value created.
  - There was confusion in the unit system. In Revit, there are two ways to change the units for the parameters. One way is to change the “Project” unit which affects all types of the equipment. Another way is to change the unit in the equipment “Schedule,” which only affects that particular type of equipment. Before importing the values from the database, we matched the “Schedule” units to those in the database. However, we noticed that when we import values from an external database, Revit recognize the values in “Project” units, not the “Schedule.” Therefore, we had to clean out the values those were converted with wrong units and import them again with modified units.

- The “Date” format was confusing. Some countries use “mm/dd/yy” format while other countries use “dd/mm/yy,” and even sometimes people misuse the format or use shorter versions like “dd/mm/yy” or “yy/mm/dd.” Thus, if the date does not indicate which format it is using, the readers can misinterpret the date easily. Since the majority of the “Date” values in the handover documents of RAM did not indicate their formats, it was difficult to identify the correct dates. Furthermore, the date format in Revit should match with the formats of either the modeler’s computer or Excel.

- Step D: After populating the model with information, we exported it to an nwc file to work with Navisworks. This conversion reduces the file size and makes it easier to navigate the model, but very limited amount of modifications can be made in the nwc file. This process did not require much time or effort as it only needed the basic function of Revit.
- Step E: However, when exporting rvt files to nwc files, unnecessary property tabs are created by default. Some attributes are automatically generated when a component is created in the model, which cannot be hidden or deleted. Also, the model layers were disorganized as layers are created when the geometric data are created. Therefore, we had to organize the property tabs and model layers. First, we hid unnecessary tabs. For example, the number of property tabs of a compressor component got reduced from 27 to four. In addition, we simplified the model layers to make it easier for the users to locate particular components or view particular data.

As a result, we spent a total of 26 hours populating and organizing the model. The majority of the time (23 hours) was spent populating the model due to the absence of shared parameters file. This time could have been saved if there was a shared parameter file created in the design and construction phases; shared parameter file can be stored in a text file to be shared with others (Autodesk, 2017b). However, as most of the parameters created in the handover model were not useful for FM purposes, we could not utilize them. In addition, as this pilot study was the first BIM project in AI, there was no existing shared parameter file created in previous projects. Therefore, we had no choice but to create the entire shared parameters manually. As we created the shared parameters file in this research, the file can be further developed and be used for the future projects. In addition to the shared parameter issue, the technical problems that occurred while importing the values into the model required an enormous amount of time. This could have been prevented if the research team was aware of the interoperability issues of Revit. For future projects, these issues should be documented as a reference.

- **The effort required to attach the O&M files to the model:**

As addressed above, the manual files were problematic for users because one file often contained information about multiple equipment types and the file names did not reflect the contents. Thus, we had to recreate the O&M files to attach to each model component. The process is again divided into five sub-steps (Figure 4.30).

