Information commissioning: bridging the gap between digital and physical built assets

Journal:	*Journal of Facilities Management*
Manuscript ID	JFM-04-2020-0024
Manuscript Type:	Research Paper
Keywords:	information commissioning, building information modelling, project information model (PIM), asset information models (AIM), BIM for FM, action research

Authors' accepted manuscript. Soojung Kim, Erik A. Poirier, Sheryl Staub-French. "Information commissioning: bridging the gap between digital and physical built assets." *Journal of Facilities Management*. 2020. https://doi.org/10.1108/JFM-04-2020-0024

Information commissioning: bridging the gap between digital and physical built assets

Abstract

Purpose – As the use of building information modelling (BIM) for facilities management (FM) continues to grow, questions remain around the quality and completeness of digital assets to support FM practices. There is a need to understand the current gap between digital and physical assets in the absence of formal information requirements and its impact on the handover process.

Design/methodology/approach – An action-research was carried out with a large public organization to understand the challenges of their current FM processes and the steps required in developing an asset information model (AIM) from a project information model (PIM). A mixed method approach was employed with interviews, document analysis, and an exploratory pilot case study.

Findings –This paper investigates the process, the challenges, and the level of effort of the information commissioning process to create a fit-for-use AIM. Four distinct steps were identified in the process: analyzing the handover PIM and documents, extracting FM-specific information, populating the model with the information, and attaching O&M documents. The research highlights the significant amount of effort that is required when no specific FM information requirements are formulated at the project onset.

Practical implications – The paper presents an information commissioning process that helps to develop an AIM from a PIM. Understanding the information commissioning process can help asset owners define their information requirements.

Authors' accepted manuscript. Soojung Kim, Erik A. Poirier, Sheryl Staub-French. "Information commissioning: bridging the gap between digital and physical built assets." *Journal of Facilities Management*. 2020. https://doi.org/10.1108/JFM-04-2020-0024

Originality/value – This paper provides empirical evidence of the impact of the absence of formal information requirements on the development of a fit-for-use AIM.

Keywords: building information modelling, project information models (PIM), asset information models (AIM), action research

Article Type: Research paper

1 Introduction

There is growing evidence of the positive impact that the digitalization of asset management practices in the built asset industry is having on bottom lines around the world. Embodied principally through the use of building information modeling (BIM) for facilities management (FM) during the operational phase of a built asset, this digitalization has shown great potential to support the delivery and use of coordinated, consistent, and computable building information throughout a building's life cycle (Becerik-Gerber et al., 2012; Edirisinghe and London, 2015; Lin et al., 2016). Many studies have addressed the potential benefits of using BIM for FM, namely that it supports the collection and modeling of facility information in a way that is universally recognized and prevents the loss of this information during project handover (Atkin and Brooks, 2009; Liu and Issa, 2015, 2013). Moreover, as BIM enables project teams to share and reuse asset data, the need to manually re-enter data into downstream FM systems is eliminated. This potentially reduces the cost of generating high-quality data (IFMA, 2013; Sabol, 2008). Despite these benefits, the adoption of BIM by owners for FM is still slow (Korpela et al., 2015). Among many explanations, the process and efforts relating to transferring the as-built information of an asset to the operations phase remains unclear (Wetzel and Thabet, 2015). Indeed questions remain as to how a project information model (PIM), an information model related to the delivery phase of an asset as defined by ISO 19650, is commissioned and handed over to an asset owner to provide value in the form of a fit-for-use asset information model (AIM), an information model which is related to the operational phase of an asset. In many cases, handover exchange requirements are often lacking, underdeveloped or overdeveloped due to a lack of understanding of the information required to support asset management and/or lacking the experience to determine the type and amount of information to be exchanged and managed through digital means (Cavka et al., 2017). Considering this, information requirements tend to be missing or misaligned which hinders or negates the potential value of asset information during the operations phase. The impact of the absence of formal information requirements on the handover of digital information for FM is a subject that requires further investigation.

The research presented in this paper aimed to understand the information commissioning process, notably the efforts required to adapt a PIM at handover for FM purposes, thus creating a fit-for-use AIM. A pilot study was conducted with a large public owner organization in the context of a longitudinal action-research project on a real-world project. The findings from the research provide empirical evidence of the effort required to support this information commissioning process. Four distinct steps are identified: analyzing the handover PIM and documents, extracting FM-specific information, populating the PIM model with FM-specific information, and attaching O&M information to the model. A total of 147 hours was spent adapting the information model for 60 pieces of equipment. The challenges involved in the process both from the organizational and information management perspective are also discussed. The practical evidence gathered and the lessons learned from this research are useful for project stakeholders that develop PIMs (builders, suppliers, manufactures, designers) and owners/ building operators to support BIM-enabled FM through AIMs for a more efficient hand-over process. In this sense, the principal findings point to the fact that the considerable effort required in developing a fit-for-use AIM is attributable to the improper organization of information in the handover model, the poor quality of handover documents, a lack of document and model templates, and unforeseen technical issues. The research points to the need for clear asset and exchange information requirements, including the obligation for the contractor to “commission” the PIMs prior to the handover and the handover documents from all suppliers/vendors to be submitted in a standardized format.

