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Article

Evaluating the Alignment of Organizational and Project Contexts for BIM Adoption: A Case Study of a Large Owner Organization

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Abstract: Building information modeling (BIM) has been presented as a potential solution to current facilities management problems related to information exchange during handover, and facilities information management during operations. However, implementing BIM in an owner organization is a complex challenge that necessitates reconfiguration of work practices and internal structures to fully realize the benefits. Owners are often unsure about how or whether they should go through the challenges related to implementation. Although previous studies have documented the potential benefits of BIM adoption for owners, such as improvements in work order processing, very little research has specifically looked at the transition to BIM and the scale of the effort required for large and diverse owner organizations. This paper presents the results of a long-term embedded case study analysis of a large owner-operator institutional organization that investigated the alignment of facility management (FM) practices across organizational and project contexts. The research objective was to examine current organizational practices in order to understand the potential, as well as the challenges, of transitioning from a paper-based to a model-based approach in handover and operations. We describe the current state of handover, information management and facility management practices and developed a framework to characterize the alignment between organizational constructs, available technology, project artifacts and owner requirements. This investigation of the current state of practice enables us to understand the gap between available and required information, processes and technology, and to better understand the enormous challenges owners face when considering the transition to BIM.

Keywords: building information modeling (BIM); facilities management (FM); handover; information management; alignment

1. Introduction

The handover of a building and its asset information upon completion of a project is a critical step for owners. It is at this stage that the owner gets all of the relevant information about the facility to support operations and maintenance (O&M) throughout the facility's life cycle. The quality, efficiency, and reliability of the information handover process are therefore critical for facility managers to achieve the performance, sustainability and economic requirements of facility operations. The operational phase of a building represents as much as 80% of the total cost of ownership [1] so these are considerable economic and environmental concerns for building owners. Information handover practices, however, are often inefficient and error-prone which limit the utility of facility information and hinder the performance of O&M during the operations phase. Previous studies and our own observations confirm that handover and facility management practices suffer from numerous challenges, including:

- Poor information fidelity: Submitted handover artifacts contain errors, and the traditional approach requires huge additional investment of resources to correct the artifacts to a sufficiently high level of accuracy [2]. When up-to-date information is missing, additional costs are incurred due to searching, validating and recreating information [3].
- Poor interoperability: The format of handover information is inadequate, not allowing others to use information effectively [4], and it does not lend itself to everyday use, and contains information in a format that is not conducive to computerized analysis [5]. Inefficient interoperability cost the construction industry more than $15.8 billion a year [6]. Two-thirds of this cost is borne by owners/operators, and 85% of owners' and operators' interoperability costs are incurred during the O&M phase [6].
- Poor building and maintenance performance: Sustaining an increasing number of buildings and rising energy consumption levels rests largely on the possibility of maintaining and operating increasingly sophisticated building equipment, and increasingly complex, and inter-dependent building systems. In current practice, there is little or no systematic correlation between design intent and building operation [5], and buildings are not performing as expected. Eighty-five percent of complaints related to comfort and high energy consumption are caused by handover of heating, ventilation, and air conditioning (HVAC) systems and maintenance issues [7].

Building information modeling (BIM) has the potential to address these challenges by providing a data-rich, non-redundant information repository of facility information that is capable of supporting a broad range of FM functions. BIM has long been claimed to bring significant benefits to FM to "*improve a buildings' performance and manage operations more efficiently throughout their life-cycle*" [8]. Many studies have documented the potential benefits of BIM in terms of reducing redundant data collection and data re-entry [9], enabling better information exchange between project phases [10], supporting certain O&M functions, such as work order management and space planning [3,11], and improving access to information during operations [12]. Progressive owners have also recognized the potential for capturing the information needed to fine-tune building system performance, establish appropriate maintenance practices and schedules, and evaluate the feasibility of proposed expansions or renovations [3].

Despite these numerous benefits and the increasing availability of design and construction BIMs, the use of BIM during building operations remains significantly limited with very few owner organizations adopting BIM. The reality is that implementing BIM in large owner organizations is a complex challenge. Each owner organization is a complex structure of departments, processes, cultures, networks of systems and databases that are used to support functions, which are performed by people from different backgrounds and with different information needs. There is also little hard evidence of the benefits of BIM in operations and maintenance activities [13], there is a lack of real life case studies on BIM in FM [14], and the changes in work practices involved in shifting from traditional FM practices to BIM-based practices are not well-known [15].

The goal of this research was to better understand what is involved in the *transition* from a paper-based approach to a BIM-based approach in handover and FM information management. We performed a long-term multi-year embedded case study analysis of the work practices of a large owner-operator institutional organization. We investigated the alignment of FM practices across the *organizational* and *project contexts* in relation to the owner's *requirements*. This case study is unique in terms of the richness of the data collection and analysis methods used, the research approach investigating alignment across two interrelated contexts at the organizational and project level, and the focus on information in terms of understanding how facility information is informed by and affected by the organizational processes, technology and requirements. This rich case study contributed to the development of a framework to characterize alignment between organizational constructs, available technology, project artifacts and owner requirements as a means to better understand the mechanisms required to transition from traditional to BIM-enabled FM practices.

The next sections describe the methodology and the literature review. Subsequent sections focus on the case study and the analysis of alignment across the organizational and project contexts.

2. Methodology

In this research we performed a long-term case study analysis of the University of British Columbia (UBC), a large owner-operator organization that operates and maintains its infrastructure using its own workforce. UBC's Building Operations Department is responsible for 225 core University-owned buildings, with a total floor area of 810,119 gross square meters. We specifically focused on the Building Operations Department responsible for O&M of educational buildings within UBC. According to the Whole Building Design Guide, O&M "*typically includes the day-to-day activities necessary for the building and its systems and equipment to perform their intended function*". O&M covers a number of FM functions but the focus of this research was on asset management, maintenance management, records management, and facility information management.

We used different methods to gather information on UBC and developed a deep understanding of the owner organization's current FM practices from three distinct perspectives: (1) the organizational context; (2) the owner requirements; and (3) the project context (Figure 1), as described below.

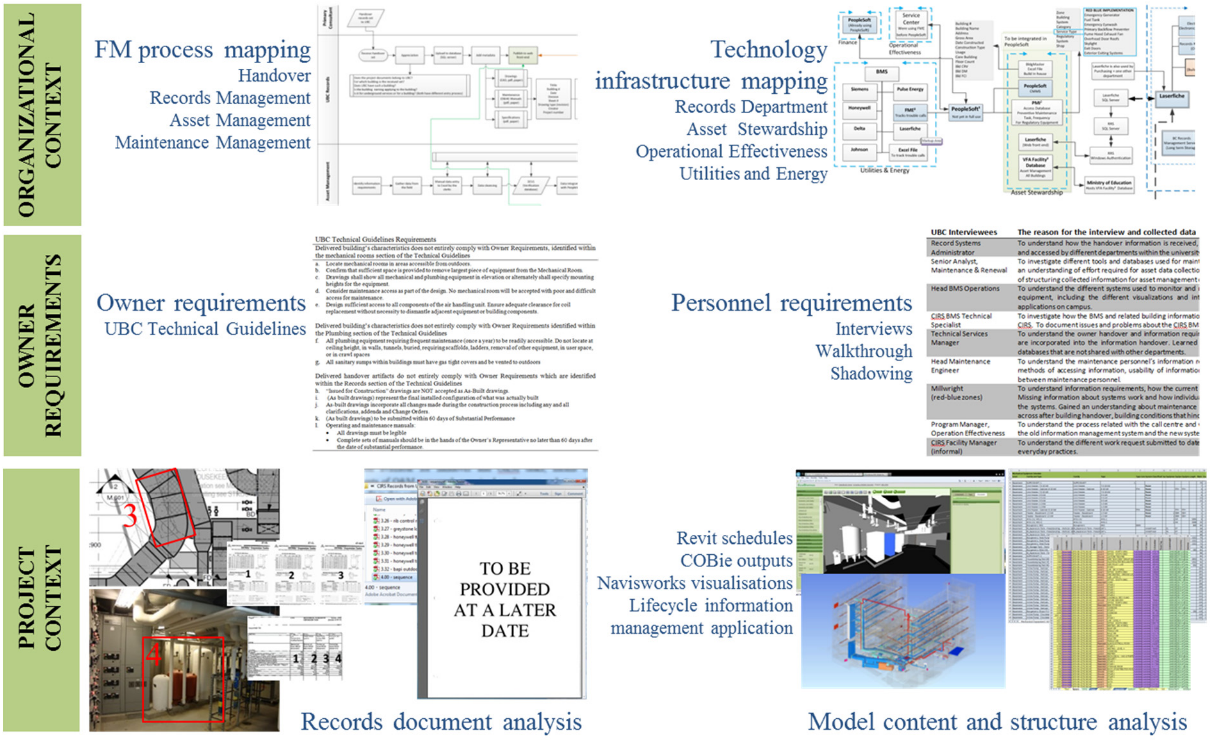


Figure 1. Overview of different methods used during data collection and analysis.

2.1. Organizational Context

The organizational context refers to the characteristics of an organization and its alignment with BIM-based data and processes. In order to understand the organizational context, we investigated numerous FM functions including building and information handover, records management, asset management, and maintenance management, as well as the technology infrastructure according to the organizational departments it supports (Figure 1). Mapping FM processes helped to understand the current practice, identify the bottlenecks and inefficiencies, and evaluate possible BIM implementation areas to eliminate bottlenecks or improve performance. Mapping technology infrastructure of applications, databases and information kept within these databases helped us understand the infrastructure available to support information flow within the organization, identify the silos of information in departments. Investigation of the organizational context helped us understand the processes utilized to perform O&M tasks, technology infrastructure available to support processes, the organizational structure, and the information flows across the organizational network. As a result of investigation of the organizational context we developed an understanding of the reasons behind the gap between what is currently available and what is required to overcome the current challenges and inefficiencies. We discuss the current organizational context further in Section 4.1.

2.2. Requirements

2.2.1. Owner Requirements

We investigated the UBC technical guidelines documents to understand owner requirements for system design, performance, and installation, and also requirements for handover process and handover information content. This led to a better understanding of the gap between what was required and what was delivered at the end of construction.

2.2.2. O&M Personnel Requirements

We conducted, transcribed, and analyzed 12 interviews with nine different people within the Building Operations department to understand current processes, available technology to support these processes, and information requirements of different personnel in the organization. We performed and documented CIRS project walkthrough to identify operational and maintainability problems and to evaluate the maintainability of CIRS mechanical systems and equipment. We shadowed a millwright during his daily routine to understand how service requests are handled, how the maintenance work is performed, and what information and tools are available to complete work. We also identified personnel requirements regarding the technology for accessing information.

We analyzed technical guidelines documents, and performed interviews, walkthrough and shadowing activities to understand FM processes, available and required information, and available technology for managing information. We discuss the owner and O&M personnel requirements further in Section 4.2.

2.3. Project Context

We performed an embedded case study on UBC's Center for Interactive Research on Sustainability (CIRS) building project to understand building information handover, O&M processes, and building information and records management at the project level. We discuss the project context further in Section 4.3.

2.3.1. Handover Documents

We analyzed CIRS project handover documents which consist of 2D drawings, manuals and specifications. We investigated the accuracy and completeness of the handover documents compared to the as-built conditions. We investigated the consistency of information between drawings, manuals, and specifications. We investigated handover documents' accessibility and reusability within the organizational technology infrastructure.

2.3.2. Building Information Model

We analyzed BIM project models from several projects to understand the model content and structure for current design and construction BIMs. This process involved investigating the model content for availability of the geometric and non-geometric information required by the owner and the O&M personnel (*i.e.*, investigation of availability of AHU geometry and required attributes about AHU, such as air filter information). We also investigated the model structure to understand the model characteristics that enable accurate and efficient information exchange with FM information management tools (*i.e.*, equipment-system-space relationships within the model). During model content evaluation, we used Revit schedules, COBie outputs using the Revit COBie Toolkit, the Ecodomus life cycle information management tool, and Navisworks visualizations. We investigated the model outputs to evaluate model information availability and available information's reusability by the owner. More specifically we evaluated the alignment of the model context with organizational processes and technology infrastructure, and its compliance with owner and personnel requirements.

3. Literature Review

The main areas of knowledge covered in this research are the organization (Section 3.1), requirements (Section 3.2), and handover artifacts (Section 3.3).

