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# BIM for Facilities Management: An Investigation into the Asset Information Delivery Process and the Associated Challenges

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**Abstract:** The most common problem facility managers face is information accessibility. While BIM has been posited as a potential solution to increase the quality and availability of asset information to support facilities management (FM), few studies have captured the challenging aspects of developing and delivering this information within the context of real-world projects with owner-defined information requirements. Based on three longitudinal ethnographic case studies that included a set of comprehensive and formal information requirements within the supply contracts, this research contributes to a better understanding of the BIM-enabled asset information delivery process and its challenges by (1) characterizing the process in eight main activities with examples, and (2) mapping the challenges of using BIM for FM that have been identified in the literature and establishing connections between them. The results demonstrate that even with the early involvement of owners through the development of information requirements, several challenges still prevent owners from taking full advantage of BIM. There is still a limited understanding of how BIM can effectively support existing FM activities and how it impacts current design and construction processes in practice, which compromises the definition of clear and efficient information requirements. In that sense, the support provided by industry standards and guidelines remains limited. The contextualized understanding of the proposed BIM-enabled asset information delivery process and its challenges will help owners and facility managers with the decision-making process regarding the development of their information requirements, preventing inefficiencies and unrealistic expectations.

**Keywords:** asset information; Building Information Modeling (BIM); Construction Operations Building Information Exchange (COBie); Computerized Maintenance Management System (CMMS); Digital Delivery; Facilities Management (FM); Industry Foundation Class (IFC); Operations and Maintenance (O&M)

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**Citation:** Tsay, G.S.; Staub-French, S.; Poirier, É. BIM for Facilities Management: An Investigation into the Asset Information Delivery Process and the Associated Challenges. *Appl. Sci.* **2022**, *12*, 9542. https://doi.org/10.3390/app12199542

Academic Editors: HaiJiang Li and Guoqian Ren

Received: 4 August 2022
Accepted: 16 September 2022
Published: 23 September 2022

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## 1. Introduction

The most common problem facility managers face is information accessibility [1]. During the operation phase of a facility, they usually do not have easy and quick access to the needed information to process work orders [2]. In recent years, Building Information Modelling (BIM) has emerged as a potential solution to overcome the fragmented management of building information across an asset's life cycle and help deliver the information needed for Facilities Management (FM) [3]. However, BIM as an enabler for the delivery of complete and high-quality information for FM purposes has not yet been fully realized [4–6].

It has been identified that the main challenges in adopting BIM in FM activities are not related to technology but to current work processes and organizational structures [7], including the lack of clear roles and responsibilities [8]. Information exchange between BIM models and FM systems is not a straightforward process [9], and there is still limited knowledge of requirements for the implementation of BIM in FM regarding what information is to be provided, when and by whom [2,8]. Although a considerable number of studies on BIM for FM have been conducted in the past years, few studies have documented the complete process of development and delivery of asset information using BIM following pre-established information requirements and its implications in real large-scale projects [10,11]. Thus, a lack of consensus remains among academics and practitioners concerning the successful and practical information exchange process between BIM and FM systems [2,9]. While many issues and challenges related to this process have been identified in the literature [5,7,10,12–17], there is still no consensus about what the key issues and challenges in BIM for FM are [10]. An analysis of the current literature shows a diffuse understanding of challenges related to BIM for FM, leading to the proposition of isolated solutions that often fail to consider the connections between these different challenges. As was recently pointed out by [15], the current slow BIM adoption is caused by a series of combined reasons rather than a single cause. Therefore, the root causes of the barriers and any potential interrelations among them should be further explored [5].

The main research gap addressed in this study is the lack of empirical data from real-world cases on the development and delivery of asset information in BIM with owner-defined information requirements. More specifically, (1) the lack of consolidated characterization of the asset information delivery process (information requirements, main activities; information workflow; scope of each stakeholder; and tools), and (2) the lack of connection between the different identified challenges in this process. To address these gaps, a qualitative case study methodology is employed with the two defined objectives: (1) to document the processes and practices developed in the context of BIM-enabled asset information delivery, including the evaluation of the artifacts used to frame and support the process, and (2) to identify and map the relevant challenges in this process based on previously identified challenges in the literature. By documenting the processes being adopted in the local industry through case studies, captured knowledge such as the common BIM data requirements for O&M, current BIM data delivery and presentation methods, use of new technologies, and hypothetical BIM-O&M use cases, will serve as the foundation for developing more powerful and generally applicable BIM-based systems and solutions for facility O&M [2]. By investigating how challenges identified in the literature manifest concomitantly, a mapped understanding of challenges is developed, which will help understand the sometimes compounding influences among challenges, and identify root causes of issues and potential bottlenecks in this complex process.

Considering that the O&M workflow and procedures followed by different organizations can be diverse and there is no one-size-fits-all approach to BIM adoption [18], many authors have indicated the need for further case studies on BIM for FM in practice [2,5,9–12,19–21]. Therefore, three ethnographic longitudinal case studies were conducted to examine the delivery of distinct projects using BIM that included a set of comprehensive and formal information requirements within the supply contracts. A mixed-methods research approach was used to examine the case studies. The data collection and analysis included document analysis, interviews, meeting observations, and an in-depth survey. Data were collected from design until the handover phase and included input from different stakeholders throughout the projects between 2019 and 2022. The research team worked in close collaboration with a design firm and later with owners as part of distinct research collaborations that enabled the research team to obtain a unique perspective on the information delivery process throughout all phases of the project.

Section 2 presents the literature review in which related studies about the existing processes of BIM for FM are discussed. The research methodology applied in the case studies is then presented in Section 3, including the different data collection methods and tools employed. In Section 4, we introduce the projects used for the case studies, including an overview of the organizations' motivations. In Section 5, the proposed process of using BIM for the delivery of asset information is presented in eight steps. In Section 6, the challenges observed in the projects are mapped. A discussion about the findings is then presented in Section 7. We conclude with some final remarks.

## 2. Literature Review

### 2.1. BIM for FM

FM constitutes an extensive field encompassing multidisciplinary and independent disciplines whose overall purpose is to maximize building functions while ensuring occupants' wellbeing [12,22]. Thus, within FM, there are a variety of potential benefits of using BIM. For instance, Ref. [2] identified and listed more than 25 FM activities that could be digitized through BIM.

Despite large potential benefits and growing interest in the various potential uses of BIM for FM, it is still not clear how the current practices around BIM can support each of these uses. Although asset owners are pointed to as the main enablers for BIM adoption [12,23,24], they still do not really understand their information needs for effective BIM-based asset management [25,26]. Realizing how different the informational needs can be [2], it becomes crucial to understand BIM for FM in more specific terms. Of the many proposed uses of BIM for FM, few documented case studies have tested these uses in a real project scenario with all its intrinsic complexities. Table 1 provides a non-comprehensive list of case studies that have focused on specific uses of BIM for FM.