2 Literature Review

Facility Management (FM), or “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) is essential for built asset owners to deliver their strategic and operational objectives while providing a safe and efficient working environment (IFMA, 2013). Indeed, well-maintained facilities can enhance an organization’s performance by contributing to the optimization of the working and business environment (Alsyouf, 2007; Atkin and Brooks, 2009; Roelofsen, 2002). A key aspect of efficient and effective FM is access to quality asset information (Barrett & Baldry, 2003; Abel et al., 2006; Dettwiler et al., 2009). The availability of such asset information is largely contingent on the quality and completeness of information at facility handover. Traditionally, facility information is handed over from the contractor to the owner and it includes a number of paper-based documents such as drawings, specifications, product data sheets, and O&M manuals (Goedert and Meadati, 2008). As this process is still for the most part manual, the information is often found to be incomplete and inaccurate (Lucas et al., 2013). Even when the documents are available digitally, heterogenous data formats and interoperability issues hinder the usefulness of this information. Rework and manual data entry are usually required, which leads to duplication of efforts and high chances of errors (Ghosh et al., 2015). Due to these inefficient workflows, the industry is spending significant resources re-entering information(Keady, 2009).

BIM-enabled practices help mitigate information loss between design, construction and operations, by enabling stakeholders to add to and reference information they acquire during their period of contribution to a project (Lucas et al., 2013). In addition, as the facility data in BIM can be easily shared and reused by the project team, it does not have to be re-entered into downstream information systems (Sabol, 2008). This potentially reduces the cost of generating high-quality facility data (IFMA, 2013). The application areas of BIM for FM include locating components, facilitating real-time data access, checking maintainability, and automatically creating digital assets (Becerik-Gerber et al., 2012). Yet, the appropriate information must be provided to support these applications.

To support the information handover process, information management and exchange standards have been developed, such as ISO 19650 and Construction Operations Building Information Exchange (COBie). The ISO 19650 series set out a standardized process for information management across an asset's lifecycle. Among others, the standard presents a specific step aimed at reviewing and accepting the information model by the owner. Based on a series of considerations, the owner reviews a PIM for compliance to a set of information requirements. As a data exchange format and process, COBie was developed to create to facilitate information handover to operations and maintenance entities (Sabol, 2008). It is intended to simplify the work required to capture and record project handover data, yet it posses many limitations (Abdirad and Dossick, 2019), including the limited scope, the lack of the format in which information is exchanged, and the limited process through which information is entered and controlled. Other avenues supporting effective and efficient handover of facility information must therefore be investigated.

Several case studies have been performed in universities which provide fertile grounds for research and development. The University of Southern California case study documents the progression of BIM into BIM-enabled FM from the owner's perspective (Aspurez and Lewis, 2013). The use of BIM for FM in three projects at Texas A&M University was also investigated (Lavy and Jawadekar, 2014). A similar study aimed at investigating the value of using COBie with BIM in FM was conduted at the University of Washington (Asl, 2015). Korpela et al. investigated the challenges and potential of utilizing BIM for FM through a case study of at the University of Helsinki (Korpela et al., 2015). These case studies have helped identify many challenges pertaining to the effective implementation of BIM for FM from an information handover perspective. Examples of the challenges include the lack of stakeholders' involvement in the BIM transitioning process, understanding the requirements of the FM team, clarity for determining who will manage the resulting AIM after facility handover, and dedicated resources required to implement BIM for FM (Aspurez and Lewis, 2013). Limitations on data sharing, the absence of standardized requirements development process, and the lack of internal BIM experts were also identified as challenges (Lavy and Jawadekar, 2014). Lastly, the development of a useful FM model and keeping it updated is seen to require a significant amount of resources (Korpela et al., 2015).

The potential benefits to be captured in adopting BIM for FM have led some owners to create BIM solely for FM purposes (Patacas et al., 2015; Volk et al., 2014). However, the practices and processes associate to do so, especially with regards to information commissioning and handover are still largely unknown. Indeed, past studies have focused on the adoption of BIM from the early phase of the projects, in essence to deliver a PIM, and there are still very few studies that have addressed the cases of developing or creating an AIM solely for FM purposes. In addition, previous studies have been limited to smaller owner organizations, typically universities (Edirisinghe et al., 2016; Farghaly et al., 2018; Kassem et al., 2015; Kelly et al., 2013; Lijun et al., 2016). The investigations of different types of owners with different level of organizational and BIM maturity is required to provide insights into better understanding the issues of BIM implementation for FM while helping validate the results from past studies. Lastly, data collection methods in the existing studies are limited to interviews, observations, or document analysis (Godager, 2011; Hossain and Haron, 2018; Hossain and Yeoh, 2018). Very little in the way of empirical evidence has been captured with regards to the process and effort required to lead pilot projects focusing on the development of a suitable AIM to support FM practices. In this sense, there is significant opportunity to investigate the AIM development process from multiple perspectives and under different conditions.

3 Methodology

3.1 Research design

The study described in this paper was part of a longitudinal action-research project with a large governmental owner organization that plans, builds, and manages over 1,900 built assets in Alberta, Canada. The overall objective of the research project was to investigate and accompany the organization in the BIM adoption process for project delivery and for operations and maintenance. An action-research approach was employed for the research due to its cyclical, iterative approach, its interventionist emphasis within the research setting (Lewin, 1946), and its grounding in the pragmatist epistemological paradigm (Azhar et al., 2010). Action-research comprises 5 distinct phases (Azhar et al., 2010; Baskerville and Pries-Heje, 1999): 1) diagnosing, 2) action planning, 3) action taking, 4) evaluating, and 5) specifying learning. Its interventionist approach was privileged in this research as the organization needed to gain an in-depth understanding of their current FM practices while developing future BIM-enabled FM practices. In this sense, the objectives laid out for this portion of the action-research project were to investigate the requirements, processes and effort needed to develop an AIM from a "uncomissioned" PIM of a large built asset to support FM practices within the owner organization. A three phased research approach was undertaken to fulfill these objectives: a series of research activities (RAs) with specific data collection methods were undertaken as below.