3.1. Organization

Developing an understanding of the flow of information within the organization is essential when evaluating how BIM implementation may potentially affect the information flow between departments, between operations personnel, and between the owner and the consultants. McAuley, Duberley, and Johnson [16] state that as organizations become more complex, there is a greater need for information flow between the different parts of the system. According to McAuley *et al.* [16], two sorts of information become highly important as the organizations become more complex: (1) information from the external environment (external information that feeds in to the organization) and (2) information flow internal to the organization (department to department or between levels of management). As the organization goes through processes of change, the flow of information must be controlled. A sophisticated IT network provides both information and control. Schulz's [17] study of, how organizational learning in subunits affects outflows of knowledge to subunits, suggests that collecting new knowledge intensifies vertical flows of knowledge, codifying knowledge facilitates horizontal and vertical flows, and combining old knowledge mainly affects horizontal flows.

Owner organizations need to adapt to a changing market in which information management and integration are becoming increasingly important, and BIM implementation is currently being suggested as an enabler to reach this goal. In the absence of clear strategy and the kind of cultural climate required to compete in both the current market and also in a market that is changing according to developing technologies, organizations may fail to harvest benefits [18]. This implies that organizations should develop clear strategies and consider adjustments to their cultures to be able to harvest benefits from BIM adoption. This requires an understanding of how to manage changes in strategy and culture according to what is required by BIM implementation. Developing interest in BIM within the institutional market can be linked to institutions that have already started leveraging BIM for handover and O&M. Peppard and Breu [19] state that:

> "*Organizations do not lead isolated lives but, instead, are linked inextricably with others. The success of one organization may, thus, be as much a function of what other organizations do as what the organization itself does.*"

Shiem-Shin Then [20] points out that initial preoccupation with tasks and functions in FM has given way to an emphasis on processes and resources and their management. In order to keep strategic advantage or to be able to compete in the changing market, universities may feel the need to reshape their organizational and technological infrastructure and processes.

A number of recent research efforts addressed challenges, bottlenecks and implications in the implementation of BIM for FM in the operations stage [15,21], or investigated more specific issues such as BIM integration with maintenance information systems [22], the role of FM in developing data for handover at project completion [23], or value of BIM in managing spaces [14]. However, the aforementioned references use interviews with project participants [23], with participants from the demand and supply side of the construction industry [21], with properties and facilities department of the University of Helsinki personnel [22] as the main source for data collection. Kiviniemi and Codinhoto [15] map FM services, map as-is and to-be process of reactive maintenance and do a comparative analysis of current and future BIM enabled states.

Organizational process and technological changes come with challenges such as the use of technology by operators and trades people, as studied by [24] and [25]. Anderson, Marsters, Dossick, and Neff [24] studied COBie and BIM implementation challenges, including complex data and software structures in organizations, organizational distributions, and problems with use of technology by operators and trades people. Their study points out that in the case of maintenance and alterations crews, people rather than information technology have traditionally been central to the flow of tacit knowledge; besides which, these crews are often not trained to use technology in daily practices. The study asks the question of how to develop information retrieval systems for construction that efficiently provide information to non-technical staff whose primary job is not computer-oriented. The answer to such questions is sought in studies such as ECO's building operator scoping study [25], in which the mechanisms necessary to assist building operators in adapting to the requirements of a sustainably built and operated environment are identified. We found similar issues and challenges during our study and we expand on this and provide rich examples to illustrate and give meaning to such challenges.

While organizations are affected by changes in technology and new processes, acceptance of that technology differs amongst organizations. Brooks and Lilley [26] suggest that "*understanding the organization at both the strategic business and operational levels is the key to deploying appropriate technology*". According to Brooks and Lilley, establishing an initial understanding of the characteristics and nature of the problem and then matching that with tried and tested solutions would help technology deployment. Although the nature of the handover and FM information management problems can be understood, deployment of BIM for FM is still a complex problem, because there is currently limited documentation on the use of BIM solutions in the FM literature.

3.2. Requirements

Defining and formalizing the information required by FM personnel is an essential step in BIM implementation. Various people working within an organization require different sets of information to perform their tasks. Although the sets of FM information provided in Table 1 is not exhaustive; the table represents the variety of information required for FM functions and by O&M personnel. It is essential for O&M personnel to access required information in order to operate and maintain equipment and systems in buildings efficiently and effectively, to extend the service life of equipment, to optimize maintenance activities, to achieve energy efficiency, and to minimize labor time and downtime.

3.3. Handover Artifacts

There are a number of issues with the current handover artifacts that are submitted to the owner at the end of construction, and utilization of these artifacts during operations. Eastman, Teicholz, Sacks and Liston [27] describe the loss of facility documentation value during the handover across project phases and increased effort to produce project information. East and Nisbet [2] found that 30% (estimated) of the content of document-based O&M manuals contain some type of error. East and Brodt [4] describe problems with the current procedure for construction handover documents, including the errors introduced when a construction coordinator is tasked with the task of creating and collating information created by others, and that deliverables prepared at the end of the construction contract time ends up being less than satisfactory. Currently, there is no single standard that addresses all of the general building industry's handover requirements [3]. The format of the current handover information is inadequate to reuse by others and not conducive to computerized analysis [4,5,10].

It is imperative to align work processes and software tools to produce and deliver required handover information [3]. According to Au [28], the consistency, continuity, and traceability of BIM have the potential to greatly reduce design re-invention, re-doing, and re-creation during different phases of building life cycle and applications. Fallon and Palmer [3] explain the correlation between longevity and reusability of handed-over information according to information structure. According to Fallon and Palmer [3], standard and structured handover information is the most reusable handed over information and has the most longevity whereas proprietary and unstructured information is the least reusable with the least longevity. However, current handover information is not structured and not reusable. A study [12] based on online survey among facilities operations personnel showed that better access to O&M information was the highest-ranked perceived benefit of BIM, followed by integration with asset management systems, a centralized location for information, and 3D visualization.

Among different approaches to structuring data for better handover information exchange, the COBie approach has been tested on a number of projects using different software, with promising outcomes. COBie reduces the time and effort that the facility management personnel spend on entering building information manually. COBie can use the information extracted from BIM over the project life cycle through various information exchange mechanisms. Information that is not represented in BIM has to be manually entered into COBie. A COBie file can also be created without using BIM. There are other approaches for structuring building objects in data models but COBie has been tested and evaluated in the industry in recent years with promising efficiency results in transferring information to computerized maintenance management systems (CMMS). Over the last 6 years, COBie case studies were performed by BuildingSmart to investigate how to (1) reduce inefficiencies from commissioning to FM (e.g., decreasing commissioning time and reducing data entry time to databases), (2) increase data quality and quantity, (3) gather and store useful information efficiently, (4) make information more accessible, (5) create a consistent work order (WO) process inside CMMS and help reduce work order cycle time, and (6) link as-built data to 3D to visualize building information. Sandia National Labs published a study in 2010 that demonstrated they could save $2.4M per year just by linking BIM to their WOs, resulting in a savings of $0.34 per square foot [11]. These studies demonstrate the promise of BIM and COBIE in particular which can be achieved when an organization implements BIM. This paper is complementary to these efforts in that we wanted to better understand the scale of effort involved in the transition to BIM, specifically looking at the challenges and benefits in getting to that level of implementation.

Table 1. Facilities management (FM), and operation and maintenance (O&M) information requirements from the literature.

Information Category	Required Information
Most important facility information categories [29]	Floor plans, design standards and criteria, design drawings, design specifications, as-built drawings, materials and components used, shop drawings, operation and maintenance manuals, equipment model and type, equipment manufacturer, equipment capacity, warranty information, condition of equipment and facility, equipment location, utility information, maintenance records, building description.
Key content for facility documentation [30]	Wall locations, door locations, room identification, furniture layout, light fixtures, finishes, mechanical systems, electrical systems, equipment identification and location, cut-off locations, distribution capacity, design rationale.
Non-geometric data requirements [13]	ID and name, service zone: site, building, floor, room, zone. Group and type based on industry standards, or organization-specific categories. Manufacturer/vendor data: manufacturer, model, serial number, acquisition date, vendor, warranty expiration date, warranty usage Specifications such as type, unit, value, lower and upper limits, and description and attributes such as weight, power, energy consumption, spare parts. Operation and maintenance data: activity status, maintenance status, maintenance history, space occupancy data.

4. Data Collection across Organizational and Project Contexts

This section presents the data collected from the embedded case study of UBC that investigated handover and FM practices across the organizational (Section 4.1) and project (Section 4.3) contexts and in relation to the owner requirements (Section 4.2).

4.1. Organizational Context

UBC is a large 405 hectare campus with over 200 buildings that employs a staff of 700 building operations personnel including trades, custodians, laborers, project managers, professional engineers, architects and management staff. The technology infrastructure is equally complex. We mapped the technology infrastructure and departments to identify the network of tools and databases used for managing information to support FM functions (Figure 2). This section will describe the processes and tools used to support different FM functions. Specifically, this section describes the current handover, records management, asset and maintenance management processes through the evaluation of organizational constructs, work practices, and available technology. For each sub-section, we first describe the FM process and available supporting technology, and then provide a critique of the process and technology.

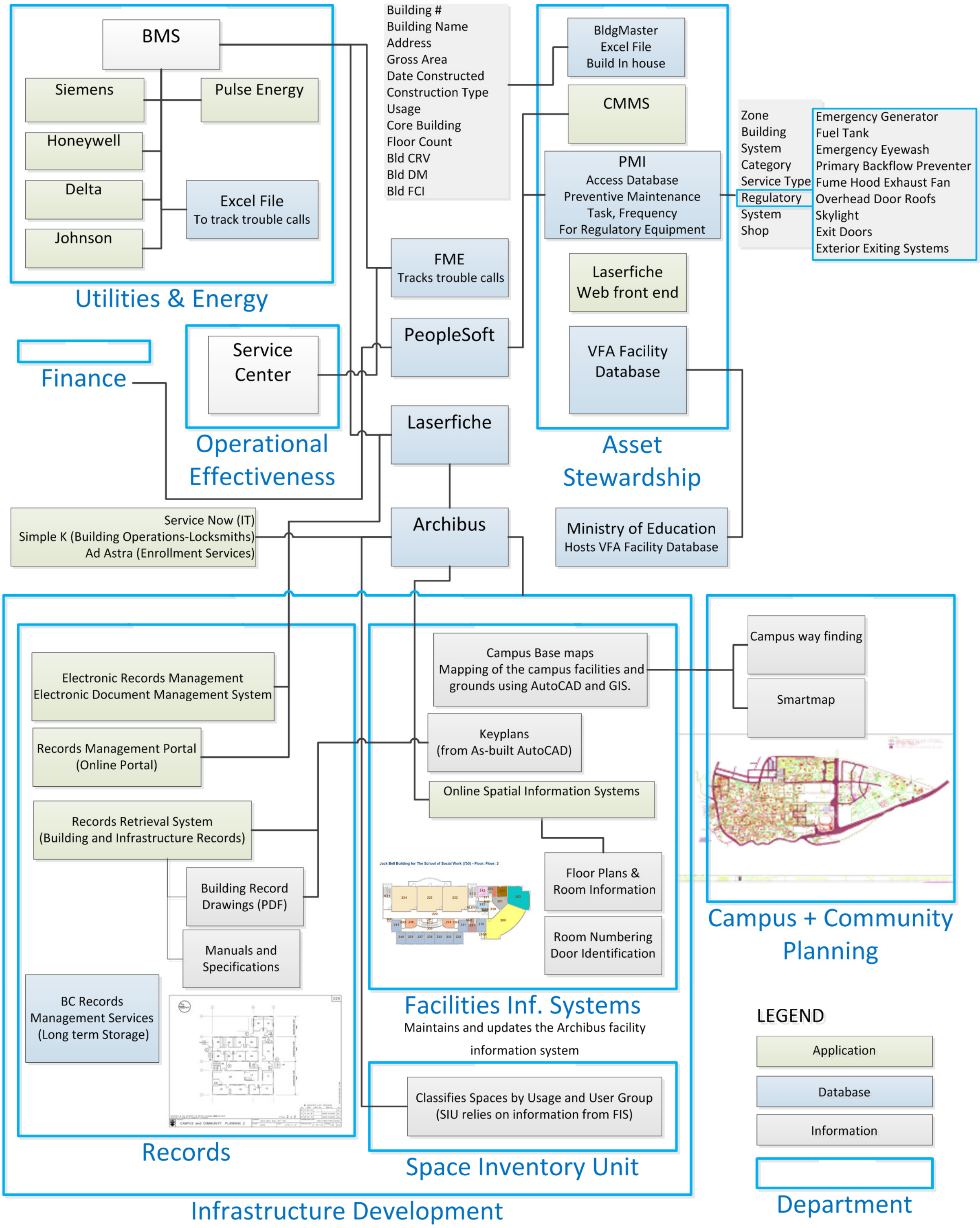


Figure 2. Overview of UBC's technology infrastructure illustrating the complexity and fragmentation of available tools to manage FM information, and the departmental silos.