**Table 1.** Example studies with specific purposes of BIM implementation for FM.

| Authors | Purpose of BIM Implementation for FM |
|---|---|
| [27] | Perform routine maintenance of the Mechanical, Electrical and Plumbing (MEP) system and its subsystems by sorting out the priority of maintenance tasks |
| [28] | Use GIS and BIM to obtain facility O&M information |
| [29] | Develop a decision support tool for preventive/corrective maintenance |
| [30] | Employ 2D barcodes to identify and locate specific equipment and utilize a wireless sensor network to monitor thermal conditions |
| [31] | Evaluate pipeline maintenance accessibility with visualization and provide a suitable traffic flow for engineers |
| [32] | Use augmented reality to display natural markers for indoor navigation and facility maintenance (such as exit signs and position marks of fire extinguishers) |
| [33] | Failure root cause detection |
| [34] | Increase the efficiency of the HVAC-related troubleshooting process by identifying applicable causes and retrieving information for HVAC-related problems |
| [35] | Use a fault detection and diagnostics algorithm to automate the process of detecting malfunctioning HVAC equipment |
| [36] | Integrate corrective maintenance data in BIM and link alarm reports of equipment failures and the related maintenance information from the Computerized Maintenance Management Information System (CMMS) |
| [37] | Emergency management |
| [38] | Run routine O&M tasks and effectively respond to MEP-related emergencies |
| [39] | Generate and schedule facility maintenance work orders |
| [40] | Develope a data management system based on location-based data analysis in the FM field |

Although each of the BIM uses proposed above has specific information requirements, they are all driven by the availability of structured and reliable information in the models. However, how to develop models with such structured and reliable information was often outside the scope of these same studies. At this point, it is useful to establish a distinction between two different concepts discussed under "BIM for FM" in the literature. The first is an exploration of potential uses of BIM for FM activities (Table 1). The second relates to the process of using BIM during the delivery phase of a project to provide the information required to support different FM activities, which will be referred to as the "BIM-enabled asset information delivery process". This paper addresses the latter.

### 2.2. BIM-Enabled Asset Information Delivery Process

A main area of interest in the literature on the BIM for FM is to improve the quality of asset information delivered at handover to inform CMMSs. This interest in the improvement of information quality is justified by the potential value that such information can bring to building owners. According to [6,41], there could be a reduction of 8.7% in work order processing time by following a BIM- and Construction Operations Building Information Exchange (COBie)-based approach. Based on the multi-million-dollar operations costs of large facilities, such as hospitals, airports, and universities, this could represent significant savings attributed to quicker access to accurate and complete digital information and documents [41]. BIM, in this case, is not necessarily used during operations, but as part of a process to develop and deliver structured asset information to the owners at handover. However, this asset information delivery process, which involves different activities performed by different stakeholders at different phases of a project, has not yet been solidified in the industry or in the literature. To that point, [42] suggests that a lack of clarity in processes, risk allocation, and understanding between parties could indeed undo the benefits and instead increase the risk of disputes.

Traditionally, once construction is completed, the general contractor would deliver all the asset information in binders and boxes to the owner. This information would be stored and rarely be maintained at any usable level [6]. However, if the information is not stored in a way that is useful, the cost to find the information that one is looking for can become so expensive that it renders the information worthless, meaning it would be easier and cheaper to replace the information than to sort through the original documents [43]. Most large owners have some form of Computerized Maintenance Management System (CMMS) such as Maximo, AiM, and Archibus in place to manage their facility maintenance, operation, and assets. However, most or all information is still manually entered [44,45]. This conventional process of collecting asset information, represented in Figure 1, is seen as inadequate, ineffective, and expensive for owners [45].

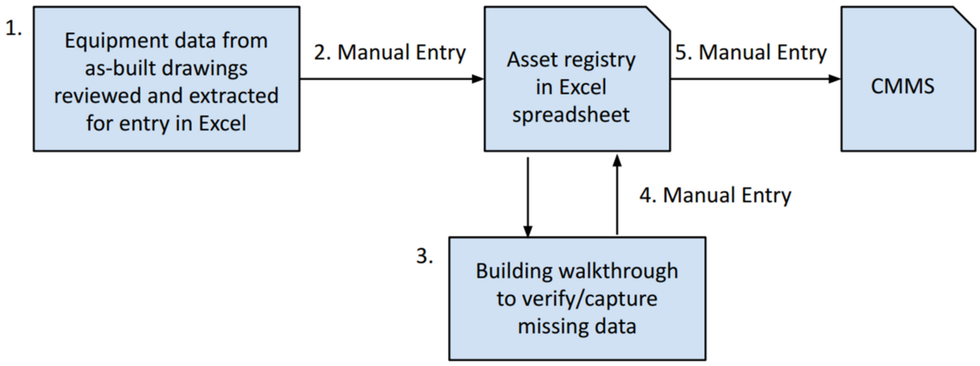


**Figure 1.** Conventional asset data collection (adapted from [45]). (1) Captured information is manually entered into an Excel spreadsheet. (2) Building walkthroughs are conducted to verify the data extracted from the as-built drawings. (3) Modifications are made to the Excel spreadsheet as needed. (4) Walkthroughs allow to verify and edit asset data, verify that equipment exists and is functional, and verify location of assets and location served by each asset. Images of assets are also captured for documentation purposes and entry into the CMMS. Once information collection is complete, it is manually re-entered into the CMMS (5).

With the adoption of BIM in design and construction, new processes for collecting asset information have been proposed aiming at taking advantage of the information created in the models. Figure 2 shows the general idea of the information flow in a BIM-enabled asset information delivery process as proposed by [46]. BIM, in this case, is not necessarily used during operations, but as part of a process to develop and deliver structured asset information to the owners at handover. However, this asset information delivery process, which involves different activities performed by different stakeholders at different phases of a project, has not yet been consolidated in the industry or in the literature [2,8].