- Phase 1: Diagnosing and action-planning (Pre-Pilot study)
  - RA 1 – Investigate the current FM Practice within the organization
    - Interviews with facility managers and maintenance workers
  - RA 2 – Investigate the existing FM information systems
    - Interviews with FM information system managers
    - Document analysis on data system templates
- Phase 2: Action-taking (Pilot study)
  - RA 3 – Examine the handover documentation
    - Document analysis on handover documents
  - RA 4 – Commissioning the PIM to develop a fit-for-use AIM
    - Document analysis on handover PIM
    - Pilot study by developing AIM
- Phase 3: Evaluating and specifying learning (Post-pilot study)
  - RA 5 – Diffusing lessons learned and implementing BIM for FM
    - Interviews with facility managers and maintenance workers

Over the course of the study, a total of 5 interviews were conducted which helped identify the current FM practices as well as the information systems used to maintain and manage facilities. The interviews also identified the current barriers to the deployment of BIM for FM within the organization. Data from the interviews were triangulated with actual system data and field observations. The second phase involved identifying and developing the information requirements to adapt the PIM into a fit-for-use AIM. To that aim, handover requirements, a total of 302 files with 11,508 pages of handover document, and one federated PIM including 8 disciplines were analysed. Finally, the pilot study, which involved members from the research team was conducted. This involved the adaptation of the PIM into the fit-for-use AIM based on the findings from the interviews and document analysis. During this stage, the development process was mapped, and the time and effort required were captured. The pilot study is described in more detail below.

3.2 Pilot Study

The pilot study was carried out on the new construction of a 37,810 m^2, four-story museum located in Edmonton, Alberta, Canada. The project was initiated in 2011 under a design-build contract, and construction was completed in 2016. BIM was used during the design and construction phase for various purposes such as visualization, detecting conflicts, estimating costs, 4D scheduling, and fabrication.

While the owner was aware of the potential for the use of BIM during the operational phase of the building there were no intentions or formal requirements set out in the contractual documents. Two reasons for this were that the owner (a) did not know how to require BIM for FM in the project and (b) did not have a clear understanding of the impact on both the project team and its internal resources in terms of time and cost. Since no formal asset information requirements (AIR) were developed at the onset, the PIM created for design and construction purposes was not developed in a way that was suitable for FM. For the pilot study, the PIM was made accessible to the research team in both proprietary and non-proprietary formats. In addition, the electronic handover documents were collected as a reference to develop the model.

In order to test and develop the information commissioning process, the focus of the pilot study was put on a boiler room which contained 60 pieces of mechanical equipment with a floor area of 400m^2 (Error! Reference source not found.). The boiler room, while limited in area, provided a practical and realistic test case for the study in order to inform the owner of the potential efforts required of developing an AIM. For instance, the boiler room contained complicated equipment that could cause serious issues in the event of a malfunction of building services, a critical area of interest from the perspective of the facility manager who wanted to evaluate how the AIM would benefit him to operate the boiler room efficiently and effectively. The boiler room also provided a test bed of reasonable scope for the research team to investigate. As a result, the information related to this area was assessed and developed for FM purposes.

INSERT FIGURE 01 HERE

4 Findings

4.1 Diagnosing and Action-Planning

In the pre-pilot stage, the organization's FM practices, and the related information systems were investigated. This provided valuable information to better understand the issues, the current workflows and how BIM could provide opportunities to address some of the challenges the organization faced.

4.1.1 Investigating the current FM practice within the organization (RA 1)

The organization's current FM practice were investigated through two in-depth interviews with maintenance service workers of the owner's existing facility, "Facility A" The interviews shed light on several limitations with current FM practices.

First of all, although Facility A was occupied for more than a year, the maintenance team had received no as-built drawings, but only construction drawings which contained a significant amount of out-of-date information. Moreover, the maintenance team was not utilizing the O&M manuals they have due to the poor quality of the documents. During the handover phase, more than 70 binders of paper-based O&M manuals were delivered to the team but were not organized in a way to support the operational tasks. Therefore, whenever the workers needed specific information about a piece of equipment, they had to go through the documents page-by-page, which was time-consuming. There was no online database or any information system through which the workers could manage their work schedules or maintenance records. Whenever a maintenance personnel made any changes on equipment or completed routine inspections, they were recorded on paper-based work log sheets.

4.1.2 Investigating the existing FM information systems (RA 2)

Among the owner's 52 information systems that were identified, one asset inventory management system, "System A," and three facility management systems, "System B," "System C," and "System D", were investigated. These four systems were deployed specifically for FM purposes. Document analysis was conducted on the data templates of the systems, and three separate interviews were conducted with the system managers regarding the required input data and data flow within these systems.

Although the four systems were all intended for FM, each system contained a different type of facility information and supported different information uses. System A is a central database where the basic facility data were originally generated. System B contained the basic equipment properties and maintenance task information. System C was used for facility condition assessment, collecting the information required to optimize long-term strategic asset management. System D carried information regarding maintenance work orders.

While System A was intended to serve as a central database for other sub-databases to retrieve facility data, only a small subset of information was being transferred from System A to other databases. Most of the data required by the other systems had to be (re-)entered manually. Moreover, the other three databases were not interoperable, even though they possess a set of common attributes. Therefore, if any change occurs in a facility prompting corresponding data in the systems to be updated, each system needed to be updated manually by different users. The manual data entry and lack of interoperability have often resulted in the loss of information as well as inconsistent records in different systems.