4.1.1. Building and Information Handover Process

The "handover" process involves the transfer of the building and the building information to the owner after completion of construction. Building occupancy follows the substantial performance, after the completion of construction, commissioning and required testing. The technical guidelines state that the as-built documentation and specifications should be submitted within 60 days of substantial performance. AIA defines substantial completion as the stage when the building is "*sufficiently complete in accordance with the Contract Documents so that the Owner can occupy or use the Work or a portion thereof for its intended use*". The architect, as the owner's representative, often gathers the required document set from the main consultants and the general contractor before the handover. According to UBC technical guidelines, a building should be turned over to UBC Plant Operations 2–4 weeks after occupancy. The Building Operations Department takes over the O&M of educational buildings on campus. The Student Housing Department is responsible for the O&M of the student residential buildings.

Although the handover process and requirements are documented in the technical guidelines, they do not guarantee that the tasks within the process completely meet the requirements. One records system administrator working for the Records Department emphasized the untimely delivery of the handover information, saying they receive the handover set simply "*when it shows up*", (records system administrator, personal communication). A complete set of required handover documents is often not delivered to UBC at the start of occupancy. For example, occupancy for the CIRS building was granted in August 2011, building inhabitation began in September 2011, and the testing balancing report dates March 2012. O&M personnel we interviewed stated that the current commissioning practice fails to produce building systems performance information in required detail. Rather than identifying performance benchmarks for equipment and systems in different performance settings, the commissioning process is often based on checking whether installed equipment or systems work. Not having a clearly defined time of handover creates ambiguity regarding who is responsible for addressing these issues during the early operations phase. Describing complications related to not having a true handover date, the UBC Program Manager for operational effectiveness reported:

> "*We never know if we are responsible for the building, if something is under warranty, should we be attending those calls or it should be somebody else?*" (Program Manager for Operation Effectiveness)

In terms of the problematic commissioning and handover process, one BMS specialist reported that there:

> "*…doesn't appear to be any real true handover date. You might have one thing handed over at one point and something else at a different time… As I mentioned our water system [sic] still aren't commissioned yet here. So that's been a year since it opened or pretty close to a year now.*" (BMS Specialist)

Although the timing of handover is defined contractually and the submission of the records set is one of the prerequisites for final payment from the owner, this does not guarantee that handover documents will be submitted completely on time, with the required quality, or in a reusable format. Even if the required documents are handed over to the owner on time, they often lack useful information because of the processes used to produce them. Although the UBC technical guidelines outline the requirements for project documentation, the evaluation criteria for handover sets are not yet formally defined. As a result, any problems with the handover set are realized during the operation phase. The manager of technical services explained the reasons behind the limited review process utilized for design concept drawings and specifications as: "*we don't have the resources to review the designs in depth to check the design details. That's the responsibility of the contractor and the consultant.*" (Manager of Technical Services)

4.1.2. Records Management Process and Technology

Once UBC receives the handover set, the Records Department adds structure and metadata to the submitted documents to make the building information searchable. Structured handover information about buildings on the campus is accessed through the records retrieval system in UBC. A project's handover set mainly consists of consultants' drawings, manuals and specifications in paper and digital (pdf) formats. The process related with readying received records documents is represented in Figure 3. Once the project drawings are handed over, the Records Department personnel manually add structure and metadata to the drawings according to UBC naming conventions and drawings' content. Meta data for a submitted drawing includes information that can be found on the drawing legend such as the specific building number, consultant ID, drawing number, and drawing title. This enables the drawings to become searchable on the record retrieval system and accessible by the users (Figure 4). According to the Records Systems Administrator:

> "*…we create the structured data. We get unstructured data, and we create a structured data environment around it… Having that structure beforehand would be fabulous.*" (Record Systems Administrator)

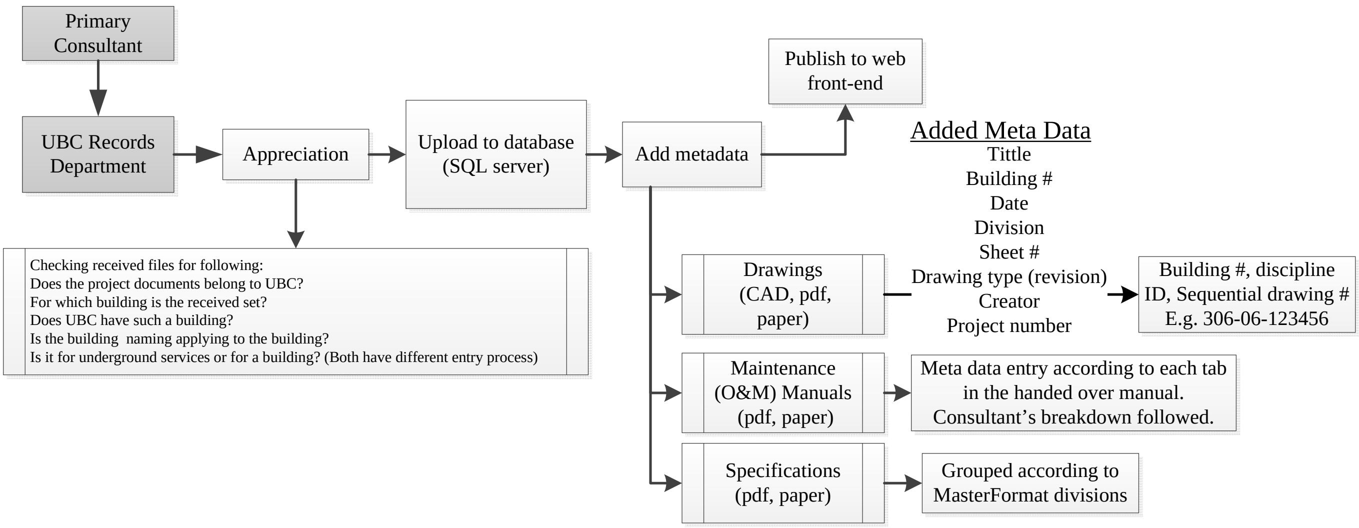


Figure 3. Process related with readying received records documents for users.

When the building construction is completed in phases, UBC receives handover documents at the end of each phase. In such cases, determining the actual handover date becomes a problem. When separate sets of information about a project are handed over to the owner, managing handover information, such as naming and structuring documents from different phases of the same project, becomes problematic. For example when a building is handed over in phases, a consultant that produces drawings for one phase may end up duplicating room names used in the previous phase's documentation.

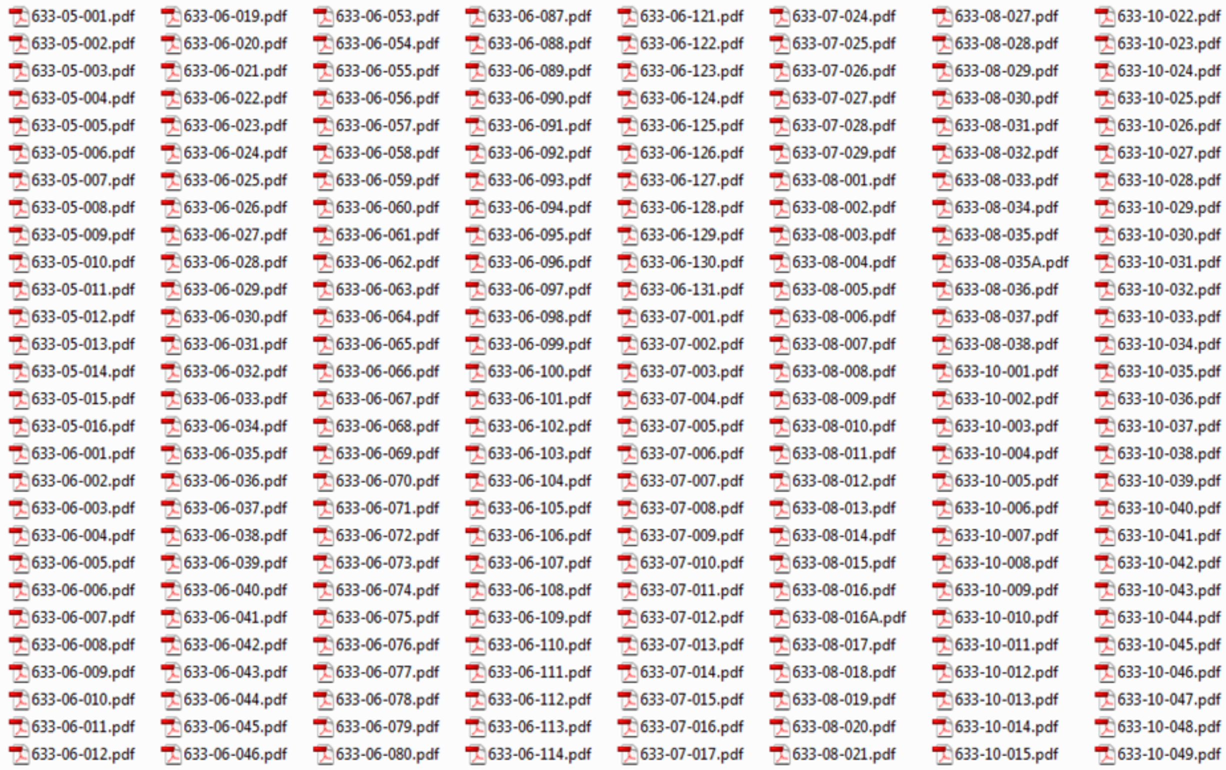


Figure 4. Handed over pdf drawings are structured according to UBC naming conventions and drawings' contents to make them accessible on the record retrieval system.

The handover artifacts that are accessible from the records retrieval system can be hundreds of pages long, and sometimes consist of poor quality or even illegible scanned pages. For example, the O&M manual for the CIRS project's mechanical systems was handed over to the owner in two pdf files—the first file consisted of 635 pages and the second file consisted of 727 pages. When the an O&M personnel is looking for information using the records retrieval system, the manuals can be viewed one page at a time which makes it extremely difficult to access information efficiently (Figure 5). Information represented in scanned documents can only be viewed on the screen; cannot be reused (copy and paste information from documents), and users cannot perform word searches within these documents. The O&M personnel we interviewed require quick and easy access to reusable information. The head of mechanical maintenance/projects reported during our interview that sometimes it is frustrating to look for required information using the records retrieval application, and he expressed the shortcomings of the current technology:

> "*We used to have all the books in our library, all the maintenance manuals, and you could go to that, flip through it really fast to that section, and if it wasn't there, sometimes you flip through the rest of the book and you would find it in the oddest places. With [current retrieval system] I find it really frustrating, because you only see one page at a time, and you can't flip quite fast. It takes a while time to use and plus I find the way they got it set up hard to see.*" (Head of Mechanical Maintenance/Projects)

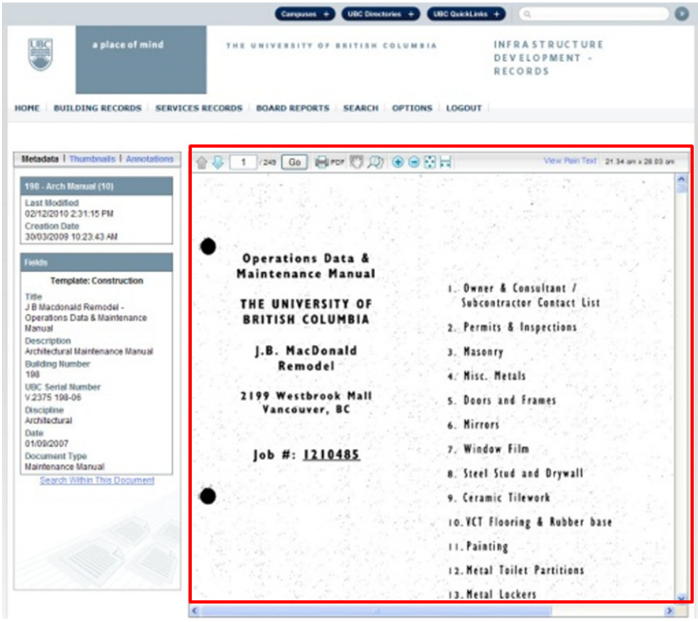


Figure 5. Handover documents that are hundreds of pages long can be viewed only one page at a time by using the records retrieval system.