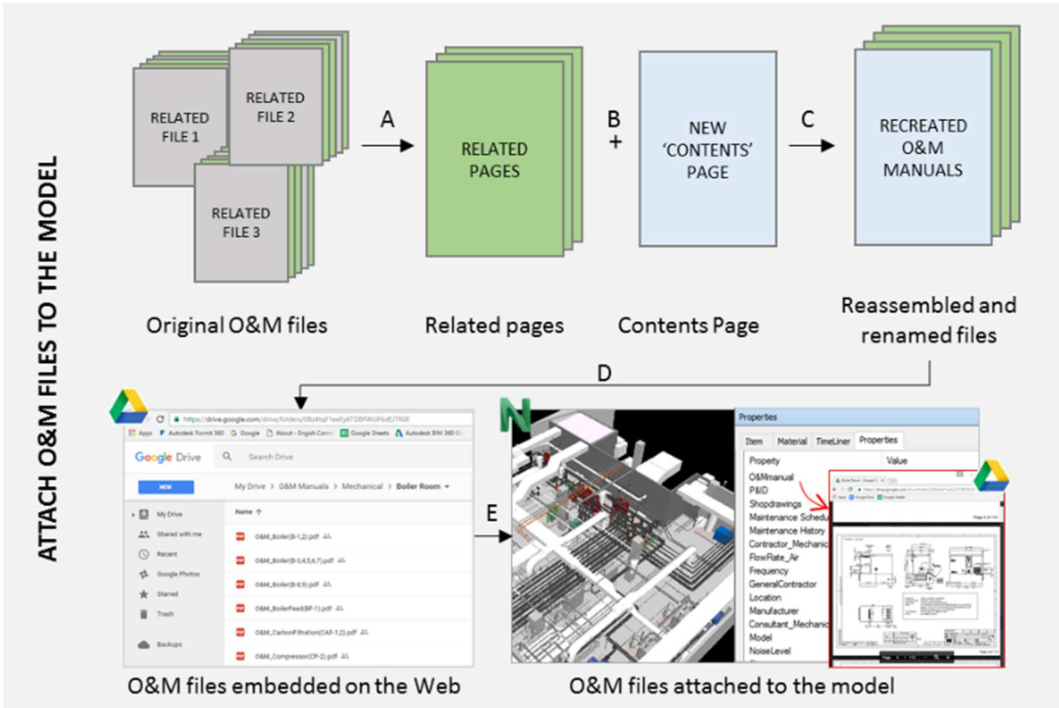


Figure 4.30 The effort required to attach the O&M files to the model

- Step A: First, we disassembled the files into separate pages and sorted out the pages that are related to each equipment. Then, we merged those pages into one file. In this way, we could eliminate unrelated information.

However, there were some problems which caused a delay in this process. In several files, we found that few of the images and their captions were not on the same page. In the example showed in Figure 4.31, the only data we needed from the front page was the image caption, but we had to include the entire page in the new file since we did not have the original word file that we could edit. This could have been prevented if the documents were reviewed enough before it was handed over to the owner.

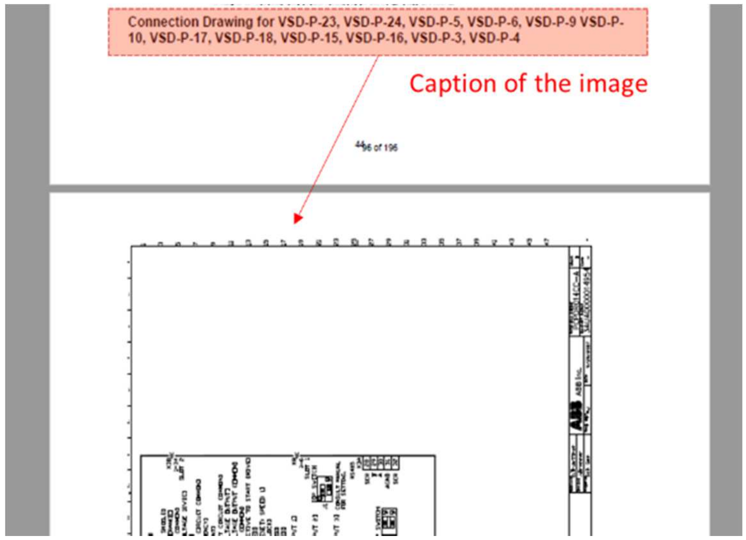


Figure 4.31 Image and its caption located on separate pages (Courtesy of Alberta Infrastructure)

- Step B: Then, we merged the file with a contents page, which we created to help readers locate information. No issue occurred during this process.
- Step C: We renamed the files to be recognizable and searchable. The names consist of the type of document ("O&M"), the type of equipment (e.g. "Boiler"), and the tag numbers of the equipment (e.g. "B-1,2"). As a result, we reduced the original 49 files with 1,270 pages to 30 files with 862 pages (Figure 4.32).