Moreover, inconsistencies were found in the terminologies used in the systems for common attributes. For example, for building location attribute, System A used term ‘Address’, B used ‘Location’, C used ‘Address/Location’, and D used ‘Client Area’. These inconsistencies occurred because the systems were designed by different suppliers/vendors and the data were entered manually by different users. This can cause confusion for users who retrieve information from the systems and is one of the main reasons why the systems are not interoperable

Several FM practices were found during the diagnosis and action-planning stage that contributed to data loss, quality reduction or inadequate information processing. The Organization was looking for a solution that would provide streamlined workflows, efficient sharing and exchange of information, which is critical for effective facility management.

4.2 Action-Taking

As a response to these limitations and the opportunities to leverage BIM for improved FM practices discussed with the organization, the pilot study was initiated on the museum project to better understand what is involved in developing an AIM to support FM practices from the PIM, in essence implementing an information commissioning process to develop a fit-for-use AIM.

4.2.1 Examining the handover documentation (RA 3)

The owner requirements regarding handover documents typically include as-built drawings, commissioning and warranty documents, as well as O&M manuals. Prior to developing the AIM, the overall handover documents of the museum project were examined to understand their quantity and quality. There were a total of 1,442 files with 46,741 pages (12.1 GB) of document, and the mechanical O&M manuals, which were used as the data source for the pilot study, consisted of 302 files with 11,508 pages (954 MB).

While investigating the O&M documents, it was noticed that some of the files contained poor quality documents. Several documents were difficult to read due to low resolution and some of them were handwritten. There was a large amount of descriptive information that could not be automatically parsed and interpreted. Moreover, some files were scanned from paper-based documents, which was a major hurdle for text-based searching within the file. Therefore, to create the AIM, the data had to be extracted manually by going through the documents page-by-page.

The extensive amount of data and poor quality of handover documentation investigated here suggest the potential challenges of FM practice in operation phase

4.2.2 Commissioning the PIM to develop a fit-for-use AIM (RA 4)

The pilot study focused on the commissioning of the PIM and integration of non-geometric information into the AIM (in lieu of the geometric data). The decision to focus on non-geometric information was made for two reasons. First, the geometric data of the handover BIM was relatively accurate. Second, existing studies have focused more on developing an AIM with the geometric data (Jung et al., 2014; Tzedaki and Kamara, 2013).

The detailed information commissioning process is illustrated in **Error! Reference source not found.** and described below. Four distinct steps were identified: (a) analyzing the handover PIM and documents, (b) extracting FM-specific information, (c) populating the model with the information, and (d) attaching O&M documents to the BIM elements. The timeline of the process was also recorded to gain an understanding of time needed on individual equipment and per unit area basis.

INSERT FIGURE 02 HERE

4.1.1.1 Analyzing the handover PIM

Successful utilization of BIM for FM requires a reduction (or elimination) of the gap between the digital asset (the information model) and the physical asset (the as-built conditions) from both a geometrical and non-geometrical data/information point of view (Won and Lee, 2016). Thus, before developing the AIM, the quality of information of the PIM was assessd by comparing it with the handover documents and as-built conditions. This exercise highlighted a considerable amount of information was already included in the model, yet that the semantic data was mostly inaccurate. The gaps in information found included:

- **Duplicate information:** For example, there were 47 attributes associated with a domestic water heater but eight of them were redundant ones that could be eliminated. The redundant information creates confusion to the users.
- **Data that was inconsistent with handover documents:** For example, we identified 572 values associated with the pumps in the model, but only 56 of them (9.7%) were accurate according to the handover documents.
- **Missing attributes:** For example, 63 attributes of a heat exchanger were extracted from the handover documents, but only three of them existed in the model (4.7%).
- **Missing data:** For example, 32 attributes were associated with an expansion tank element, but five of them did not have any values entered. Moreover, only three of other 27 values were accurate.

As shown above, the handover PIM contained an extensive amount of information but much of it was inaccurate and therefore useless. The first task was therefore to clean out all the non-geometric data except the tag numbers.

Due to the extensive amount of non-geometric data contained in the handover model and the handover documents, a large amount of time was required to compare these two. For example, for a pump alone, a total of 200 attributes were identified from the model, and additional 70 attributes from the handover documents. As there were 60 pieces of equipment which needed to be verified, a total of 21 hours was spent identifying the non-geometric modeling gap. Moreover, most of the non-geometric information embedded in the handover model was found to be inaccurate and/or unnecessary according to the FM practices identified in the diagnostic stage. Had the handover model does not contain such unreliable data, the amount of time analyzing the non-geometric data could have been significantly reduced. In other words, no data would have been better than the data that was included in the PIM.

4.1.1.2 Extract FM-specific information from handover documents

In order to embed the correct data within the related objects in the AIM, the relevant information from the handover documents was extracted. Within this process:

- Among 304 mechanical O&M files, 49 files with 1,270 pages were related to the pilot study and had to be sorted. As the file names did not clearly reflect the information contained in them, extra time had to be spent locating the files.
- The information related to the 60 pieces of equipment was unstructured and/or structured in a nonlogical order. The files therefore had to be perused and sorted to obtain the desired information. As a result, 982 pages out of the 1,270 pages were found to be directly related to the targeted equipment.
- The 982 pages of documents were analyzed to obtain the necessary data to be embedded into the AIM. The documents had varying templates as they were provided by different vendors. Also, the descriptive nature of the information found in the documents needed to be interpreted.
- Handover documents and other datasets included different terminologies and units to describe the same type of equipment and their properties. As such, the terms and units had to be consolidated first before populating the model.
- As a result, a single list of attributes for use with all 14 types of equipment was created, which comprised a total of 544 attributes.