Regarding accessibility of information, the records system administrator we interviewed admitted that rather than the capability of the records retrieval system, it was his familiarity with the drawings that enabled him accessing required information:

> "*I have spent a lot of years, almost seven years now looking through the drawings; I am pretty good at it. But that is more about familiarity with the drawings than it is with the software…*" (Records System Administrator)

4.1.3. Asset Management Process and Technology

UBC performs a periodic maintenance program on regulatory equipment and systems. When our data collection started information required for asset management was stored in and accessed from a number of applications such as PMI (preventive maintenance for regulatory equipment, VFA Facility (database hosted by Ministry of Education), an excel file containing required information on campus buildings, and records management application (Figure 6).

UBC implemented a database of system and equipment information for campus buildings in 2014, which is currently the integrated information source for most FM functions, such as trouble call management, and maintenance management. To populate the database, O&M personnel collected asset information from existing buildings. It took UBC a period of one year to collect information about 20,000 items (components, systems) within about 175 existing buildings. Three clerks worked about three months to enter information manually into the database (Figure 7). Entering collected information into the right database fields require a level of familiarity, knowledge and expertise about systems, equipment and buildings. Information entered into the database by clerks needs to be validated continuously for consistency and accuracy, because data collection from the field is based on personal interpretation regarding nomenclature and attributes required.

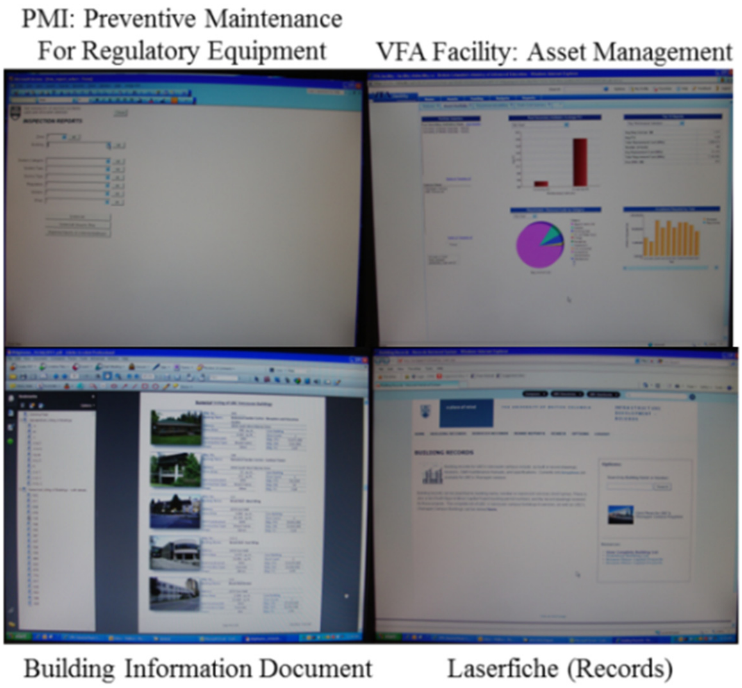


Figure 6. A number of applications have to be used together to make informed decisions for asset management within the Asset Stewardship Department.

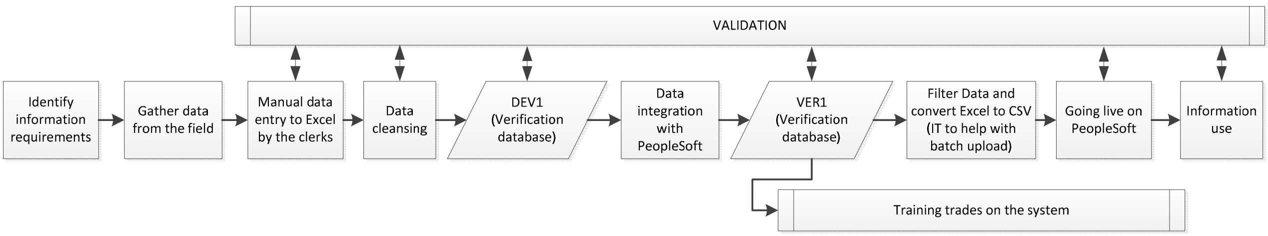


Figure 7. Process of gathering data from the field and populating asset database for existing buildings.

The requirements for gathering asset database information, in a reusable format from the project participants, are currently unavailable for new projects. The process to populate the asset database for new buildings that come online involves manual data entry. Maintenance and renewal senior analyst explained unavailability of processes required to support population of asset database with new building information:

> "*…how do I get that information from the consultant into PeopleSoft? I don't have a good solution yet, I don't know if I can get the consultants to fill out my forms, in my format so it works…*" (Maintenance and Renewal Senior Analyst)

4.1.4. Maintenance Management Process and Technology

In addition to the periodic maintenance on regulated equipment and building components, we identified reactive maintenance as the main type of maintenance activity at UBC. Issues regarding building components and performance are reported to the Service Center, which dispatches service requests to the appropriate trades. The requests can be accessed from trades' cell phones and they contain relevant information, such as the start date, priority code, and subject line briefly describing the problem. Depending on the complexity of the problem, the trade person either fixes the equipment according to the problem priority or requests additional help according to the complexity of the issue. The trade person refers to the records retrieval system to find the required information on the equipment or system. This information includes, but is not limited to, the manufacturer information, warranty information, intended purpose and performance, routing, manual and specification information. The personnel need to locate the required information within manuals and specifications that are hundreds of pages long, and the drawings only represent systems in 2D. There is often no guarantee that a complete set of required information will be readily available within the retrieval system, and with the required accuracy or level of detail. Once the work is completed, the service request is assigned a completed status. The building monitoring systems (BMS) division monitors building systems by using applications that read data from the data points installed throughout a building. We learned that buildings on the campus are equipped with BMS systems from four different brands (Figure 8). O&M personnel either log into each system to identify issues with buildings or use a system that maps data points from all systems into one interface. However the integrated system often does not represent all of the available data points in a building, and the system visualizations are not always a true representation of the as-is condition.

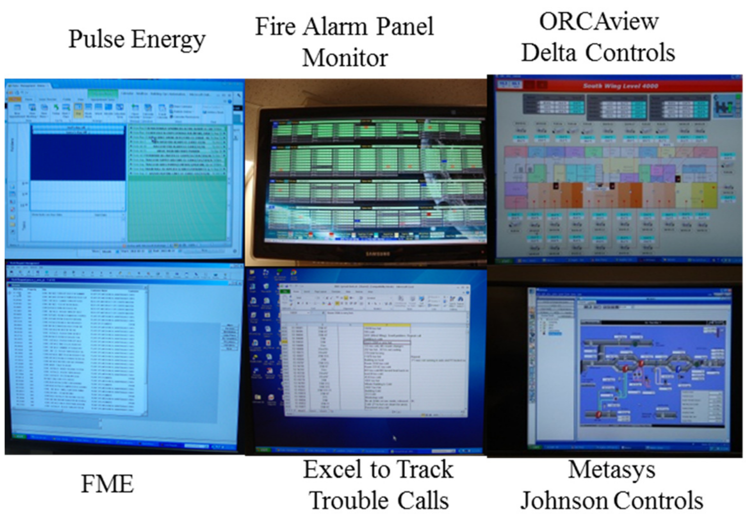


Figure 8. A number of applications have to be used together to make informed decisions when operating and monitoring building systems in the Building Monitoring Systems (BMS) Center.

Before the recent implementation of the integrated asset database, work orders (WOs) have been assigned to buildings rather than systems or equipment. For instance, if there was a problem with a pump in a building, this issue was documented under the maintenance history of that building. The maintenance work performed on the equipment was stored under the specific building history. There were also no shared sources of maintenance information, such as excel files where maintenance information was kept according to a breakdown of system or equipment. This practice had been making it almost impossible to track maintenance issues and related costs per equipment or system. A database of equipment and systems within the campus buildings was made available in 2014. This database has allowed the assignment of WOs to equipment and systems within buildings, making it possible to manage costs and previous work on equipment and system level. To date, maintenance history information, such as what kind of maintenance was done on equipment, who was the last maintenance call assigned to, or things to be careful about when maintaining/operating equipment have been mainly kept in the minds of personnel. The method of transferring such information among personnel has been via personal communication. We learned that when such information is not readily available and accessible by all personnel, owner's resources are wasted in cases as such where different O&M personnel end up spending time to travel and inspect the same problem:

> "*There is no one central point where you can see what maintenance, what history has been done on that piece of equipment, so you don't know how many times somebody has visited that [equipment], is there a reoccurring problem that somebody has fixed, you got to remember there is operations and maintenance, and sometimes both of us go to a call.*" (Head of Mechanical Maintenance/ Projects)

UBC has been using a zone approach for maintenance management, where the available maintenance workforce has been divided into different zones within the campus. From the interviews we performed, we learned that one of the reasons for using this approach is to ensure that the maintenance personnel are familiar with the buildings' equipment and systems. This approach is heavily dependent on personnel's memory that currently cannot be stored, shared or transferred automatically. As the head of mechanical maintenance projects reports,

> "*…what we are relying on and we have relied on for the last twelve years I have been here is peoples' experience. Well you know if you go to "X", X will know all the history on that machine. He knows background of that machine, he might know "Y" has done some work on it on and it has that piece of equipment…*" (Head of Mechanical Maintenance/ Projects)

4.2. Requirements

The first part of this section presents the comparison of the handed over building and building information with the Technical Guidelines which represent the owner's requirements. The second part of this section documents the information and information visualization requirements of the O&M personnel based on the interview data.

4.2.1. Owner Requirements

The UBC Technical Guidelines "outline the principles of design and construction and include: performance objectives, technical requirements, recommended practices, project documentation requirements, sample front-end documentation, plus steps to follow to expedite completion of UBC projects" (http://www.technicalguidelines.ubc.ca). These guidelines (Table 2) serve as the code of quality and performance, and we identified issues regarding compliance to these requirements.

Contrary to the owner's technical requirements, during our analysis we identified mechanical rooms with poor access for maintenance, plumbing equipment located at ceiling height, and as-built records drawings that fail to completely represent what was actually built. Buildings on the UBC campus, even the ones most recently constructed, have maintainability problems that conflict with the UBC technical guidelines. For example, in order to maintain the pumps which are installed at the ceiling height in the CIRS mechanical room, maintenance crews will need to remove components that block the access space, use additional equipment (like ladders and lifts) to remove the pumps, and therefore spend additional time on maintenance (Figure 9). However, as noted above, UBC technical guidelines clearly state that plumbing equipment shall not be located at ceiling height, and should be readily accessible.

Table 2. Examples from the technical guidelines regarding mechanical room and plumbing designs, and requirements for records drawings submission.

Mechanical Rooms Section of the Technical Guidelines
a. Consider maintenance access as part of the design. No mechanical room will be accepted with poor and difficult access for maintenance.
b. Drawings shall show all mechanical and plumbing equipment in elevation or alternately shall specify mounting heights for the equipment.
c. Design sufficient access to all components of the air handling unit. Ensure adequate clearance for coil replacement without necessity to dismantle adjacent equipment or building components.
d. Locate mechanical rooms in areas accessible from outdoors.
e. Confirm that sufficient space is provided to remove largest piece of equipment from the Mechanical Room.
Plumbing Section of the Technical Guidelines
f. All plumbing equipment requiring frequent maintenance (once a year) to be readily accessible. Do not locate at ceiling height, in walls, tunnels, buried, requiring scaffolds, ladders, removal of other equipment, in user space, or in crawl spaces
g. All sanitary sumps within buildings must have gas tight covers and be vented to outdoors
Records Section of the Technical Guidelines
h. “Issued for Construction” drawings are not accepted as as-built drawings.
i. (As built drawings) represent the final installed configuration of what was actually built
j. As-built drawings incorporate all changes made during the construction process including any and all clarifications, addenda and Change Orders.
k. (As built drawings) to be submitted within 60 days of Substantial Performance
l. Operating and maintenance manuals: • All drawings must be legible • Complete sets of manuals should be in the hands of the Owner’s Representative no later than 60 days after the date of substantial performance.