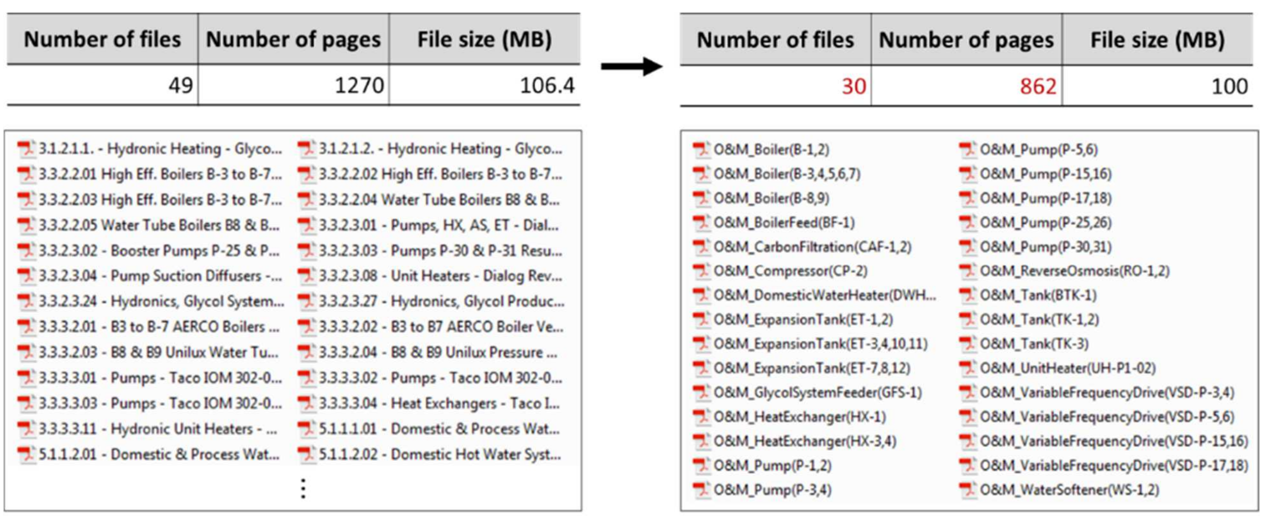


Figure 4.32 Reduced amount of O&M manuals after recreation (Left: Before, Right: After)

- Step D: Then we embedded the files on the Web drive. For this pilot study, we used a personal Web drive as we only needed 100MB of space to embed the files. For the future projects, a Web drive with a large amount of space should be provided by the organization.
- Step E: Last, we attached the links to the model. There was no issue identified.

As a result, we spent a total of 13 hours recreating the O&M files and attaching them to the model. No significant issues were found during this process. However, this process itself could have been skipped if the O&M files were well organized in the first place. For future projects, the owner should require the contractors to deliver the O&M files in a format that can be embedded in the model without any further modification.

- **The total time required to develop the FM BIM**

Figure 4.33 and Table 4.3 Time spent on each step of developing the FM BIMshow the timeline of developing the FM BIM. The largest portion of time was required to extract the information and consolidate the terms and units of the attributes. This was due to the different templates of handover documents collected from various suppliers. In addition, the time needed per a piece of equipment and per unit area (m^2) are calculated. As the model development was done on a small portion of the entire building, it helps to envision the amount of effort we need for developing the entire model; the entire floor area of RAM is 38,000m^2, and the boiler room area is 400m^2. However, because the modeling for this study was done by a non-BIM expert, and it was done on the particular type of room, this data should not be used to anticipate the exact amount of time needed for different types of spaces.