A total of 87 hours was spent extracting information from the handover documents. This included sorting out the related files (39 hours) and consolidating terminology and units (48 hours). This was due to the lack of consistency and the unorganized nature of the handover documents. Indeed, each supplier used different templates, terminologies, and/or units on their submittals. These challenges could have been addressed through clear guidelines and a set of standardized formats or templates provided to the subcontractors in the early phase of the project. The guidelines or templates should indicate not only the data requirements, but also the order, format (descriptive or non-descriptive), terms, and units of the data the owner needs.

4.1.1.3 Populate the PIM with the information

For the purposes of this pilot study, a proprietary modeling software was used to perform the information commissioning process. The information extracted from the previous stage was used to populate the AIM. A total of 26 hours was spent on the following activities:

- Having identified the proper information requirements, the attributes were included within the digital assets. A total of 544 attributes were included within the AIM.
- The attributes were then mapped to the appropriate type of equipment within the information model.
- Once each equipment type was assigned the appropriate attributes, the individual attribute values were populated.

4.1.1.4 Attaching the O&M files to the model

Not all properties were deemed important or useful enough to be included as values in the AIM. However, easy access to asset information being the key of BIM-enabled FM, parts of the O&M manuals were linked to their digital assets through URLs. As mentioned earlier, the O&M files were problematic because a file often contained information about multiple equipment types. Furthermore, file naming conventions were not implemented and/or not respected. It was therefore decided that separate O&M files would be recreated for each model component. This involved the following process:

- First, the O&M files were reassembled into logical packages relating to specific assets. As a result, the number of files was reduced from 49 (1,270 pages) to 30 (862 pages).
- 'Table of Contents' were included to help readers easily locate information.
- Files were renamed to be recognizable and searchable. The names consist of the type of document, the type of equipment, and the tag numbers (e.g. O&M_Boiler_B-1,2,3).
- Lastly, the files were uploaded to a cloud drive and linked to the model.

13 hours were spent recreating the O&M files and attaching them to the model. This process could have been eliminated 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 needing to do any further modification.

Below shows the time spent on each step of the information commissioning process. The breakdown of time spent per equipment (unit) and area (m^2) are also shown.

(a) analyzing the handover PIM and documents: 21 hours total (0.35 hr/unit, 0.05 hr/m^2)

(b) extracting FM-specific information: 87 hours total (1.45 hr/unit, 0.22 hr/m^2)

(c) populating the model with the information: 26 hours total (0.43 hr/unit, 0.07 hr/m^2)

(d) attaching O&M documents: 13 hours total (0.22 hr/unit, 0.03 hr/m^2)

In total, 147 hours were spent, which is 2.45 hours per equipment and 0.37 hours per m^2. The largest portion of time was required to extract the information and consolidate the terms and units of the attributes. While the data are indicative of modeling for the 400m^2 boiler room, extrapolation to the entire facility is possible.

4.3 Evaluating and Specifying Learning: Diffusing lessons learned and implementing BIM for FM (RA 5)

While the information commissioning and AIM development process took the Owner organization's legacy FM practices into account to ensure fitness-for-use, these FM practices and processes had to be adapted to suit new data-driven approaches. In piloting the use of the AIM in FM, two facility operators of the owner organization were interviewed to get their feedback.

The need for training to utilize BIM for FM is a significant factor hindering widespread adoption. The need for additional resources including proper hardware and software tools was also identified as a significant factor. The development of an accurate, complete model should not be underestimated as extensive amount of work is involved to create the AIM in the first place. The development of clear and concise asset information requirements (AIR) and exchange information requirements (EIR) is a priority to compress the information commissioning process. Moreover, the FM team needs to have confidence that the model that it is complete, verified and accurate to be useful. Equally important aspects, according to the facility operators, are model maintenance and updating, which would require dedicated BIM experts. Otherwise, the model will become outdated and lose its value down the road.

Previous case studies have reported similar challenges in the BIM for FM adoption process. These challenges include: the lack of BIM expertise within the organization, the lack of tangible benefits of BIM-enabled FM, interoperability issues, the lack of clear requirements for developing an AIM, model maintenance, and BIM software and hardware requirements and costs (Kelly et al., 2013; Kiviniemi & Codinhoto, 2014; Korpela et al., 2015).

5 Discussion and Conclusion

The research presented in this paper aimed to understand the process and efforts required to adapt a PIM at handover for FM purposes, in essence creating a fit-for-use AIM. A case study was conducted on a recently completed museum project of a large public owner organization, where BIM was used for the design and construction phases without any formal FM information requirements. To better understand the efforts required to develop and utilize the handover BIM for FM, a part of the PIM was "commissioned" into an AIM; the focus was put on a 400 sq.m boiler room. The research process included the analysis of the handover model, the identification of owner requirements, the extraction of necessary information from the handover documents, the population of the model with the appropriate information, namely the inclusion of the operation and maintenance files to the model.