(a) **(b)**

Figure 9. Maintainability problems in the CIRS mechanical room that are contrary to the owner requirements will lead to inefficiencies when performing maintenance during the operations phase. (**a**) Requirements to facilitate O&M, UBC Technical Guidelines: "No mechanical room will be accepted with poor and difficult access for maintenance.", "Do not locate plumbing equipment at ceiling height, requiring scaffolds, ladders, removal of other equipment.", "All plumbing equipment requiring frequent maintenance to be readily accessible."; (**b**) Compliance issues identified during CIRS walkthrough: The CIRS mechanical room is one of the most cramped and problematic mechanical rooms on the campus. Pumps in the mechanical room are installed on the ceiling and buried under a maze of pipes. Problematic maintenance access to pumps requiring maintenance as often as every two years.

The main maintainability issues we identified during the building walkthrough and shadowing activities were related to installation and maintenance access space problems, as well as lack of information on equipment design intent and performance. Describing equipment access problems, a BMS specialist reported:

"*I think that that's the largest problem we have got and it's not just this building it is a lot of buildings but this building they really made the mechanical room tight. And it's like a new car, where you can't access one thing without removing three other things. It is going to be very difficult for people to work on it and maintain these things in the future.*" (BMS Specialist)

4.2.2. O&M Personnel Requirements

It is often not clear for the owner and the project team what information is needed at handover in terms of representing the requirements of all the different users within the organization. An organization's information requirements vary depending on the FM functions to be supported, the O&M personnel information requirements, and the processes and tools that are used to perform FM functions. The users that we interviewed emphasized information and information visualization requirements that weren't formalized anywhere (Table 3).

Table 3. Breakdown of interviewed personnel according to departments and FM functions.

Department	FM Function	Interviewed Personnel
Infrastructure Development	Records Management	Records System Administrator
Building Operations	Asset Management	Maintenance & Renewal Senior Analyst
	Maintenance Management	Manager of Technical Services
	Maintenance	Maintenance Technical Specialist
		Head Maintenance Engineer
		Millwright
	Building Operation Monitoring & Control	Head Maintenance Engineer (BMS Center)
		BMS Specialist
	Service Call Management	Program Manager

FM personnel require information to be in different levels of detail, in reusable format, and prefer different information visualizations depending on the task they perform. We identified types of information required by different O&M personnel through the analysis of the interviews we performed (Table 4).

Table 4. Information required by O&M personnel to perform maintenance, building systems monitoring, and manage assets.

	FM Function	Required Information, Component & System Attributes
Maintenance Personnel	Maintenance • Preventive • Scheduled/Periodic • Reactive	Design criteria, commissioning information (e.g. component performance), replacement part information, vendor information, serial number, location, warranty information, cost (to replace, maintain, *etc.*), system visualization, system performance information, locations of panels and valves that control equipment (e.g. electrical panel location, shut off valve location), sequence of operation (start-up/shut down information), maintenance history
BMS	Operation Monitoring/Tracking	Location, commissioning information, design criteria, equipment performance information, system performance information, accurate system visualization that includes all required system components
Asset Management	Asset Management • Track operational costs • Track life cycle costs • Maintenance info • Maintenance schedules • Procurement	PM maintenance schedule, PM inspection report, key plans, backflow prevention assembly test report, systems list, equipment lists, part of what system, required database attributes (e.g. supplier and manufacturer information, manufacturer, performance data), cost information related to replacing and maintaining equipment/system, maintenance history, installation manuals

During our interview, the head of mechanical maintenance/projects explained the types of equipment information he requires and the implications of not having that information:

> "*Sometimes you go to a piece of equipment especially older piece of equipment, there is no history on it, there is nothing in the maintenance manual what this thing did, and the data tag on a piece of equipment is rusted, it is missing, and then you have a sump pump and it goes through the ceiling and you don't actually know where it goes, and how far it goes, you are guessing how much gallons per minute, and you have to know how many feet ahead it can pump, that can be challenging.*" (Head of Mechanical Maintenance/Projects)

During our interview, a millwright explained the different types of information he uses and how the current technology and artifacts do not fit with his requirements:

> "*When I refer to the record drawings, it is when I need to know how a system functions. I may know what the problem is already if it is a mechanical problem but, when we get into the technical aspects of balancing issues, supply or return issues we need to know how the system functions. So we refer to the records drawings not only to find out what the system was balanced at, but we also need to know what areas it serves, where certain components*

> *are. The BMS system doesn't show everything. On their graphics they'll show an air handler, a room, and a valve. But where is that valve?*" (Millwright)

A building monitoring system specialist would like to have access to accurate system representations, with space information, supported by design and as-is performance information. We identified that the current technology for building monitoring system (BMS) representations are often not detailed enough to represent all required system components and their locations, and they may not represent the as-is condition. We learned that it would have been easier for a building operator to identify the source of a problem in a system or make informed decisions, if 3D detailed and accurate system visualizations were available. A building operator we interviewed mentioned that air handling system visualizations indicating all required systems components such as the AHU, ducts, dampers, diffusers, positions of VAVs, spaces served by the components would help during problem source identification regarding a hot/cold space. A zone millwright we interviewed explained that he needs to know what areas an equipment serves, and where certain components are in the building. According to this millwright the BMS system does not show everything, and it may be challenging to understand things like what area an equipment serves from the 2D drawings.

We identified organizational processes that are not adequate to create the required information. For example, our interviews indicate that the extent and quality of information created during commissioning often does not meet the requirements of operations personnel. When detailed commissioning information about how the systems should work together, or how components should perform under different conditions are not transferred to the operators, they are left without a performance benchmark to operate the buildings accordingly. The BMS specialist we interviewed explained the importance of access to accurate sequence of operation information to understand how equipment within a building should interact with each other:

> "*Having a clear accurate sequence of operation available to maintenance personnel is becoming increasingly important. As buildings become complex it is harder to determine how a piece of equipment is intended to interact with other equipment in the building without the sequence of operation.*" (BMS Specialist)

4.3. Project Context

Artifacts are the main information sources of building information for the owner during the operations phase. The owners refer to this information set to make informed decisions while performing FM tasks. In this section, we document our investigation the CIRS project handover documents and the design model.

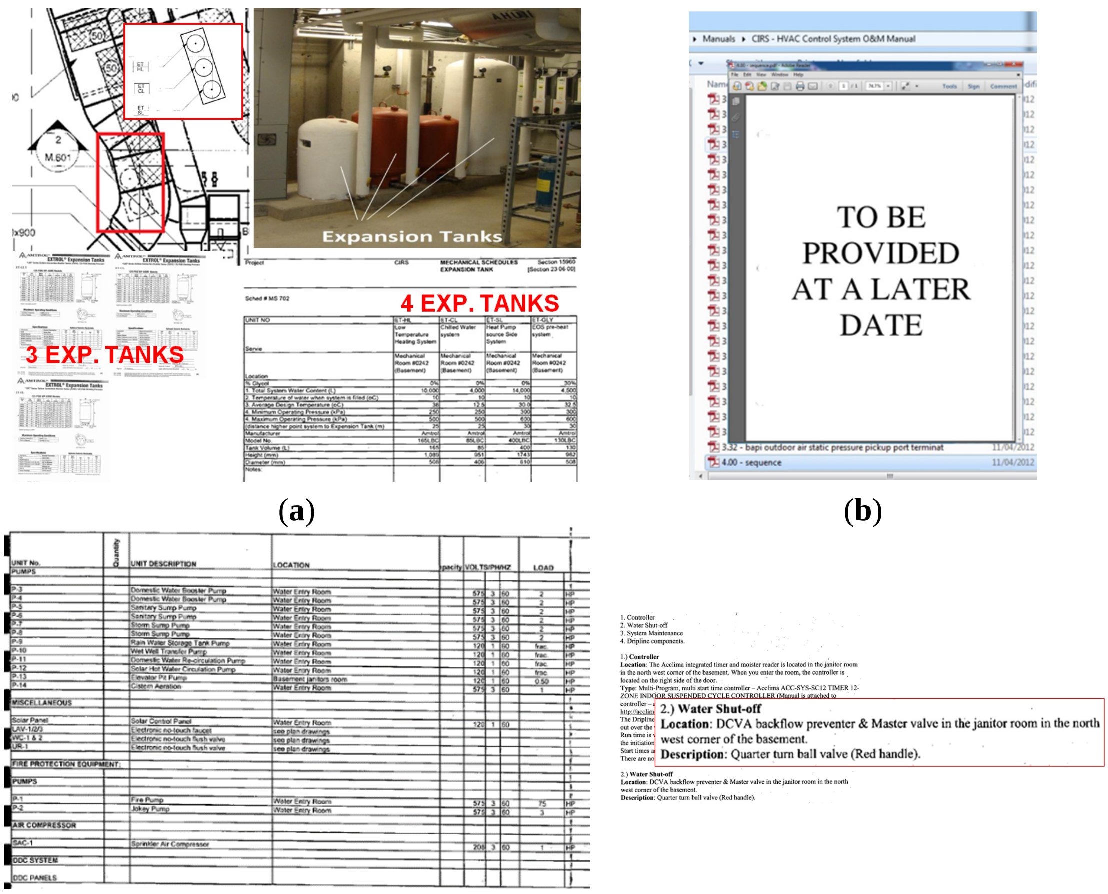
4.3.1. Artifacts—Handover Documents

Handover documents contain information that is required by the owner to operate and maintain buildings. As mentioned earlier these documents are accessed by the personnel through the records retrieval system, after they are structured and rendered searchable by the records department. In this section, we analyze the handover artifacts from different perspectives to understand the accuracy, reusability and accessibility of this information.

According to the Records Administrator, the handover documents are often reflective of the condition of the project documentation at the time of handover, and there is no guarantee that accessed information in the owner's records management system is accurate or up-to-date (Figure 10a). The characteristics of the handover documents (including quality and/or accuracy) may vary depending on the project team:

> "*If you come in looking for information about any building, I can show you what we have, that's the strength....What I can't tell you is that it is right. We entirely depended on what was sent to us….The biggest weakness is that what we get is what we get. We don't have plan checkers. We don't have a department reviewing the drawings saying yes this isn't right, it is wrong.*" (Record Systems Administrator)

During the analysis of the handover set we identified that sequence of operation information required by the personnel for operating and maintaining the building was not available at the time of handover (Figure 10b). Handover documents are often in paper format, and digital copies of these documents are also received by the owner at the end of projects. Although much of the information is created digitally at one point, often the information set contains scanned images of information which don't allow for reuse of content (Figure 10c). We identified scanned pages of the manufacturers' generic information within O&M manuals, rather than project specific information. The format of the documents also leads to information accessibility problems when using the records retrieval system. Because simple word searches cannot be performed on documents containing scanned images, making it challenging to access important building information such as location of water shutoff locations (Figure 10d).



(**a**) (**b**)

(**c**) (**d**)

Figure 10. Identified issues with the handover artifacts lead to problems related to usability of handover information during operations. (**a**) Inconsistencies between drawings information, manual information, and building; (**b**) Information required for operating and maintaining the building may not be available at the time of handover; (**c**) Information which is initially created electronically is handed over to the owner as scanned image; (**d**) Important information within documents that are hundreds of pages long cannot be accessed easily using the records retrieval system, since scanned images do not allow for word searches.

4.3.2. Artifacts—Building Information Models

We analyzed different BIM models to understand the information that is currently represented in design and construction models, and the degree to which these models meet the needs of FM functions. We focus on the CIRS design model and use illustrative examples to convey the issues and shortcomings of this model for FM purposes. Our analysis focused on the *model content* that is related with geometric and non-geometric information availability within the model, and *model structure* that is required for accurate computation of model information and to enable exchange of model information with owner's FM systems.