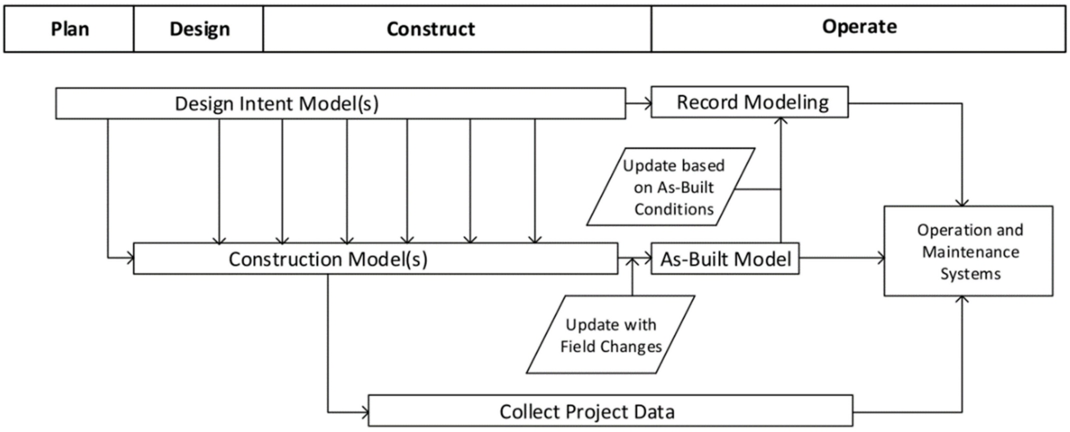


**Figure 2.** Typical information flow map for a BIM-enabled asset information delivery process proposed by [46].

A number of studies have been conducted to explore BIM-enabled asset information delivery processes in theory and in practice. Ref. [44] examined one of the first few pilot implementations of FM-enabled BIM, and discussed the challenges encountered and the lessons learned. Ref. [47] developed a workflow for BIM data transfer to asset management systems used for FM. Ref. [45] proposed a BIM-FM workflow, according to which an owner uses standardized data collection to incorporate BIM facility information into project FM systems at close-out for improved efficiency and more accurate information. Ref. [48] discussed the process flow for the creation of the FM-BIM and its integration with the Integrated Workplace Management System (IWMS) platform and proposed a method for assessing the quality of BIM deliverables at the commissioning and handover stage. Ref. [49] developed a BIM-based workflow to capture object attributes and make seamless data transfers from BIM models into FM systems. Ref. [8] explored the value and challenges of BIM in FM empirically through a case study of Northumbria University's city campus. Ref. [11] investigated how BIM-FM integration was performed in a large-scale project, covering BIM-FM platform selection and development processes, and identified the technical challenges and lessons learned. Ref. [50] explored the details and possibilities of transforming an old building into a smart and more sustainable building by using BIM-FM techniques and self-designed sensors. Ref. [51] framed the normative asset information delivery process based on the assumptions and planned procedures outlined in the COBie documentation and compared it with a descriptive process observed in a case study. Ref. [36] proposed an approach that implements industry foundation classes (IFC) BIM to link and present alarms reported by FM systems, such as building energy management systems (BEMS) and building automation systems (BAS), with related data from computerized maintenance management systems (CMMS). Ref. [52] proposed a methodology to extract BIM-related data directly from a model into a relational database for integration with existing asset management systems. The authors also discussed BIM model requirements, development of the extraction platform, database architecture and framework.

Although many variations of a BIM-enabled asset information delivery process have been proposed, there have been few successful cases of BIM implementation for FM in practice [53]. Most of the existing case studies were conducted as part of a research study, in which the findings were tested through small or medium-scale pilot studies in the context of a real-life project [11]. Furthermore, few of the published case studies provide in-depth information on both (1) owner information requirements; and (2) process of developing the asset information in BIM during the delivery phase of a project. Even though theoretical research on these two topics has been conducted through surveys, interviews, and group discussions [1,9,12,45,49,54,55], and based on industry professionals' experience and beliefs, the findings have not been tested and examined within the context of real-world projects.

Thus, the pros and cons, including challenges and barriers associated with implementing the suggested methods and processes have not yet been clarified [44].

*2.3. Standards for the BIM-Enabled Asset Information Delivery Process*

The most prominent initiatives toward the standardization of this process are COBie and ISO 19650, which will be discussed next.

COBie is an open data transfer specification developed by the U.S. Army Corps of Engineers that facilitates the delivery of managed asset information by using low-level formats such as Excel spreadsheets [56,57]. COBie is built upon the concept of model view definitions (MVD), which are predefined subsets of information contained in an Industry Foundation Class (IFC) file to facilitate BIM data exchanges between specific domains [58]. Although COBie was created as a data transfer specification, the term COBie became often used to describe the whole underlying process of asset information delivery using BIM. Consequently, it is often hard to draw the line between limitations specific to COBie as a data specification and the challenges related to the whole process of using BIM for the delivery of asset information. For this reason, and considering that many asset owners are opting for ad-hoc solutions (including the case studies in this research), the discussion of the asset information delivery process will not be framed in COBie terms.

The ISO 19650 standard is an international standard published in 2018 for managing information over the whole life cycle of a built asset using BIM. This standard contains all of the same principles and high-level requirements as the UK BIM Framework and is closely aligned with the previous BS 1192/PAS 1192-2 standards. It provides an internationally accepted framework for digital information management processes that intend to facilitate communication between stakeholders and reduce or control costs and time and improve the quality of a project [42]. However, there are limited data from case studies that could provide empirical evidence about the proposed framework in ISO 19650. So far, the main role of ISO 19650 has been to provide support for owners interested in developing and fulfilling their information requirements. Although ISO 19650 was not officially stated in the requirements of the projects discussed in this paper, its concepts were adopted to discuss the asset information delivery process in an effort to converge the findings towards a common understanding among researchers and practitioners.

ISO 19650-1 breaks down the information requirements in four documents (Figure 3) and emphasizes that a clear definition of Organizational Information Requirements (OIR) and Asset Information Requirements (AIR) is the most important factor in achieving successful asset information delivery. However, when defining information requirements for the BIM process, many owners tend to request just COBie or IFC files without carefully considering what they will need in the FM phase [59]. A critical issue here is the difficulty in identifying relevant information for BIM FM integration [60].

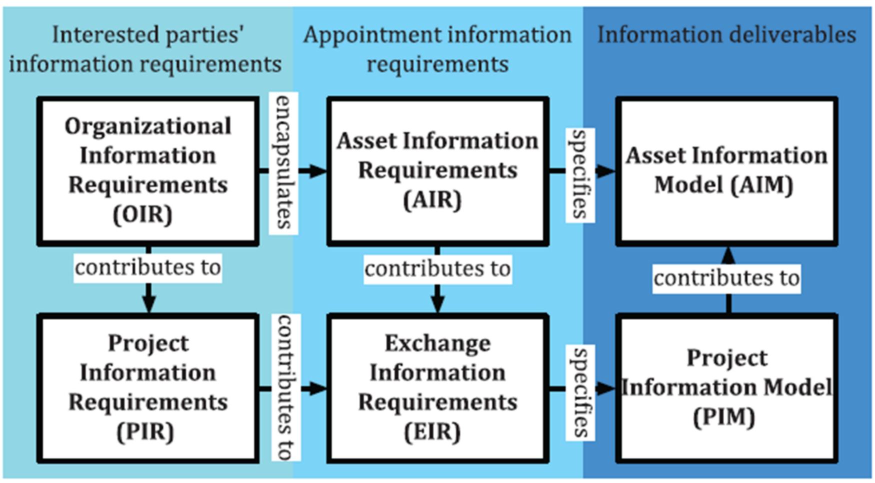


**Figure 3.** Hierarchy of information requirements (source: ISO 19650-1).

### 2.4. Synthesis of Relevant Challenges in BIM-Enabled Asset Information Delivery

Many studies have identified the lack of owner-defined information requirements as a critical barrier hindering the integration of BIM for FM [12,24,61]. This study therefore investigated a project with owner-defined information requirements to understand what the remaining challenges are and how they manifest in a project context. A review of the related literature provides a point of departure for the analysis of challenges in the case study presented in this paper.