An extensive amount of time and efforts were required in developing an AIM, mainly due to the improper organization of information in the handover model, the poor quality of handover documents, the lack of the document templates, the absence of the model templates, and unforeseen technical issues. Thus, to utilize handover BIM for FM in future projects, it was recommend that the owner organizations develop clear exchange information requirements, including the obligation for the contractor to "clean out" the PIMs prior to the handover and the handover documents from all suppliers/vendors to be submitted in the standardized format. In addition, the owner should develop the model attribute templates and document the technical issues in developing the AIM to avoid similar problems in the future. In this sense, Owner organizations that perform facilities management activities need to develop BIM capabilities to leverage BIM for FM. This includes BIM training for facility operators, availability of dedicated BIM experts responsible for maintaining the models, and readily available proper hardware/software support. Understandably, the transition to BIM-enabled FM practices requires the commitment of the top management to embrace for change and provide the necessary resources.

Judging from the significant level of efforts required to turn the PIM into an AIM, it is anticipated that a considerable amount of time and money would be needed to adopt BIM for future projects if the owner is not ready in terms of knowledge, planning, and resource. The potential challenges identified here are expected to support the owners in addressing these challenges on future projects. Also, the lessons learned from this study can be used as a reference to develop the owners' BIM requirements. Once the pilot project was completed, the owner understood the potential benefit of BIM for FM and decided to develop the rest of the model into an AIM. Currently, the model is almost fully developed and being ready for use in the facility management.

Limitations of the research project include the limited scope of the AIM and the information commissioning process. As the facility contains various spaces with different conditions, various parts of the model should be developed to identify other potential challenges. A broader scope of generalization could have been achieved through extension of the scope of the pilot study. In addition, the usefulness of the AIM requires further validation in justifying the efforts spent during the development process. Before populating the model with the information, the facility manager of the museum was asked to review the data to confirm its usefulness. However, useful feedback from him could not be obtained because of the time constraints, which resulted in embedding all 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, the use of the AIM in use should be validated. 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.

In this study, handover documents were used as the data source for the development of the model after the facility was handed over. In contrast, in future projects, the owner should set the BIM requirements and demand that all the involved stakeholders, including the designers, contractors, sub-contractors, and suppliers, stick with them. More pilot projects are needed to inform an organization on how to develop information requirememets for a particular project or facility that are aligned with the type, size, and use of the facility as well as FM practices. Furthermore, it is important to note that the research activities and the information commissioning were conducted by one researcher on one pilot study. Had there been more than one researcher working on the same process, the validity of the results could have been enhanced through *investigator triangulation* (Denzin, 2009).

The focus of the research reported in this paper is purely on the perspective of a large public owner organization, specifically the infrastructure arm of a provincial government in Canada. While a limitation, it is also significant as large public building owners are often considered as one of the most efficient drivers for BIM adoption by the industry at large (Cheng and Lu, 2015; MGI, 2017; Newton et al., 2009). Future research could investigate scaling the scope of the information commissioning process to an entire building. Moreover, future work could investigate the impact of having clear and targeted information requirements on the information commissioning process.

References

Abdirad, H. and Dossick, C.S. (2019), "Normative and descriptive models for COBie implementation: discrepancies and limitations", *Engineering, Construction and Architectural Management*, Vol. 26 No. 8, pp. 1820–1836.

Abel, J., Diez, K. and Lennerts, K. (2006), "A Standard Database Model for Computer Aided Facility Management in Hospitals", *Joint International Conference on Computing and Decision Making in Civil and Building Engineering*, Montreal, pp. 535–542.

Alsyouf, I. (2007), "The Role of Maintenance in Improving Companies' Productivity and Profitability", *International Journal of Production Economics*, Vol. 105 No. 1, pp. 70–78.

Asl, B. (2015), *Value Proposition of COBie at University of Washington*, University of Washington, available at: http://hdl.handle.net/1773/33675.

Aspurez, V. and Lewis, A. (2013), "Case Study 3: USC School of Cinematic Arts", in Teicholz, P. (Ed.), *BIM for Facility Managers*, Wiley, pp. 185–232.

Atkin, B. and Brooks, A. (2009), *Total Facilities Management*, *Wiley-Blackwell*, Chichester.

Azhar, S., Ahmad, I. and Sein, M.K. (2010), "Action Research as a Proactive Research Method for Construction Engineering and Management", *Journal of Construction Engineering and Management*, Vol. 136 No. 1, pp. 87–98.

Barrett, P. and Baldry, D. (2003), *Facilities Management: Towards Best Practice*, Blackwell Science, Oxford.

Baskerville, R. and Pries-Heje, J. (1999), "Grounded Action Research: A Method for Understanding IT in Practice", *Accounting, Management and Information Technologies*, Vol. 9 No. 1, pp. 1–23.

Becerik-Gerber, B., Jazizadeh, F., Li, N. and Calis, G. (2012), "Application Areas and Data Requirements for BIM-Enabled Facilities Management", *Journal of Construction Engineering and Management*, Vol. 138 No. 3, pp. 431–442.

BSI. (2007), *Facility Management. Terms and Definitions*, No. BS EN 15221-1:2006.

Cavka, H.B., Staub-French, S. and Poirier, E.A. (2017), "Developing Owner Information Requirements for BIM-Enabled Project Delivery and Asset Management", *Automation in Construction*, Vol. 83, pp. 169–183.

Cheng, J.C.P. and Lu, Q. (2015), "A Review of the Efforts and Roles of the Public Sector for BIM Adoption Worldwide", *Journal of Information Technology in Construction*, Vol. 20, pp. 442–478.

Denzin, N.K. (2009), *The Research Act: A Theoretical Introduction to Sociological Methods*, *AldineTransaction*, New Jersey.