We analyzed the available model content using a variety of tools, including Revit schedules, Ecodomus, COBie outputs, and Navisworks visualizations. The model content evaluations that we performed indicated that it is a significant challenge to identify available information in the models. We compared the schedules created from the model, the O&M personnels' information requirements from the interviews, and the information tracked within the UBC asset database (Table 5). We identified that the model was lacking content that the owner tracked and required to perform FM functions. When we compared the tracked user defined asset attributes with the model information available, we identified that the model was lacking this information as well as the information required in the asset database, as listed in the middle column in Table 4 (Figure 11). Available information in the schedules, which we derived from the mechanical model, failed to match the asset database and personnel requirements. Useful information on system classifications, system types, and system names was also not available for all components in these schedules (Table 6). Not having this information related to systems made it challenging to understand the available building systems in the model and the components that belong to each system.

Table 5. Comparison of information required by O&M personnel, information tracked in the owner's asset database, and information available within the model regarding a pump.

	Information Required by O&M Personnel*	**Tracked Information in Asset Database**		**Information Available Within Design Model**	
Equipment Type: Pump – System: HVAC	Vendor information	Unit	*UBC*	Level	*Basement*
	Serial number	Asset ID	*000000005504*	Family	*Inline Pump—Vertical*
	Location	Acq Code	*P*	Type	*120 GPM Capacities—10.85 Feet Heads*
	Maintenance history	Building Tag Number	*63300*	System Classification	*Undefined, Power*
	Warranty information	Descr	*CIRS*	Equipment #	*AH1*
	Maintenance plans	Region	*633F*	Equipment Type	*P*
	Maintenance schedule	Descr	–	Mark	*110*
	Cost information	Asset Type	*HVAC*	Count	*1*
	Replacement part information	Asset Subtype	*CW PUMP*	–	–

Table 5. *Cont.*

	Information Required by O&M Personnel*	Tracked Information in Asset Database		Information Available Within Design Model	
Equipment Type: Pump – System: HVAC	Performance criteria (design criteria, commissioning information)	Description	*Circulating Pump P-2*	–	–
	Location of electrical panel Location of shut off valve	Status	*I*	–	–
	System that equipment belong to	Acq Date	*01/01/2011*	–	–
	Area served by the equipment	In Service Dt	*01/01/2011*	–	–
	Number and locations of a type of component	Description	*Circulating Pump P-2*	–	–
	Routing of the system which an equipment belongs to	Short Desc	*PCW002*	–	–
		Taggable	*Y*	–	–
		Tag Number	*63300PCW002*	–	–
		Version	*ClosedLoop*	–	–
		Criticality	*N*	–	–
		Manufacturer	-	–	–
		Model	-	–	–
		Serial ID	–	–	–
		Equipment Location	*B1242*	–	–
		VIN	–	–	–
		User defined attributes:		–	–
		Length	*0.000*	–	–
		Length Units	–	–	–
		Capacity	*400.000*	–	–
		Capacity Units	*GPM*	–	–
		Power	*5.000*	–	–
		Rating Units	*HP*	–	–
		Custom Attributes	*HEAD 16 FT*	–	–

* identified from interviews

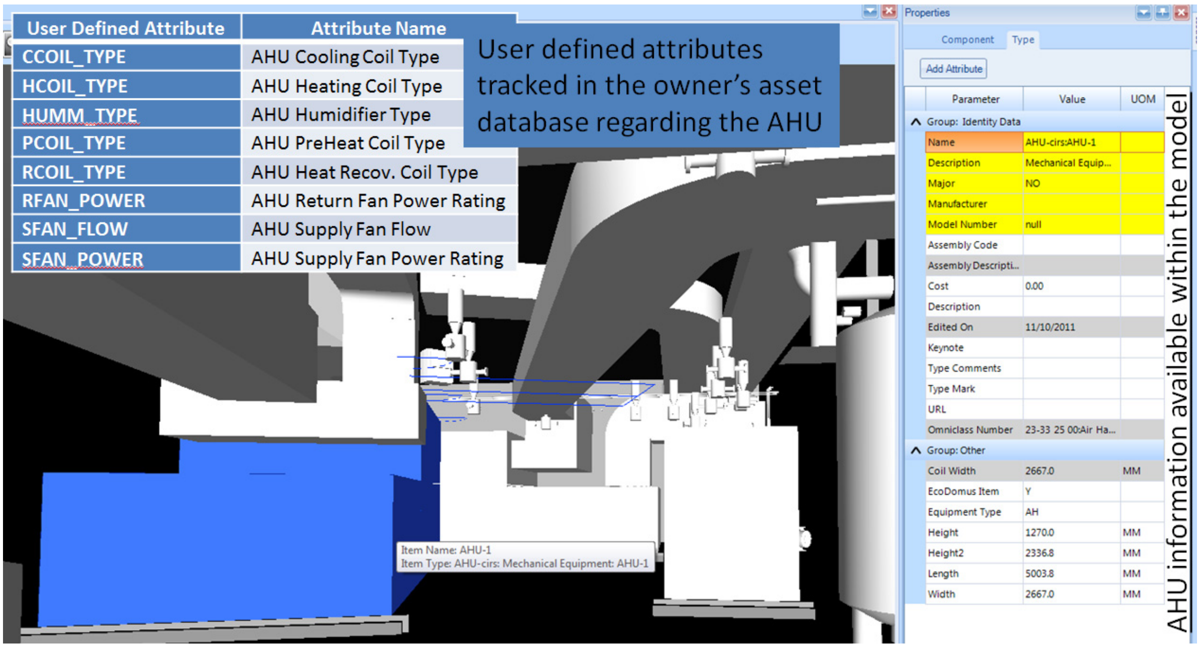


Figure 11. The available AHU information within the model falls short on representing the user-defined attributes tracked for the AHUs within the owners asset database.

Comparison of the available model geometry to the as-built conditions indicated the components that were not modeled, and components that were modeled but did not represent the as-is condition. For example, Figure 12 illustrates inconsistencies between what the as-built drawing shows, what the model represents, and what actually exists in the building. The actual number of expansion tanks and the size and location of the MCC unit are inconsistent with the modeled information.

Table 6. Analysis of mechanical model for available component attributes using Revit schedules.

Schedules Derived from Mechanical Model	Information Available Within the Schedules
Mechanical Equipment Schedule	**Attributes that have assigned values for all components in the schedule** Level, Count, Family, Type, Type Comments, Equipment Tag (MAN), IS-HL, Length, Mark. **Attributes that have assigned values for a number of components in the schedule** System Classification, System Name, Neck Height, Neck Width, Air Flow, Color, Equipment #, Equipment Type, Comments, Comments_1
Multi-category Schedule	Level, Family, Type, Category, Mark, Length, Equipment Tag, IS-HL, Type comments, Neck Size, Count, Comments1-2-3-4.
Duct Schedule	Family, System Classification, System Name, System Type, Flow, Free Size, Area, Bottom Elevation, Count, Diameter, Equivalent Diameter, Additional Flow, Friction, Height, Hydraulic Diameter, Length, Loss Coefficient, Mark, Overall Size, Pressure Drop, Reynolds number, Section Size, Size Lock, Top Elevation, Type, Velocity, Velocity Pressure.
HVAC Zone Schedule	One line of information available: Cooling Air Temperature (12 °C), Cooling Set point (23 °C), Dehumidification Set Point (0.7), Heating Air Temperature (32 °C), Heating Set Point (21 °C).
Schedules that do not contain information	Space Schedule, Parts Schedule, Sprinkler Schedule, Area schedule (gross building), Assembly Schedule, Duct Insulation Schedule, Duct Lining Schedule, Duct Placeholder Schedule, Flex duct schedule

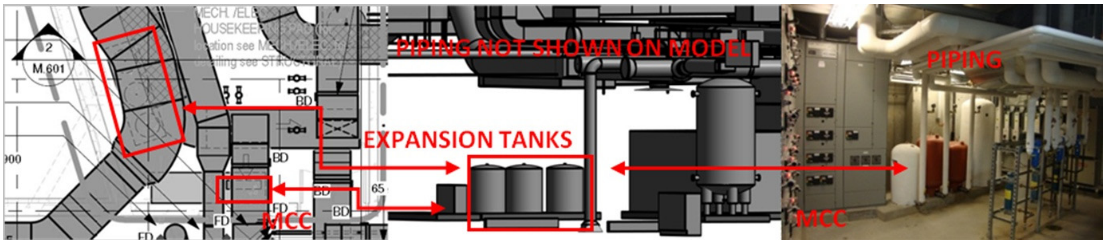


Figure 12. Inconsistent information was identified between record drawings and the design model.

The design and construction models are not immediately usable because they lack the model structure such as consistent and instance specific nomenclature. Table 7 shows the comparison of information required by O&M personnel, information tracked in the asset database, and information available within the model regarding pump equipment. Type and instance names (bold in the figure) in the model are not consistent. Generic box is used to model a pump instead of using a pump family. Data derived from the models requires reorganization and restructuring because information output from unstructured models has limited value and use for an owner.

During the model analyses, we compared the available model content with the information tracked in the owner's asset database and user requirements from the interviews. We identified modeling errors that negatively impacted the quality and reusability of the information derived from the model. The modeling errors affected space boundaries that prevented getting meaningful information from the models. We identified issues that lead to miscomputation of model information and information reusability problems such as:

Issues related with the modeled information include:

- Unidentified system-equipment-space relationships; when such relationships are not defined it becomes challenging to understand available systems within a model, identify equipment which belong to a system, and where this equipment is located within the building (Figure 13a).
- Errors in spaces, such as duplicate/overlapping spaces and unintentional openings left within the walls, lead to miscomputation of space information for equipment locations (Figure 13b).
- Errors in elevations, such as inconsistent floor elevations between linked models, lead to miscomputation of space information.
- Errors in floor to floor height definitions lead to computation of space that equipment is located in rather than the space it is serviced from.
- Errors in representing all components continuously within a system; unconnected or missing system components affect identification of systems within the model (Figure 13c).
- Issues with equipment and system nomenclature;
    - Components named as individual systems (Figure 13d).
    - Non-standard system names.
    - Equipment that are not named uniquely or consistently.

Table 7. Inconsistent model component nomenclature and asset breakdown structure make it challenging to reuse model information, because they do not align with owners database.

	Family Name	**Inline Pump—Vertical**	**Inline Pump—Vertical**	**Box-generic**	**Box-generic**
Model	Type Name	120 GPM Capacities—10.85 Feet Heads	120 GPM Capacities—10.85 Feet Heads	HP4	HP05
	Instance Name	HL-3	HL2	1	2
	Instance Description	P	P	HPWA	HPWA
Owner's database	Asset Type	HVAC			
	Asset Subtype	CW PUMP			
	Description	Circulating Pump P-2			
	Short description	PCW002			
	Tag number	63300PCW002C			

In this section, we investigated the current FM processes, technology, requirements and artifacts within the UBC context. In the next section, we will introduce the framework we developed to characterize the alignment organizational constructs, available technology, project artifacts and owner requirements along with illustrative examples using the UBC case study.