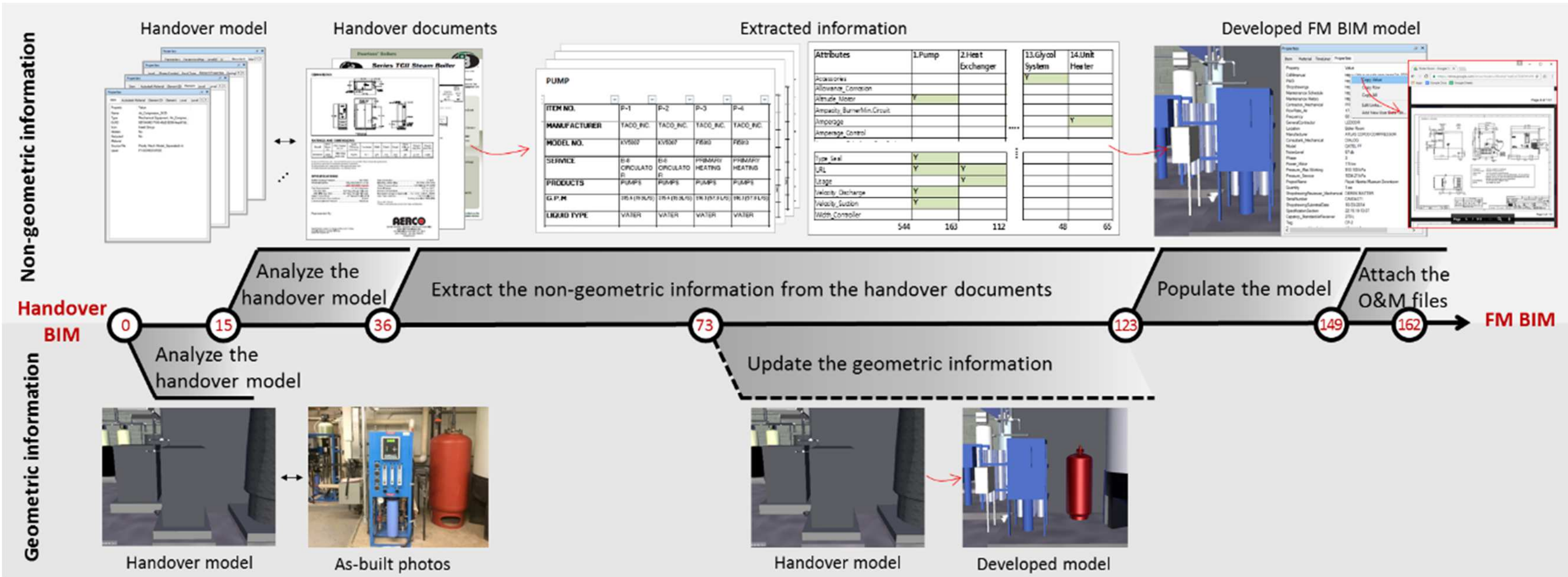


Figure 4.33 Timeline of developing the FM BIM

Table 4.3 Time spent on each step of developing the FM BIM

Steps of developing the FM BIM	Information type	Time spent (hours)	Time per equip. (min/pc)	Time per floor area (min/m^2)
Analyzing the handover model	Geometric + Non-geometric	36	36	5.4
Updating the geometric information*	Geometric	50	50	7.5
Extracting the information from handover documents	Non-geometric	87	87	13.05
Populating the model with the information	Non-geometric	26	26	3.9
Attaching the O&M files to the model	Non-geometric	13	13	1.95
Total		212	212	31.8

* As the geometric modeling was done by a modeling contractor, this time is negligible in this research.

4.2.5 Discussion

To summarize, the process of developing a handover BIM to FM BIM includes the steps shown in the Table 4.4.

Table 4.4 Process of developing FM BIM

Main step	Analyze the handover BIM
Sub-steps	A. Capture the as-built condition by taking photographs on site B. Assess the geometric data by comparing the model with the photos C. Assess the non-geometric data by comparing the model with the handover document
Main step	Update the geometric information
Sub-steps	A. Update the geometric data according to the as-built condition B. Clean up the inaccurate non-geometric data
Main step	Extract the information from handover documents
Sub-steps	A. Sort out the files related to the subjects of interest B. Sort out the pages related to the subjects C. Extract the related data and create a raw database with attributes and values D. Consolidate the terms and units used for attributes and values E. Create a single list of attributes throughout the subjects
Main step	Populate the model with the extracted information
Sub-steps	A. Create the shared parameters in Revit B. Associate the parameters to each equipment family file C. Import the associated values D. Export the model into Navisworks file E. Organize the properties tab and model layers
Main step	Attach the O&M files to the model
Sub-steps	A. Sort out the related pages of O&M manuals B. Make a Contents page C. Merge all related pages and rename the files D. Embed the files on the Web E. Attach the file links to the model

Prior to developing the FM BIM, we first examined the overall handover documentation of the project. The documents consisted of more than 46,000 pages with an extensive amount of data but had poor quality with inconsistent templates. Thus, we had to choose to extract the data manually for the model development. It would have been easier if the documents had been provided with a consistent template in a convertible format (e.g. Excel).