Dettwiler, P., Bainbridge, M. and Finch, E.F. (2009), "Getting the Attention the Facilities Manager

Deserves", *Facilities*, Vol. 27 No. 7/8, pp. 277–290.

Edirisinghe, R., Kalutara, P. and London, K. (2016), "An Investigation of BIM Adoption of Owners and Facility Managers in Australia: Institutional Case Study", *COBRA*, pp. 1–10.

Edirisinghe, R. and London, K. (2015), "Comparative Analysis of International and National Level BIM Standardization Efforts and BIM adoption", *Proceedings of the 32nd International Conference of CIB W78*, pp. 149–158.

Farghaly, K., Abanda, F.H., Vidalakis, C. and Wood, G. (2018), "Taxonomy for BIM and Asset Management Semantic Interoperability", *Journal of Management in Engineering*, Vol. 34 No. 4, p. 04018012.

Ghosh, A., Chasey, A. and Mergenschroer, M. (2015), *Building Information Modeling for Facilities Management: Current Practices and Future Prospects*, *Building Information Modeling : Applications and Practices*, American Society of Civil Engineers.

Godager, B. (2011), "Analysis of the Information Needs for Existing Buildings for Integration in Modern BIM-Based Building Information Management", *International Conference on Environmental Engineering*, pp. 886–892.

Goedert, J. and Meadati, P. (2008), "Integrating Construction Process Documentation into Building Information Modeling", *Journal of Construction Engineering and Management*, Vol. 134 No. 7, pp. 509–516.

Hossain, M.A. and Haron, A.T. (2018), "Intelligent BIM Record Model for Effective Asset Management of Constructed Facility", *MATEC Web of Conferences*, Vol. 195, p. 06004.

Hossain, M.A. and Yeoh, J.K.W. (2018), "BIM for Existing Buildings: Potential Opportunities and Barriers", *IOP Conference Series: Materials Science and Engineering*.

IFMA. (2013), *BIM for Facility Managers*, edited by Teicholz, P., John Wiley & Sons, New Jersey.

Jung, J., Hong, S., Jeong, S., Kim, S., Cho, H., Hong, S. and Heo, J. (2014), "Productive Modeling for Development of As-built BIM of Existing Indoor Structures", *Automation in Construction*, Vol. 42, pp. 68–77.

Kassem, M., Kelly, G., Dawood, N., Serginson, M. and Lockley, S. (2015), "BIM in Facilities Management Applications: A Case Study of a Large University Complex", *Built Environment Project and Asset Management*, Vol. 5 No. 3, pp. 261–277.

Keady, R. (2009), "Financial Impact and Analysis of Equipment Inventories", *Facilities Engineering Journal*, Vol. 27 No. 5, pp. 13–17.

Kelly, G., Serginson, M., Lockley, S., Dawood, N. and Kassem, M. (2013), "BIM for Facility Management: A Review and a Case Study Investigating the Value and Challenges", *International Conference Applications of Virtual Reality*, pp. 30–31.

Kiviniemi, A. and Codinhoto, R. (2014), "Challenges in the Implementation of BIM for FM Case Manchester Town Hall Complex", *International Conference on Computing in Civil and Building Engineering*, pp. 665–672.

Korpela, J., Miettinen, R., Salmikivi, T. and Ihalainen, J. (2015), "The Challenges and Potentials of Utilizing Building Information Modelling in Facility Management: The Case of the Center for Properties and Facilities of the University of Helsinki", *Construction Management and Economics*, Vol. 33 No. 1, pp.

3–17.

Lavy, S. and Jawadekar, S. (2014), “A Case Study of Using BIM and COBie for Facility Management”, *International Journal of Facility Management*, Vol. 5 No. 2, pp. 13–27.

Lewin, K. (1946), “Action Research and Minority Problems”, *Journal of Social Issues*, Vol. 2 No. 4, pp. 34–46.

Lijun, S., Edirisinghe, R. and Goh, Y.M. (2016), “An Investigation of BIM Readiness of Owners and Facility Managers in Singapore : Institutional Case Study”, *CIB World Building Congress*, pp. 259–270.

Lin, Y., Chen, Y., Huang, W. and Hong, C. (2016), “Developing the Framework of BIM Execution Plan for Facility Management”, *ICCCBE*, pp. 782–789.

Liu, R. and Issa, R. (2015), “Survey: Common Knowledge in BIM for Facility Maintenance”, *Journal of Performance of Constructed Facilities*, Vol. 30 No. 2010, p. 4015033.

Liu, R. and Issa, R.R.A. (2013), “Issues in BIM for Facility Management from Industry Practitioners’ Perspectives”, *ASCE International Workshop on Computing in Civil Engineering*.

Lucas, J., Bulbul, T. and Thabet, W. (2013), “An Object-oriented Model to Support Healthcare Facility Information Management”, *Automation in Construction*, Vol. 31, pp. 281–291.

MGI. (2017), *Reinventing Construction: A Route To Higher Productivity*, *McKinsey & Company*, available at: http://www.ceo-na.com/business/management-leadership/china-leading-gains-construction-productivity/.

Newton, P., Hampson, K. and Drogemuller, R. (2009), *Technology, Design and Process Innovation in the Built Environment*, Taylor & Francis, New York.

Patacas, J., Dawood, N., Vukovic, V. and Kassem, M. (2015), “BIM for Facilities Management: Evaluating BIM Standards in Asset Register Creation and Service life”, *ITcon*, Vol. 20 No. January, pp. 313–331.