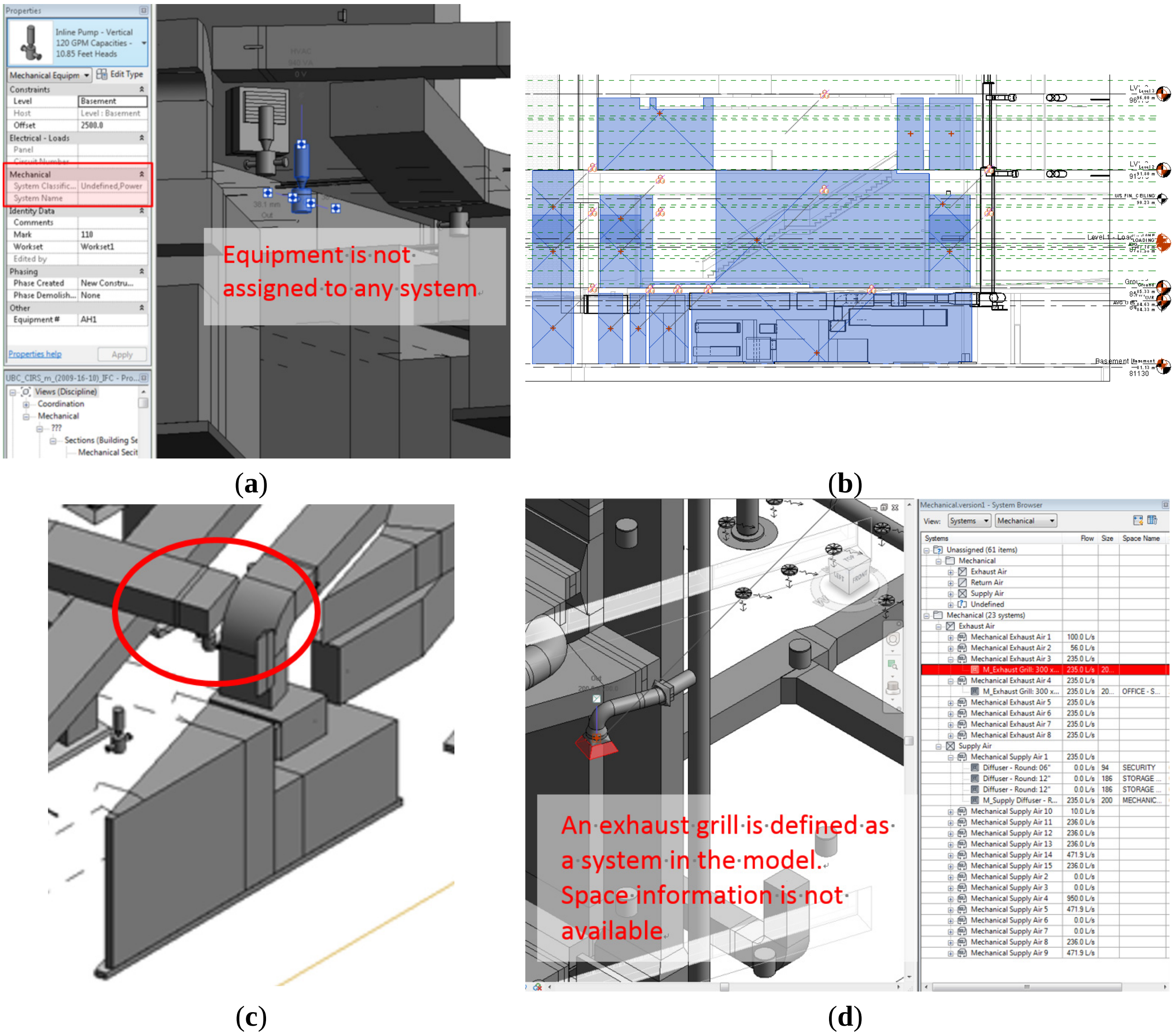


Figure 13. Identified modeling issues lead to information reusability problems and miscomputation of model information. (**a**) Equipment and system relationships are not defined in the model; (**b**) Overlapping space defining objects, space duplications, and unintentional openings left within the walls lead to miscomputation of equipment location information; (**c**) Unconnected system components lead to issues when defining systems, e.g., the duct in the picture is not connected to the AHU; (**d**) A single component is defined as a system within the model.

5. Framework for Investigating Organizational Alignment

Our investigation of the owner operator organization indicates the challenges involved with managing infrastructure. An organization is a network of departments, technologies, processes, and people. Transitioning from a paper-based to a model-based approach in handover and operations is a complex challenge and will necessitate changes in work practices and information flows within an organization. We investigated alignment as a way to better understand the complexity and the changes required to transition to a model-based work flow. This section introduces the framework we developed to characterize alignment between organizational constructs, available technology, project artifacts and owner requirements (Figure 14). The framework emerged from our analysis of the detailed case study data collected and a thorough review of the literature on alignment. This framework helped us to understand how well the different pieces within the organization work together to achieve organizational goals through the lens of potential BIM-based information exchange and FM practices.

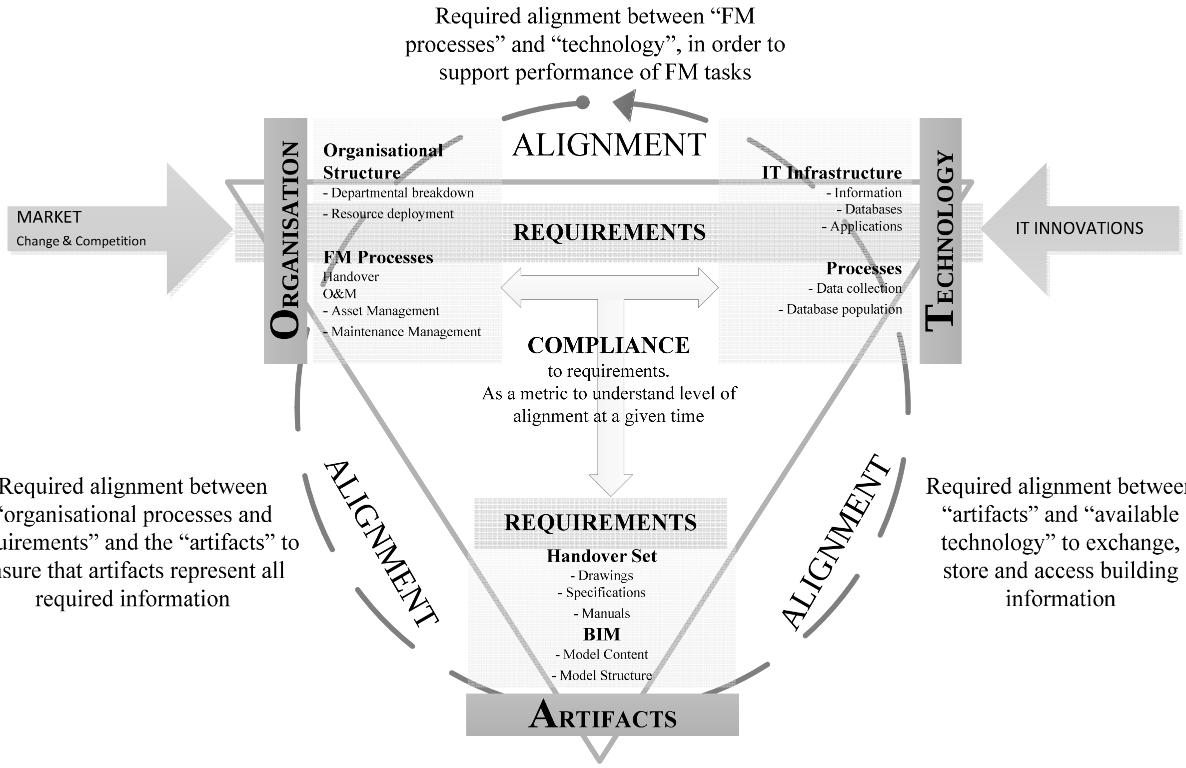


Figure 14. Framework we developed to analyze organizational alignment, and compliance to requirements from the perspective of BIM implementation for FM.

We use Henderson and Venkatraman's Strategic Alignment Model (SAM) [31] as a point of departure for our framework (Figure 15). Henderson and Venkatraman define alignment as "*the degree of fit and integration among business strategy, IT strategy, business infrastructure, and IT infrastructure*" (as cited in Chan and Reich [32]). Alignment in this study refers to the degree to which all parts of the organization-specific context, as a system, work together efficiently to achieve the organizational goals. Misalignment therefore refers to any issues within the organization-specific context that limit or hinder the ability of organizational processes, technology and artifacts to work together and support each other. We used SAM as a starting point for our framework because it is the most relevant, comprehensive, and most cited alignment models in the literature. The SAM identifies two types of integration between business and it domains. The first, strategic integration, "*is the link between business strategy and IT strategy. It deals with capability of IT functionality to both shape and support business strategy.*" [31] The second, operational integration, "*deals with the link between organizational infrastructure and processes and IS infrastructure and processes.*" [31] It "*highlights the criticality of ensuring internal coherence between the organizational requirements and expectations and the delivery capability with the IS function.*" [31] We exclude the business and IT strategies in our framework because in many organizations not all personnel are aware of organizational strategy that has been put in place [19]. Peppard and Breu describe the element of chance that seems to influence deployment of information systems (IS) in companies by referring to Ciborra's study of organizations and observing that in certain cases "*achievement of competitive advantage from the deployment of IS was due more to serendipity than formal planning*" (Peppard and Breu [19]). Although we do not have data suggesting that our observations about UBC were directly related with external factors such as market changes/competition, and IT innovations, we still included these important factors in the framework. However, the changes we observed within the organization, such as implementing an integrated asset database, leveraging PeopleSoft to support a number of FM functions, and organization's interest in BIM for delivery of new projects, may have been influenced by changing FM practices of other owner organizations and advancements in IT. One other reason for the observed changes within the organization may be the organization's internal effort to align processes, organizational structure, and technology infrastructure to improve work practices through technology adoption. This study extends SAM's operational integration characterization by considering artifacts as a medium to investigate alignment between organization and technology.

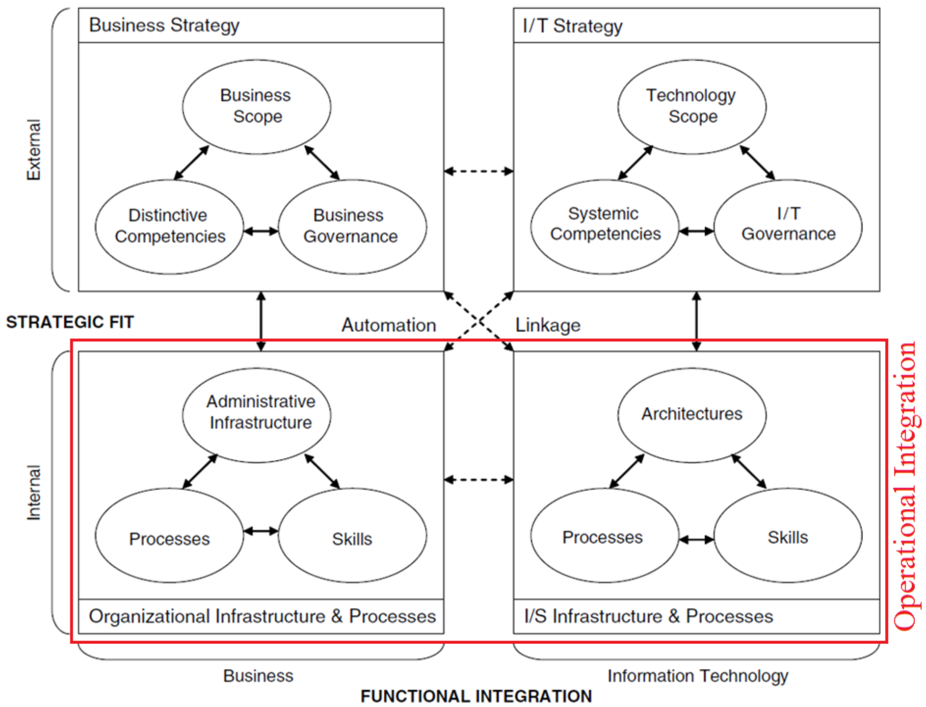


Figure 15. The Henderson and Venkatraman strategic alignment model. Original image from Chan and Reich [32].

The main dimensions of the framework are Artifacts, Technology, and Organization because they were the most distinct categories that emerged during our data collection and analysis. The building information is exchanged through artifacts, it is stored in and accessed through the available technology, and it is used by the O&M personnel to perform FM functions via defined processes. We recognized that in order to perform handover and FM functions efficiently, organizational processes, structure, technology infrastructure and artifacts have to support each other, and there has to be a high level of compliance to the organization's requirements. We use the term 'compliance' within our framework to describe the ability to act according to a set of requirements, such as owner, personnel and technology infrastructure requirements. Compliance to requirements is introduced as a metric to improve alignment within the organization-specific context, where more compliance to requirements leads to better alignment.

Figure 16 provides an illustrative example of alignment issues we observed between current artifacts, technology, and processes within the organization. We use an example from Section 4.1 that focused on maintenance management processes and related technologies, and in particular, the process related to work requests and how they are assigned to buildings rather than systems and equipment. This process made it challenging to access equipment maintenance history or make informed decisions on procurement and planning. The main reason for this practice was the unavailability of the necessary technology infrastructure to support a database of systems and equipment available in campus buildings (Figure 16, refer to text numbered as 1). In the absence of such technology, work requests have been assigned to buildings rather than equipment, and the work performed on equipment was not captured digitally but rather resided with the personnel who performed maintenance activity. This process made it significantly challenging to track equipment maintenance history for performing tasks, like tracking the maintenance costs based on equipment, or supporting the flow of maintenance history information within the work-force. Since the maintenance history was not documented and shared, the organization preferred a zone-based approach to workforce management so that personnel familiar with the building systems and equipment are responsible for their maintenance. Although a database for systems and equipment in campus buildings was recently created, the process for getting the required information for new projects in a reusable format is not available, entering information into the database is still a manual process, and handover artifacts do not contain the required system and equipment information in a reusable and structured format (Figure 16, refer to text numbered as 2).