To identify the gaps in modeling, we analyzed the handover model. Part of the project model was selected as a pilot case. We determined that geometric data was close to the as-built condition, whereas the majority of the non-geometric information in the model was inaccurate. Thus, we maintained the existing geometric data and developed into as-built condition. During that process, we cleaned out the non-geometric data. Since assessing the model and eliminating the data require much time and effort, we suggest that the model should be handed over with no inaccurate or unverified information.

Finally, we developed the handover model into a FM BIM and reflected on the efforts required for the development. We learned that this calls for an extensive amount of work, mainly due to the unorganized nature of the handover documents. For example, every supplier used different templates, terminologies, or units upon their submittal. This caused a delay in locating the right information or consolidating the different formats. Thus, to reduce the time and effort required for developing a FM BIM, we recommend that the owners request the documents be provided in standardized formats. In addition, there were no attribute templates available for the modeling. The research team had to manually populate the model with the information, which also required much time. Thus, for future projects, attribute templates should be developed.

For this section, document analysis and a pilot study were used as the data collection methods. There is a limitation of the validating these outcomes as the research activities were done by one researcher on one pilot case due to the financial and time constraints of the research project. Had we had more than one researcher working on the same model, we could have enhanced the validity of the results by overcoming the researcher's bias through *investigator triangulation* (Denzin, 1978). Furthermore, if we could have conducted the same study in different parts of the model or different project model, it would have helped to generalize the results, which is called data triangulation (Denzin, 1978). The usefulness of the developed model should also be validated to justify the efforts identified during the development process.

4.3 Post pilot study

4.3.1 Investigate the organizational barriers to BIM adoption (RA 7)

To adopt BIM for FM, the organizational barriers should also be understood. The perceptions of facility operators in AI were investigated through interviews to identify the potential barriers to adopting BIM. We conducted two individual interviews with the maintenance worker from Facility A and the facility manager from RAM. The potential barriers mentioned by both of the interviewees included the following:

- There is a need for training all the related employees to utilize BIM, which would require time and money. The facility manager said, *"It will be really useful, but I'll need to train my team. It will take much time to make them familiar with the software."* In addition, the maintenance worker mentioned, *"I'm the youngest guy here, and the other two guys are kind of afraid of computers. So I don't know if they will use it."*
- An extensive amount of work would be required to develop the model, which would also require dedicated people to work on it. The maintenance worker said, *"It sounds nice.*

But, isn't the work too extensive? Collecting all the information and entering into the model, who should do it?"

- There were concerns about the maintainability issue. Both of the interviewees said that they would need dedicated BIM experts in their team to update the model whenever it is necessary. Otherwise, the model will become unreliable and lose its value as time goes by.
- The most important thing was the completeness of the model. They said the model should be 100% complete and have complete information to be used for the operation. The facility manager said, *"There is no meaning if the model is incomplete. I won't trust the information."*
- There is a need for proper software and hardware to support the process. The maintenance worker said, *"We will need to have the smartphones or iPads to use it. Here, I'm the only one who uses a smartphone (among the maintenance people), the others use flip phones."* Also, the facility manager said, *"How big is the model file? We will need proper computers on site to use the models."*

4.3.2 Discussion

Lastly, to understand the barriers to implementing BIM for FM, we investigated the owner's perceptions of BIM adoption. We learned that there are concerns with the time and cost required for the changes, including employee training, extra workforce for model management, and hardware/software updates. This indicated the need for more support from the high-level management. Currently, the organization is going through hardware and software updates for the employees who are supposed to use BIM for the design review task. However, still, there is no support for the facility management side.