Roelofsen, P. (2002), “The Impact of Office Environments on Employee Performance: The Design of the Workplace as a Strategy for Productivity Enhancement”, *Journal of Facilities Management*, Vol. 1 No. 3, pp. 247–264.

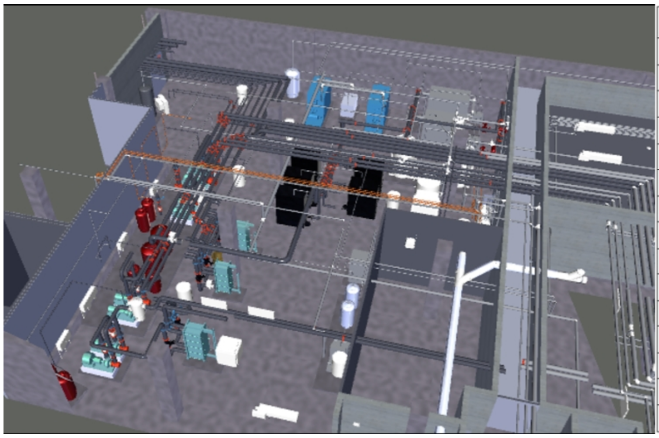
Sabol, L. (2008), “Building Information Modeling & Facility Management”, *IFMA World Workplace*, Dalas, pp. 1–13.

Tzedaki, V. and Kamara, J. (2013), “Capturing As-Built Information for a BIM Environment Using 3D Laser Scanner: A Process Model”, *Architectural Engineering Conference*, pp. 486–495.

Volk, R., Stengel, J. and Schultmann, F. (2014), “Building Information Modeling (BIM) for Existing Buildings - Literature Review and Future Needs”, *Automation in Construction*.

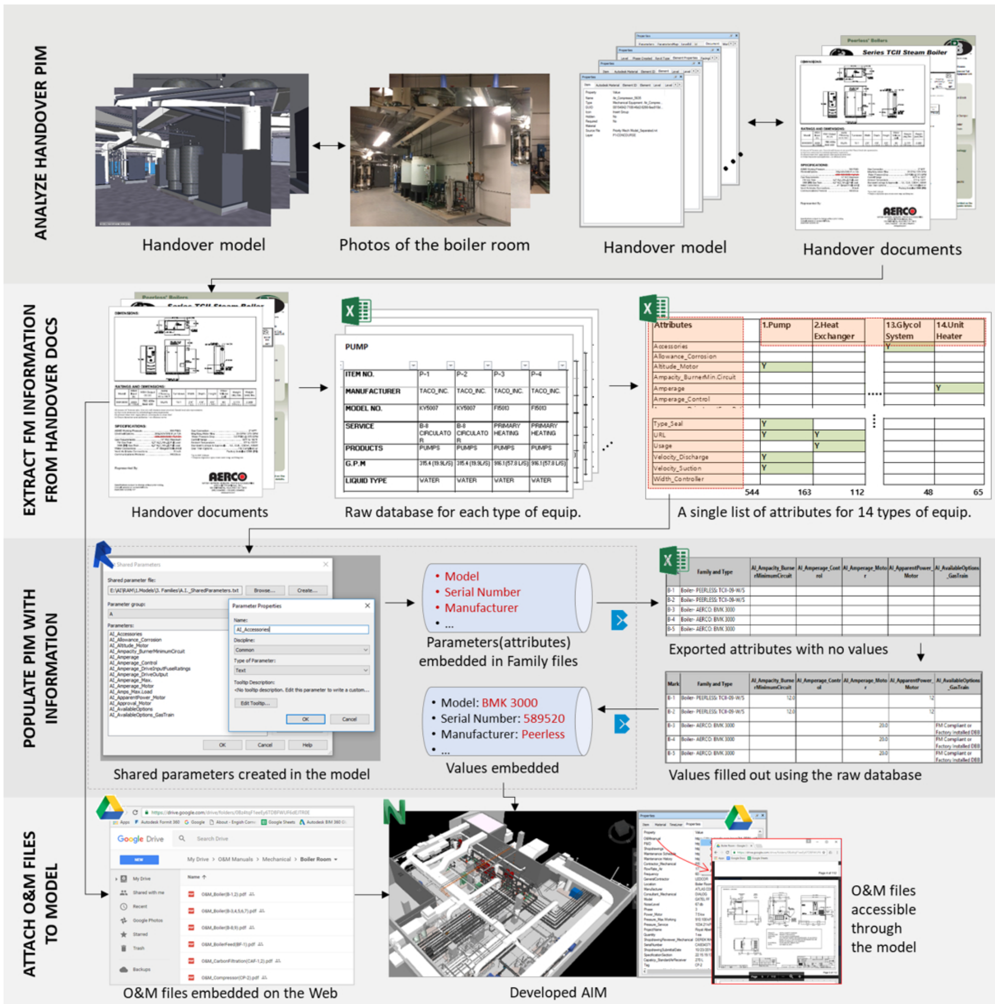
Wetzel, E. and Thabet, W. (2015), “The Use of a BIM-based Framework to Support Safe Facility Management Processes”, *Automation in Construction*, Vol. 60, pp. 12–24.

Won, J. and Lee, G. (2016), “How to Tell if a BIM Project is Successful: A Goal-driven Approach”, *Automation in Construction*, Vol. 69, pp. 34–43.



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**

PIM of the boiler room with mechanical equipment



Information commissioning process to adapt a PIM and develop an AIM