The misalignment between the process related to managing work requests, the technology related to keeping required equipment and system information, and the artifacts that should contain data to populate databases remains to be a challenge. Available technology for accessing artifacts fails to comply with user interface requirements, such as the ability to quickly skim through handover documents that are hundreds of pages long (Figure 16, refer to text numbered as 3). Artifacts on the other hand, fail to comply with the technology requirements (e.g., the data structure) and personnel requirements (such as the need for an accurate and complete set of information required by O&M personnel). The information that is required by the personnel to perform FM tasks mainly resides within the handover documents. The records retrieval system is intended to store handover documents, but it lacks the user interface required by the O&M personnel. Specifically, O&M personnel require structured, quality information that also meets their information visualization requirements. O&M personnel often refer to manuals and specification documents within the records retrieval system. Such documents are hundreds of pages long, however the available system allows users to only view one page at a time. Since the documents often contain scanned images, the system does not allow for word searches or simple interactions like copy and paste information. Information within the records retrieval system is also accessed by other departments to support the functions that they perform. The information in the system is often re-categorized and regrouped within departments according to their information requirements. This process leads to inefficiencies due to duplication of effort to enter, structure, and update information within departments. Since the information is not integrated, O&M personnel have to use multiple tools to access the sets of required information and they have to manage information in all these applications and databases separately.

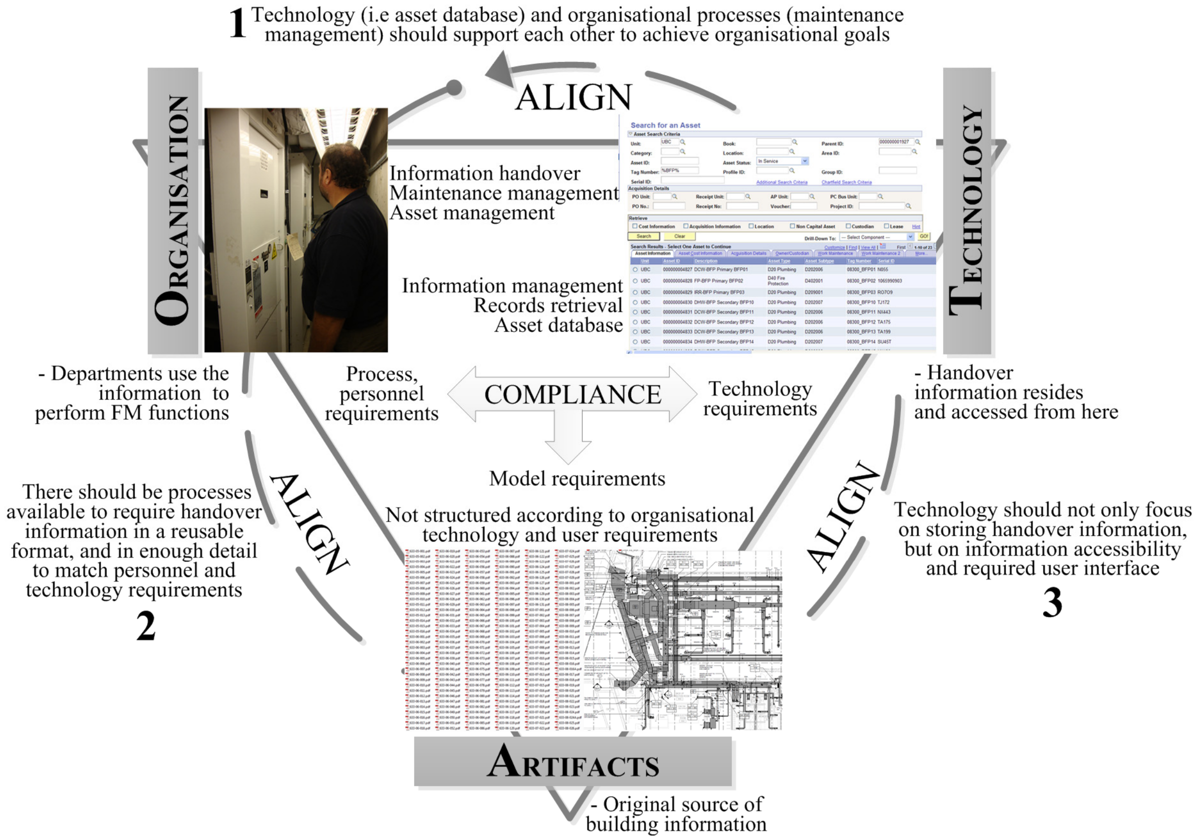


Figure 16. O&M personnel access handover information through technology infrastructure that fails to comply with user requirements (such as accessibility), and process requirements (such as an asset database for maintenance management).

Figure 17 provides an illustrative example of alignment issues we observed between current information requirements, organizational technology, and artifacts when considering the potential uses of model-based artifacts. We use examples from Section 4.3.2 that focused on information required by O&M personnel, information tracked and managed within the organizational asset management database, and available mechanical equipment information in the design model. When we compared the information required by O&M personnel, the information available within the owner's asset database and the information available within the analyzed model, we identified that neither the information tracked within the asset database nor the information available in the design model is complete enough to satisfy the personnel's' information requirements. The available asset database contains a limited set of information regarding the mechanical equipment and systems within the university buildings. The design model information on the other hand, fails to cover the limited set of information that is tracked within the asset database. When we analyzed the available information within the model, we identified misalignment between the model information structure, asset database information structure, and how O&M personnel search for information within a database. Figure 17 also exemplifies structural issues within the model regarding nomenclature, such as not using the required families to model mechanical components, using inconsistent methods for indicating individual components (such as naming one instance as HL-3 and naming other instance as HL2, or using HP4 and HP05 to identify two instances of the same type of equipment). When we look at the type of information breakdown structure used within the asset database, we see that the type and subtype breakdown utilized is not consistent with the model.

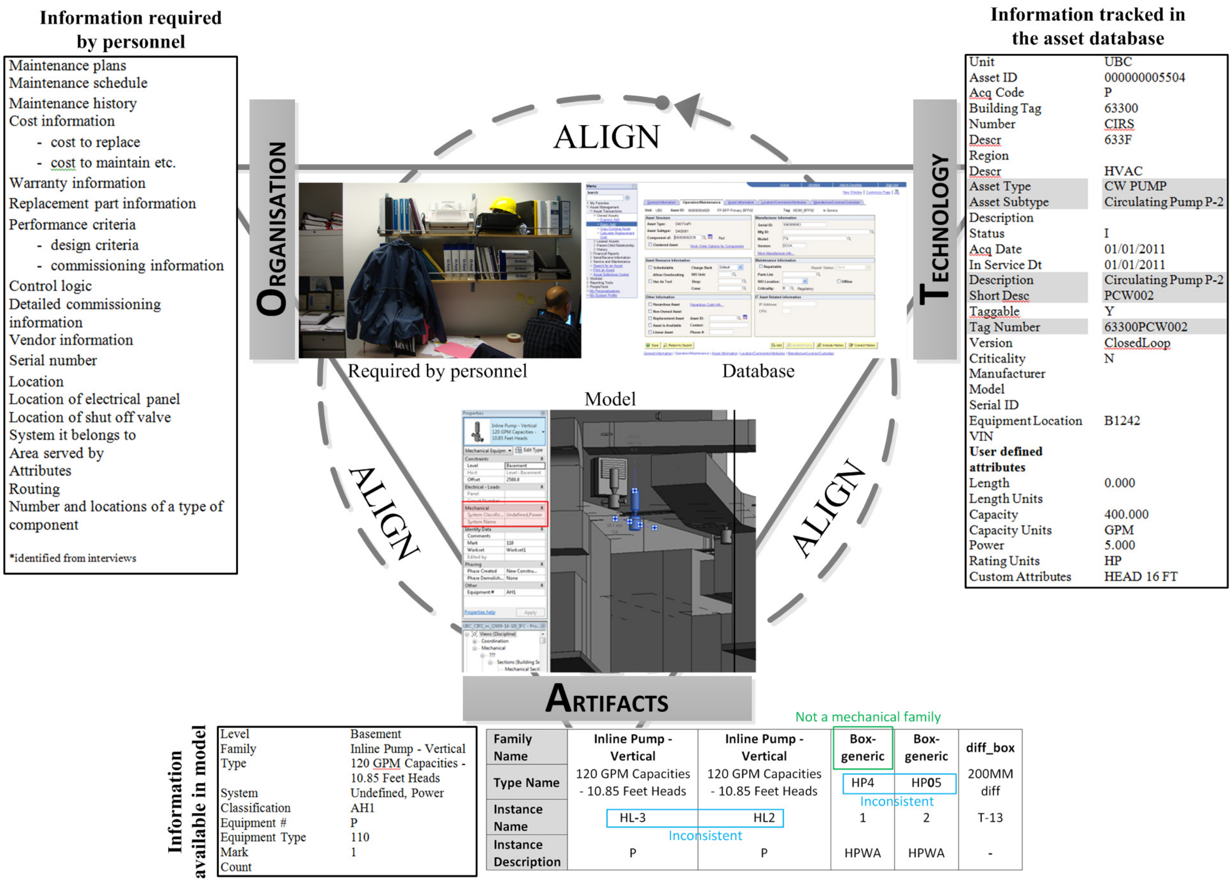


Figure 17. Information within the investigated model is not sufficient to capture information tracked within the owner's database, which is only a portion of the information required by the personnel.

The examples above indicate misalignment between processes, technology and artifacts, and lack of compliance to requirements within an organization. In order to leverage BIM, organizations need to align artifacts, supporting technology, work practices, and processes to harvest the potential benefits. Introducing BIM as a new technology into the current state of an organization without carrying out the required alignment process would not be adequate to solve the current FM issues. The information required in an FM BIM is often not formalized by owners, and most owners are not aware of the different types of information required by different personnel. Formalizing the requirements would acquire identification of information related to FM functions, identification of how users access and use such information, documenting how such information should be made available in a model, and reconfiguring processes and organizational technology to accommodate model information. Aside from the internal changes required within an organization, BIM use in handover and FM also necessitates changes to the way the project teams work in terms of preparing and delivering the necessary handover artifacts to suit FM purposes.

6. Summary and Conclusions

The aim of this research was to better understand what is involved in the transition from a paper-based approach to a BIM-based approach in handover and FM information management. This research was motivated by our own observations and references in the literature about the low adoption rate of BIM for facility owners despite the many promised benefits and the increasing availability of design and construction BIMs. We performed a long-term embedded case study analysis that investigated the work practices of a large owner organization that spanned several years. We investigated numerous FM functions across organizational and project contexts to better understand their work practices and processes, information flows, and technologies used. We further investigated the owner's information requirements and project artifacts to better understand the current state and quality of building information artifacts typically transferred to building owners at project completion. This rich case study informed the development of a framework to characterize alignment between organizational constructs, available technology, project artifacts and owner requirements as a means to better understand the mechanisms required to transition from traditional to BIM-enabled FM practices.

The case study of a large owner organization illustrated the many shortcomings with current FM practices and the enormous opportunity that BIM enables, particularly for owner operators. The case study also illustrated, however, the complexity involved in transitioning to model-based work flows and practices. This transition is significant and complex and helps to explain why so few owners are adopting BIM. The framework that emerged from the case study illustrates the importance of alignment between the organization, technology, artifacts and requirements for owners considering the transition to BIM. The reality is that implementing BIM in large owner organizations will require significant changes in the way organizations are structured, the way information is represented and exchanged, and the way work practices are configured and executed. These changes are both internal to the organization, as well as external to the organization in terms of the way project teams produce and exchange project information. Future work will focus on evaluating other owner organizations and verifying the applicability of the framework across different organizational contexts. Further research will also be pursued to better understand owner requirements and the computational mechanisms needed to evaluate a given BIM's compliance against these requirements.

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Author Contributions

This study is based on Hasan Burak Cavka's PhD research and he was responsible for the research design, data collection and analysis under the supervision of Sheryl Staub-French. Sheryl Staub-French contributed to this paper by guiding the overall structure and content of the paper, and helping with the final editing. Rachel Pottinger provided input on the framing of the research and the overall organization of the paper.

Conflicts of Interest

The authors declare no conflict of interest.

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