Based on the current literature, there are still significant challenges preventing owners and facility managers from seamlessly integrating asset information produced as part of a BIM process. These challenges are framed in many different ways across the literature. Table 2 categorizes some of the main challenges:

**Table 2.** Summary of challenges described in the literature.

| Challenge/Issue | Mentioned by | Short Description or Example |
|---|---|---|
| Limited interoperability (Lack of integration between BIM and FM systems) | [2,6,8,11,12,16,19, 44,60,62,63] | "There are still many limitations with BIM integration into existing CAFM systems; this integration is necessary as not all FM related information is suitable for hosting in a BIM Environment." [19] |
| Unclear BIM requirements for FM at early project stages | [6,8,16,19,60,62–66] | "BIM requirements for data interoperability with enterprise systems is a complex topic, since facilities information systems are widely divergent, and will be a key issue with deploying BIM within FM." [6] |
| Lack of consolidated guidance, protocols, and standards for BIM FM (Industry level) | [10,17,19,63,65] | "Lack of standardized tools and processes . . . remains a key challenge for both the design team members and the building owner." [19] |
| Lack of end-user Involvement in the definition and validation of the requirements (Internal buy-in) | [10,17,52,60,65,66] | "Generally, asset owners do not engage in the design and engineering of a new project and therefore the operations and management of the facility are not considered in the formative stages." [66]; "FM team direct relationship with business core activities or FM was limited or nonexistent." [65] |
| Lack of delivery team's engagement in the process (External buy-in) | [18,44,65] | "It is also important that there is buy-in from all the team members so that all parts can have as much success as possible. Without buy-in from all members, it will decrease the quality of the BIM product, lead to added work by other project members and could result, at worst, in unsuccessful implementation of BIM on that project." [18] |
| Impact on current processes (Increased complexity, scope, cost, schedule) | [10,51,60,62,65,66] | "The challenge around producing specific asset registers with related COBie requirements can result in increased project costs and time, generating repetitive activities during the project lifecycle." [60] |
| Lack of top management support for innovative BIM processes | [13,67] | "If the BIM guidance from the top level is insufficient, then people will continue working on their project islands and will focus on their own uncoordinated developments. In other words, the top management must facilitate internal boundary spanning to make sure that people within the organization will share BIM developments not only within their respective departments or projects but throughout the entire organization." [13] |
| Contractual barriers | [10,12,17,60,64] | "Communication is inhibited by the contractual boundaries" [60]; "Lack of sufficient legal framework for integrating owners' view in design and construction" [12] |
| Lack of information quality in BIM for FM | [14,19,44,52,62–64] | "The asset management team notes that the BIM model is "simply not fifit for purpose" and does not meet their requirements, with often bulk COBie excel sheets handed over with little structure in place." [52] |

**Table 2.** *Cont.*

| Challenge/Issue | Mentioned by | Short Description or Example |
|---|---|---|
| Limited evidence of value | [2,8,66,68–70] | "Many asset owners are still skeptical about the value of adopting and integrating BIM technologies and processes into their existing organizational infrastructure and operations. Such a view deserves exploring as it is the asset owner who is ultimately best positioned to realize the benefits that can be derived by implementing a BIM strategy." [66] |
| Limited BIM maturity and/or capability | [60,62] | "Shortage of BIM skills in the FM industry" [8] |
| Limited project resources allocated to support innovation | [12,44] | "The time constraint imposed on this highly demanding and complex project makes this first-time implementation of the new FM-enabled BIM process challenging." [44]; "Undefined fee structures for additional scope" [12]. |

### *2.5. Summary of Literature Review*

To summarize, there are many potential ways in which BIM can be beneficial during the operations phase of a project. However, the central objective of using BIM to support FM activities in the literature, and also in this work, is not about using the models during operations. Instead, it is about the delivery of structured asset information through the use of BIM during design and construction. To achieve this objective, a process is needed that involves well-defined requirements and a well-planned set of activities performed by different stakeholders at different phases of a project. This process, here referred to as asset information delivery, has not been exhaustively studied. Although standards have been developed to guide stakeholders in this process, such as ISO 19650 and COBie, there have not been enough iterations between theory and practice to consolidate an understanding of the process, its challenges, and its value. Due to the limited number of projects with detailed owner requirements for BIM [71], few studies have assessed the implementation of BIM for FM from the beginning of the project until its delivery, including how the asset information is developed and delivered through the use of BIM. This research aimed to address this gap by studying recently delivered projects in which comprehensive and detailed owner information requirements related to the BIM process were formulated and included in the contractual documents.

## 3. Materials and Methods

### *3.1. Case Study Approach*

This research employed a multiple case study approach to provide an in-depth investigation into particular instances related to the research subject [72]. This strategy was suitable for answering questions related to what information should be included in the models and how this should be done [73]. Three longitudinal ethnographic case studies were conducted, hereinafter referred to as projects A, B, and C (Table 3), in which the research team was closely involved with the stakeholders during different phases of the projects. Project A was the main source of data for this study because it was the first project and had data collected for the longest period. Data collected from projects B and C were used to complement and validate the findings from project A. Although the data collected from projects B and C do not capture the whole development and delivery of asset information in BIM, these projects add significant value to this research. Project B is a continuation of the BIM implementation in project A and captures some of the lessons learned from project A in its information requirements. Project C is a relatively small residential building and uses Construction Manager as delivery method, which helps increase the external validity of this study and its relevance towards different types of projects. The main criteria for the selection of these projects was the owners' intent of using BIM to support FM and the presence of a thorough and comprehensive set of BIM requirements established before the design phase.

**Table 3.** General information about the projects used as data sources.

| Project | A | B | C |
|---|---|---|---|
| Building type | Hospital | Hospital | Residential |
| Location | BC, Canada | BC, Canada | BC, Canada |
| Owner type | Public sector | Public sector | Public sector |
| Budget | $258.9 million | $807.0 million | $30.0 million |
| Estimated completion | Summer 2020 | Early 2025 | Late 2023 |
| Delivery method | Design-Build | Design-Build | Construction Manager |
| Area | Approximately 36,500 square meters | (Information currently unavailable) | Approximately 7735 square meters in gross floor area |
| BIM requirements | BIM required for FM | BIM required for FM | BIM required for FM |
| Data collection | Interviews, survey, document analysis (including models), meeting observation | Interviews, document analysis (including models) | Interviews, survey, document analysis (including models), meeting observation |
| Project phases covered in data collection | Planning, design, construction, and handover | Planning, design, and beginning of construction | Planning and design |
| Picture |  |  |  |

Case studies combine several data collection techniques, including archival research, interviews, questionnaires, and observations [74], allowing the research team to holistically explain and understand the dynamics of the phenomenon under study [73]. The goal of using case studies as the investigation method was to analyze actual project data in its own particular context, without focusing on statistical generalizability. Although case studies cannot be easily generalized, they provide in-depth accounts of phenomena in context and can help practitioners judge whether a specific technology or process can benefit their own organization or projects [75].

*3.2. Data Collection*

The main case study is that of a large healthcare facility in Canada, hereinafter referred to as project A. A multifaceted approach was adopted that included several data collection and analytical steps. The data for this research were collected between 2019 and 2021 during which time the principal investigator worked in collaboration with the design firm and later with the owners as part of two research collaborations. During this time, data were collected using mixed methods, including document analysis, meeting observations, semi-structured interviews, and an in-depth survey (Table 4).

The document analysis was conducted using the native BIM files, BIM compliance documents, contract agreements, project requirements, and the documents produced as part of the asset data collection.