The interview result has its validity as the two interviewees responded in the same way. In addition, to enhance its validation, we studied the existing literature where the challenges of implementing BIM-enabled FM were identified through case studies (Kelly et al., 2013; Kiviniemi & Codinhoto, 2014; Korpela et al., 2015). The common challenges that were identified from our interviews and the literature include the following: the lack of BIM experts in the organization, the lack of tangible benefits of BIM-enabled FM, the interoperability issues, the lack of clear requirements for developing a FM BIM, the maintainability issues, the absence of BIM software, and the cost for setting up the infrastructure for BIM. Although the existing studies and this research were conducted in different cases, the common results indicate that the owner organization has certain common challenges to adopt BIM for FM.

Chapter 5: Conclusion

5.1 Summary

The overarching objective of this study was to understand the process and effort required to develop and utilize the project BIM for FM purposes. A case study was conducted on a large public owner organization, who operates and manages more than 1,900 facilities but has no experience in using BIM for FM.

Currently, the owner manages its facilities in a traditional method, without employing BIM. According to an interview, one of its facilities was being managed inefficiently due to the poor quality of handover data and lack of proper data management system. FM information systems deployed by the owner were also being managed inefficiently due to the lack of single data source and the lack of interoperability. As these could lead to a poor facility management and cause considerable losses in time and money, there is a need and potential opportunity to adopt BIM for FM to manage the facility data efficiently and generate high-quality data.

A new museum project, where BIM was adopted for the design and construction phases, was recently handed over to the owner with the project BIM. The owner wanted to understand what is required to employ the handover BIM in the facility management phase. To better understand the effort required to develop and utilize the handover BIM in FM, a part of the handover model was developed into a FM BIM by the research team. A significant amount of effort was required to develop the model. The process includes the following: analyzing the handover model, updating the geometric data, extracting information from the handover documents, populating the model with the information, and attaching the O&M files to the model. A total of 212 hours were spent developing 60 pieces of equipment component. Detail steps and time spent are summarized in Table 5.1.

Table 5.1 Process and time required for developing FM BIM

Process required	Time required (hrs)
Analyze the handover BIM A. Capture the as-built condition by taking photographs on site B. Assess the geometric data by comparing the model with the photos C. Assess the non-geometric data by comparing the model with the handover document	36
Update the geometric information A. Update the geometric data according to the as-built condition B. Clean up the inaccurate non-geometric data	50
Extract the information from handover documents A. Sort out the files related to the subjects of interest B. Sort out the pages related to the subjects C. Extract the related data and create a raw database with attributes and values D. Consolidate the terms and units used for attributes and values E. Create a single list of attributes throughout the subjects	87
Populate the model with the extracted information A. Create the shared parameters in Revit B. Associate the parameters to each equipment family file C. Import the associated values D. Export the model into Navisworks file E. Organize the properties tab and model layers	26
Attach the O&M files to the model A. Sort out the related pages of O&M manuals B. Make a Contents page C. Merge all related pages and rename the files D. Embed the files on the Web E. Attach the file links to the model	13
Total	212

These efforts were required mainly due to the unorganized handover model, the poor quality of handover documents, the lack of the document templates, the absence of the model template, and unforeseen technical issues. Thus, to utilize handover BIM for FM in the future projects, we suggest the owner require the construction models to be cleaned out prior to the handover and also require the handover documents to be submitted in a standardized format throughout the suppliers. In addition, the owner should develop the model attribute templates through other pilot projects and document the technical issues to avoid the same problems.

Furthermore, to utilize BIM in future projects, BIM training should be provided to the facility operators, dedicated BIM experts should be hired to maintain the models, and proper hardware/software should be provided to support the use of the model. Beyond these issues, support from the high-level management is required to adopt BIM in FM, as it is not just about adopting a new technology, but changing the overall work process of an organization.

According to the research, a significant amount of effort was required to utilize the handover BIM in FM. It is predictable that a considerable amount of time and money would be needed to adopt BIM for future projects. However, adopting BIM by owners is unavoidable as the whole AECOO industry is moving toward BIM. The owners, particularly large public organizations, should lead this change by further studying and investing in levering BIM in their facilities. Moreover, the project BIM guidelines and BIM deliverables should be developed by the owners to require the project teams to follow.