**Table 4.** Different methods, types of data and quantitative description of the data collection in project A.

| Data Collection | Type of Data Collected | Data Collected from Project A |
|---|---|---|
| Document analysis | Native BIM files | 20 models: 4 disciplines, 5 design stages |
| | BIM compliance documents | 7 model audit review reports, 2 compliance meeting minutes |
| | Project requirements | Request for Proposal, Statement of Requirements, BIM Requirements (included the Owner Standard Requirements, the Data and Geometry Specifications, and the BIM Execution Plan) |
| | Asset data collection documents | Asset data collection reports, several spreadsheets used for the asset data collection and management, access to the BIMFMi external database, and spreadsheets with data exported from Maximo |
| Semi-structured Interviews | Owners | 11 interviews with different participants including the director involved in the BIM implementation process, asset information specialist, senior design leader, facilities systems and support project leader, and maintenance planner |
| | Design team | 1 interview with the BIM manager |
| | General contractors | 2 interviews, one with the virtual design and construction coordinator and another with the design manager |
| | Trades | 1 interview with the project manager of the electric trade |
| | Consultants | 5 interviews with the BIM consultants, 2 interviews with the asset data consultants, and 1 interview with the CMMS consultant |
| Meeting observation | BIM and asset data collection meetings | 22 meetings during the end of construction and handover, including owners, BIM consultants, asset data consultants and the CMMS consultant |
| Survey | In-depth survey with design team | 19 responses to a survey containing 12 multiple-choice and open-ended questions that was internally distributed in the design firm |

Twenty-three semi-structured interviews of approximately one hour each were conducted with industry experts from different organizations involved in project A. The interviews were recorded and analyzed using the categories that emerged from the document analysis. Open-ended questions were used in the interview to encourage respondents to provide a more detailed response and to build rapport between the respondent and the interviewer [76]. Questions about the BIM process for FM were asked covering challenges, familiarity with the BIM requirements, perceptions of value, and quality of the information in the models. Each interview also had a different set of bespoke questions focused on specific aspects of the asset information delivery process pertinent to the interviewee's area of expertise. The questions were aimed at (1) filling the gaps of information not captured during document analysis and meeting observations, (2) addressing new emerging questions from previously collected data, and (3) capturing individual perceptions of benefits and challenges. The data collected from the interviews and questionnaires were analyzed through an iterative coding process [77], in which themes emerged, were refined, and tested as part of a grounded theory approach [78].

For the number of respondents required to achieve data saturation, depending on the nature of the study, Ref. [79] recommended 15 ± 10 respondents because of the typical time and resources constraints. Similar to other studies within the construction industry, the quality of experts (i.e., having the required qualifications in the field under study) is preferred over quantity [80]. A total of 15 local experts in BC were interviewed, being all directly involved with project A. Sample size was based on a judgment, in coding and analyzing, of theoretical saturation of categories, which implies that "no new properties emerge and the same properties continually emerge" [81] and that gaps in major categories were more or less filled [82]. It is worth mentioning that saturation is always a subjective judgment and the decision to stop theoretical sampling, using the methodological guidelines, was influenced by the scope of the research project, particularly in terms of time and resources [83].

The data collected from the interviews and questionnaires were analyzed through an iterative coding process [77], in which themes emerged, were refined, and tested as part of a grounded theory approach [78].

The research team members attended 22 meetings that were being held regularly by the owners during the end of construction and handover. During these meetings, the owners, BIM consultants, asset data consultants, and CMMS consultants discussed details of the asset data collection and utilization of the data for the development of preventive maintenance job plans. The research team's participation in these meetings was as an observer, and questions were asked only when the principal investigator was invited to do so.

A survey was conducted online in June 2019. The purpose of the survey was to increase the reach of the data collected towards different design team members with different roles considering the limited time and resources for interviews. It comprised 12 multiple-choice and open-ended questions. It received responses from 19 participants from the design firm who were involved in the design phase of project A. Given the small number of participants, the analysis focused on the answers to the open-ended questions about the BIM process for FM, including challenges, familiarity with the BIM requirements, perception of value, and impacts on their activities. Open-ended questions are useful for surveys that target a small group of people because there is no need for complex statistical analyses, and the qualitative nature of the questions solicits valuable input from each respondent. Anonymity was guaranteed to motivate open feedback about problems and challenges.

The data collected from projects B and C were also obtained from document analysis, meeting observations, semi-structured interviews, and a survey. However, the data collection in projects B and C was limited to data from the planning and design phases and focused on validating the findings from project A.

### 3.3. Use of the Data

The overarching objective of this research project was to perform an in-depth investigation and analysis of the BIM-enabled asset information delivery process. Two sub-objectives were articulated: (1) to document the processes and practices developed in the context of BIM-enabled asset information delivery, including the evaluation of the artifacts used to frame and support the process, and (2) to identify and map the relevant challenges in this process based on previously identified challenges in the literature. For each sub-objective, the following data were collected and analyzed:

Sub-objective 1 was based on interviews with the BIM consultants and owners and observations from the asset data collection meetings. This data served to document and formalize the processes. The evaluation of the artifacts used to frame and support the process involved document analysis of the BIM requirements and the standards and guidelines.

Sub-objective 2 served to validate and build off of the challenges identified in the literature, which were used as initial categories for a thematic analysis of all the data previously collected. Based on the observation of how these challenges manifested in projects A, B, and C, they were then mapped across different project phases and structure levels (i.e., project level, organizational level, and industry level) with the identified causal links between them. Mixed methods were employed iteratively to identify and map the challenges as shown in Figure 4.

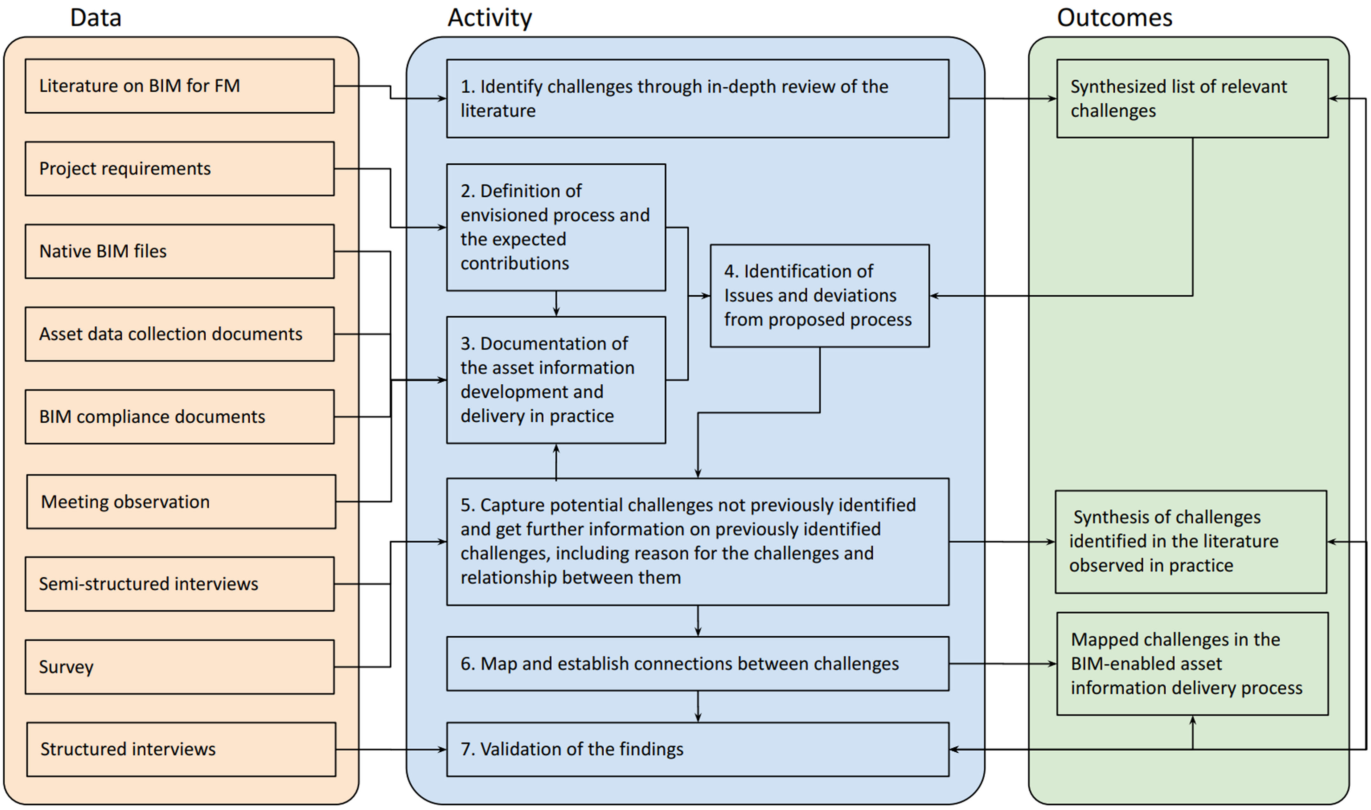


**Figure 4.** Mixed methods approach to identify and map the challenges in the BIM-enabled asset information delivery. (1) Identification of main challenges in the literature relevant to BIM-enabled asset information delivery. (2) Definition of envisioned process and the expected contributions based on the BIM requirements. (3) Documentation of the asset information development and delivery in practice based on analysis of the asset information available in the models, external database, and meeting minutes. (4) Identification of limitations of the proposed process in practice and the deviations from the proposed process captured through comparison between envisioned process and actual data developed in the models. (5) Interviews and surveys to capture potential challenges not previously identified and get further information on previously identified challenges, including the reason for the challenges and the relationship between them. (6) Mapping and establishing connections between challenges based on previously captured information about the challenges. (7) Validation of the identified challenges in the literature, how they manifested in the projects, and the mapping and connections between them.

### 3.4. Validation

Although validation occurs naturally in the ethnographic research process [78], Ref. [84] outlined triangulation as a main strategy for validating data and constructs. To increase construct validity and overcome issues of bias [85], multiple sources of evidence were used and the data collected from different sources (i.e., interviewees, documents, BIM models/BIM-FM platform) was triangulated. The triangulation also happened across the data collected from three different projects. For the characterization of the BIM-enabled asset information delivery process in eight steps, the BIM requirements were the initial source of data, providing an understanding of how the process was envisioned and the expected contributions from the different stakeholders. The analysis of the models, FM data collected in the external database, and BIM compliance reports, along with the meeting observation provided insights into the limitations of the proposed process in practice, and the deviations from the proposed process were captured. As part of a research collaboration with the design firm in Project A, one of the research team members was provided with a workstation inside the design firm for a year with access to project A files and weekly meetings with design team members involved in project A. Therefore, numerous ad hoc communications were also made in person to clarify the collected data and ask questions about the BIM models and the BIM compliance documents. Finally, the interviews and the survey were used to verify the characterization of the process, and inquire additional information about the observed limitations, deviations, and challenges, including the reason for the challenges and relationship between them. Being a longitudinal case study, the data collection was continuous and different data collection methods were employed concurrently at times. These overlaps allowed new emerging questions to be incorporated and addressed along the research progress.

The triangulation also happened across the data collected from three different projects. O&M workflow and procedures followed by different organizations can be diverse [18]. Therefore, the discussion pertaining to the BIM for FM should be based on clearly defined information requirements for FM; otherwise, these discussions would appear over-general and ambiguous [2]. However, there are a limited number of real-world case studies on BIM for FM with owner information requirements, and they lack diversity in terms of building type, size and delivery methods. The information requirements for BIM in projects B and C helped provide a clear overview of the envisioned asset information delivery process and the expected contributions and deliverables expected from each stakeholder, which supports the characterization of the normative process and increases its external validity. Most challenges identified at a project level were concerning planning and design phases. These challenges and the challenges encountered at an organizational and industry level were also observed in Projects B and C, which helped refine and verify the related findings.

In addition to triangulation through cross verification from multiple sources, dedicated meetings were conducted with BIM experts involved in projects A, B, and C for validation. During these meetings, the findings of this study were presented to the experts. Adjustments were then made to incorporate their feedback. The experts were also asked how the findings from projects A, B, and C compared with their experience in other projects to increase external validity.

For the validation of the findings related to challenges in Section 6, the procedure was carried out in three parts:

Part 1—Verification of the synthesized challenges and their observation in project A.—First, the BIM experts were presented with the synthesized challenges observed in the process. They were then asked whether they agreed with the categorization of the challenges and whether any other relevant challenges were not captured. Next, they were asked, on a scale from 1 to 5, how they perceived the level of influence of each challenge on the successful implementation of BIM for FM in project A and also in the industry in general.

Part 2—Verification of the mapped challenges and the identified connections between them.—The BIM experts were presented with the mapped challenges. For each challenge, they were asked whether they agreed with their placement as an industry level, organizational level, or project level challenge. The project-level challenges were also subdivided into planning, design & construction and handover.

Part 3—Verification of the identified connections between challenges.—The BIM experts were presented with each of the causal links identified. They were then asked whether they agreed with each of the causal links established between the challenges. Finally, they were asked whether any other causal links could be established.

At the end of each part of the procedure, they were asked whether there were any additional comments or suggestions regarding the individual challenges.

## 4. Case Study Projects

### *4.1. General Project Information—Project A*

Project A is a new 75-bed mental health substance use building of 40,163 square meters comprising the following: a central energy plant, including the fit-out of equipment required to service the whole existing campus; four levels of underground parking; associated tunnel and bridge connections to the current campus; and an advanced IT fiber optic and utilities pathway that ties into city infrastructure and enables advanced health care technologies. The project started in February 2017, and the construction was estimated to be completed by the summer of 2020. The initial project budget was approximately $260 million. It is located in Canada, and it was procured using a Design-Build delivery method.

The owners had limited expertise in BIM, and project A was a pioneer project of this scale to have formal owner-mandated BIM requirements for FM. The general contractor and trades had previous experience with BIM projects but limited knowledge of the FM-enabled BIM process. Although the design firm is listed among the top ten international design firms [86], dealing with BIM requirements for FM was a new experience for the local team involved.