This research informs the owners of potential challenges of utilizing handover BIM for FM to support them in identifying and minimizing the challenges in advance. Also, the lessons learned from this study can be used as a reference to develop the owners' BIM deliverables.

Furthermore, the study can be used as preliminary research for additional research on the implementation of BIM for FM.

5.2 Limitations and further studies

For the pilot study, only a small part of the project model was selected to be developed into the FM BIM; the floor area of the boiler room was one percentage of that of the entire building. As the facility contains various rooms with different conditions, various parts of the model should be developed to identify other potential challenges.

In addition, there is a limitation on the validity of the developed model. Before populating the model with the obtained information, we asked the facility manager of RAM to review the data to confirm its usefulness. However, we could not obtain useful feedback from him because of the time constraints, which resulted in embedding the entire data into the model. For future projects, facility managers should be involved in the process of model development to review the data to be embedded in the model. Also, we should validate the use of the developed model. It can be done by comparing the FM process of using the model with handover documents as opposed to using the developed model with the same scenarios. The model should be further developed based on the feedback from this process.

Furthermore, the BIM requirements of the organization should be developed through more case studies. In this study, we used the handover documents as the data source, as the model was developed after the facility was handed over. In contrast, in future projects, the owner should set the BIM requirements and demand that all of the stakeholders, including the designers, contractors, sub-contractors, and suppliers, follow them. This should be done by investigating the existing BIM-FM requirements and filtering them with all of the related parties, including facility managers and asset managers. Since the information requirements depend on the type, use, and scale of each project, the requirements should be developed for each type of project.

For long term perspectives, further research on the process and challenges of leveraging BIM in FM should be carried out through different projects with different natures. Moreover, solutions for the challenges should be investigated to promote the adoption of BIM for FM by the owner organizations.

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Appendix

- List of software used

1. Google Drive: Google Drive is a file storage and synchronization service operated by Google. It allows users to store files in the cloud, synchronize files across devices, and share files. Google Drive is available for both PCs and mobile devices. It also has a website that allows users to see their files from any Internet-connected computer, without the need to download an app (Wikipedia, 2017a).
2. Microsoft Excel: Microsoft Excel is a spreadsheet developed by Microsoft. It has the basic features of all spreadsheets, using a grid of cells arranged in numbered rows and letter-named columns. Version 12.0 can handle 1M (220 = 1048576) rows, and 16384 (214 as label 'XFD') columns (Wikipedia, 2017b).
3. Revit: Revit is a design and documentation platform that supports the design, drawings, and schedules required for building information modeling (BIM). In the Revit model, every drawing sheet, 2D and 3D view, and schedule is a presentation of information from the same virtual building model. As you work on the building model, Revit collects information about the building project and coordinates this information across all other representations of the project. The Revit parametric change engine automatically coordinates changes made anywhere—in model views, drawing sheets, schedules, sections, and plans (Autodesk, n.d.-a).
4. BIM link: With Ideate BIMLink, Autodesk Revit users can pull information from a file into Microsoft Excel and push volumes of precise, consequential BIM data back into Revit model (Ideate Software, n.d.). Without this function, the users should add the values manually.

5. Navisworks: Navisworks is a 3D design review package. It enables coordination, construction simulation, and whole-project analysis for integrated project review. Some Navisworks products include advanced simulation and validation tools (Autodesk, n.d.-b).
6. iConstruct: iConstruct allows users to configure and manage a range of information from various design models (plus additional data) into a manageable, multi-user format. Using the standardized data within these models, iConstruct’s tool sets can extract information at any stage of the construction process. It can also be extracted and presented with a variety of customizable reporting tools, which means better communication and project accuracy (iConstruct, n.d.). In this study, the ReConstruct function was used to organize the data in Navisworks model.
7. A360: A360 is a cloud-based workspace that centralizes, connects and organizes the project team and project information across the users’ desktop, the web, and mobile devices. Integrated viewer lets the team access and view, share, search and edit 2D and 3D design files—Autodesk and competitive formats—directly from a browser (Autodesk, n.d.-a).