The owners, one of five regional health authorities in BC, Canada, are responsible for the delivery of hospital and community-based health services to over 1.8 million people. The asset managed by the owners comprises one million square meters of lease space across 85 sites including 12 acute care hospitals, 7760 long-term care beds, outpatient care facilities, surgery centers, mental health and public health clinics, and space for home health and community care services and is supported by over 26,000 employees.

Although the Facilities Maintenance & Operations (FMO) team deals with approximately 18,000 maintenance requests per year at the campus where project A is located, the asset information digitally available in their CMMS provides limited support for the execution of these maintenance jobs. During a site visit, the maintenance planner provided a demonstration of the CMMS and the asset information available before the completion of project A. The maintenance planner mentioned that a lot of information in the system was not being kept up to date. An assessment of 80 categories of key assets for maintenance in the existing facilities, including 1275 assets, revealed that the information available in the CMMS at that moment precluded an optimal response to reactive maintenance and hindered thorough planning of preventive maintenance. This assessment revealed, for example, that 73% of the assets had no information about their maintenance procedures, which is typically contained in maintenance manuals. Other relevant fields of information in the system were also missing, as shown in Figure 5.

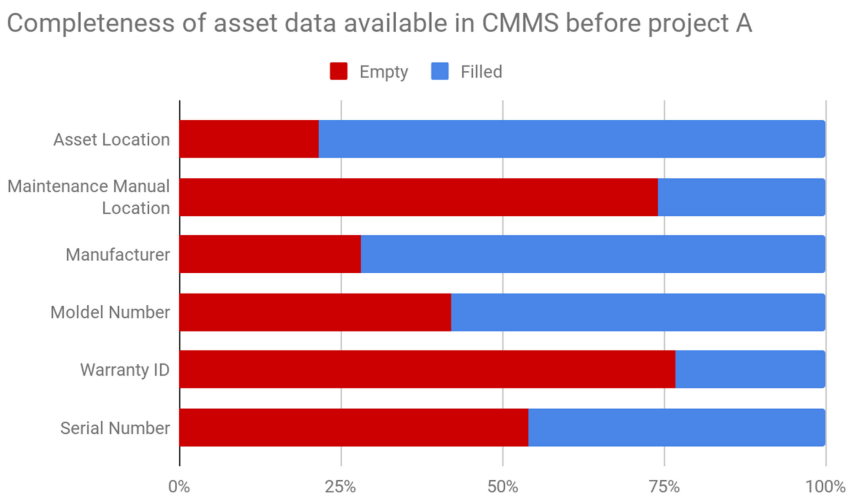


**Figure 5.** Percentage of missing fields of information for the existing facilities prior to project A. More than half of the verified assets did not have any information about maintenance manual location, warranty, or serial number.

In an effort to optimize FMO activities through better-informed decisions, the Asset Risk and Quality Technical Services department (ARQTS) of the owners proposed the implementation of BIM as a requirement for the delivery of their future projects, starting with project A.

### 4.2. General Project Information—Project B

Project B has the same owners as project A and is currently under construction on the same site as project A. It is a new 350-bed acute care tower that will include multiple floors for acute and critical care patients, an emergency department with a satellite medical imaging unit, an interventional floor with operating rooms, interventional radiology and cardiology suites, recovery suites, an underground parkade, a main entrance, and a rooftop heliport. The implementation of BIM in this project is a continuation of the BIM implementation in project A and has a similar set of BIM requirements included in the Request for Proposal.

### 4.3. General Project Information—Project C

Project C is a residential building that is currently in the design phase and has a similar set of BIM requirements for FM established by the owners and included as part of the Request for Proposal. The owner is a public sector company that works in partnership with the private and non-profit sectors, provincial health authorities and ministries, other levels of government, and community groups to develop a range of housing options. The owner develops, manages and administers a wide range of subsidized housing options across the province, helping more than 110,000 households in communities across British Columbia. Although the owners in project C were familiar with BIM being used in other projects, project C is its first project to have a consolidated set of BIM requirements that includes asset information requirements.

## 5. BIM-Enabled Asset Information Delivery Process

In this section, the asset information delivery process is presented by breaking it down into eight key activities that are further explained with examples from project A. Although the examples are from project A, the presented process was the same as proposed for projects B and C. Figure 6 presents a schematic representation of key components and activities in the asset information delivery process. The project phases are defined separately here for simplification. However, there are overlaps between them that can vary according to the delivery method employed.

a. *Definition of the Information Requirements*

The first step focuses on identifying the relevant assets that will be tracked to support FM activities, what kind of information will be collected for each of these assets during the design and construction phases, and how this information should be structured in the models.

ISO 19650 suggests the development of the information requirements in three distinct documents, the OIR, AIR, and Exchange Information Requirements (EIR), starting with the development of OIR, which should contain the information requirements at an organizational level. Although the owners had elements of an OIR in their Statement of Requirements, there was no document specifically developed as an OIR. Therefore, the scope of the analysis of the requirements in this case study was limited to the project level. The elements expected in the AIR and EIR were presented together in a set of documents called BIM Requirements.

The overall goal defined by the owner for BIM implementation was to: "Utilize a BIM process to derive consistent digital data that can be used to drive downstream uses during the entire life cycle of the facility, from design, through construction and on into Facility Maintenance and Operations." In practical terms, there were three main purposes of BIM in the project: (a) To facilitate design review and communication of design intent through 3D visualization of the model, (b) To allow virtual coordination within and between disciplines to identify and address design and constructability issues before construction, and (c) To collect asset data to support FM activities. In this paper, we focus on the third purpose, which was the owner's priority: the collection of asset data to feed their new CMMS, Maximo©, to support FM activities.

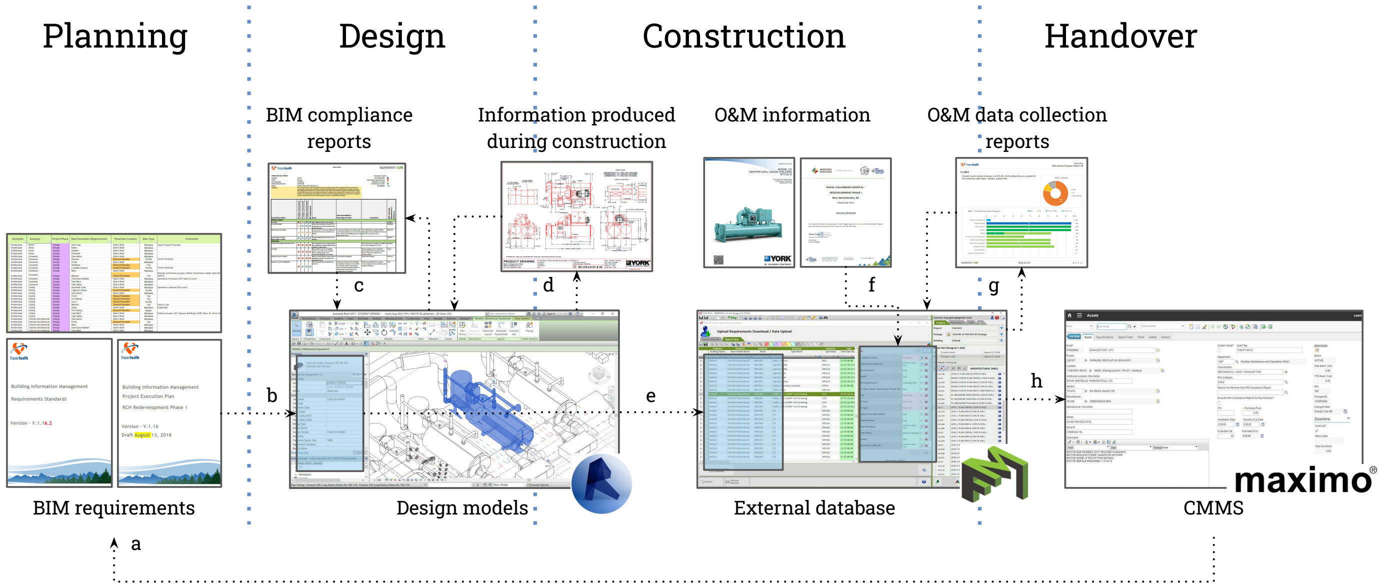


**Figure 6.** Schematic representation of the asset information delivery process in BIM. Legend: (**a**) Definition of the information requirements (BIM requirements). (**b**) Model development observing BIM requirements (creation of digital assets in BIM). (**c**) Validation of the asset information in BIM (compliance with BIM requirements). (**d**) Model updates based on design changes during construction. (**e**) Data extraction from design models into an external database (creation of an asset registry). (**f**) Association of asset information from construction phase with respective digital assets in the external database. (**g**) Validation of the asset information in the external database. (**h**) Asset information upload into FM systems.

The BIM requirements documentation comprised three main documents:

1. Owner Standard Requirements (OSR).—A standardized document used by the health authority (owner), to describe their goals and processes and establish the minimum BIM requirements in their projects. The OSR covered legal aspects, specific modeling requirements for the different disciplines, an accuracy table, virtual coordination workflows, etc.
2. BIM Project Execution Plan (BEP).—A guideline for the coordination of the BIM development process in this specific project. The BEP was meant to be a roadmap to facilitate the reuse of the models in the future. It was prepared in collaboration between the BIM consultants and the design build teams. The content included modeling strategies, quality control protocols, and collaboration tools. It was required to be updated over time to reflect the reality of the process during the design.
3. BIM Data and Geometry Specification (DGS).—This document established the information requirements for each category of objects through the specification of parameters to be added and populated in the model. A total of 130 different data parameters were specified. It also provided the Level of Development (LoD) for each category of objects. This document also included an Object List spreadsheet containing 217 different types of assets required in the model along with their importance for FM, category specification, discipline, and naming convention.

To convey asset information for FM, virtual objects employed in BIM during design are used as containers, which are here defined as digital assets. However, not all virtual objects are relevant for FM, and not all assets relevant for FM are necessarily modeled using virtual objects during design. For this reason, a spreadsheet called Object List (Figure 7) was provided as a means to ensure that all assets that will be tracked by owners in a post-construction setting have their digital representation in the model.

| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| 1 | Equipment Code Requirement | Description | Required for FM? | Model Element Author (MEA). Complete if object is in model | Category - Subcategory Requirements To be filled by MEA if blank | Discipline | Family Type Name Requirements Include as part of Type Name when applicable |
| 119 | SWB | Switchboard | TRUE | ELEC | Electrical Equipment | Electrical | Circuit Breaker, Metering, Transformer, Utility |
| 120 | SWGR | Switchgear | TRUE | ELEC | Electrical Equipment | Electrical | Arc Resistant [Amerage + KV] |
| 121 | SF | Supply Fan | TRUE | MECH | Mechanical Equipment | Mechanical | |
| 122 | TNK | Tank | TRUE | MECH | Mechanical Equipment | Mechanical | [Hotwell, Oxygen, Nitrous Oxide, Blowdown] |
| 123 | TNKAIRR | Tank, Air Receiver Tank | TRUE | MECH | Mechanical Equipment | Mechanical | Compressed |
| 124 | TNKEDHW | Tank, Domestic Hot Water Expansion Tank | TRUE | MECH | Mechanical Equipment | Mechanical | |
| 125 | TNKDHW | Tank, Domestic Hot Water Tank | TRUE | MECH | Mechanical Equipment | Mechanical | |
| 126 | TNKGEN | Tank, Generator Day Tank | TRUE | MECH | Mechanical Equipment | Electrical | Diesel |
| 127 | TNKBHRCHW | Tank, Heat Recovery Chilled Water Buffer Tank | TRUE | MECH | Mechanical Equipment | Mechanical | |
| 128 | TNKHWB | Tank, Heating Water Buffer Tank | TRUE | MECH | Mechanical Equipment | Mechanical | |
| 129 | TNKEHW | Tank, Heating Water Expansion Tank | TRUE | MECH | Mechanical Equipment | Mechanical | |
| 130 | TTB | Telephone Terminal Board | TRUE | ELEC | Electrical Equipment | Electrical | |
| 131 | TNKPHDHW | Tank, Pre-Heat Tank (Domestic Hot Water) | TRUE | MECH | Mechanical Equipment | Mechanical | |
| 132 | WC | Toilet | TRUE | ARCH | Plumbing Fixtures | Mechanical | |

**Figure 7.** Partial screenshot of the Object List spreadsheet showing the required pieces of equipment to be tracked in BIM, their code, description, author, Revit category, discipline and name requirements.

Once the design team has the information about which virtual objects are used to represent the required assets for FM, the crucial pieces of information for each asset have to be defined. All of the asset information that could be conveyed through alphanumeric parameters (semantic information) was defined in a spreadsheet called Data and Geometry Specification (DGS). Figure 8 shows an example of the DGS spreadsheet with some of the required fields of semantic information for the Revit category 'Doors'. This spreadsheet predefined the minimum asset information requirements for objects on a per category basis. It was also used to define how the information should be provided (i.e., parameter type and data type), and when the information should be made available in the model (i.e., phase and percentage completed). A separate tab of asset information requirements was provided for the information to be collected at that construction phase.

| | A | B | C | D | E | F | H | I |
|---|---|---|---|---|---|---|---|---|
| 1 | Discipline | Catego | Projec | Data Parameters Requirements | Parameter | Data Type | Phase | Phase |
| 55 | Architectural | Doors | Design | Acoustic Gasket | Shared Parameter | Yes/No | CD | 100% |
| 56 | Architectural | Doors | Design | Barricade Solution | Shared Parameter | Text | CD | 100% |
| 57 | Architectural | Doors | Design | Card Lock Access | Shared Parameter | Yes/No | CD | 100% |
| 58 | Architectural | Doors | Design | Closer | Shared Parameter | Yes/No | CD | 100% |
| 59 | Architectural | Doors | Design | Connection to Fire Alarm | Shared Parameter | Yes/No | CD | 100% |
| 60 | Architectural | Doors | Design | Control Switch | Shared Parameter | Yes/No | CD | 100% |
| 61 | Architectural | Doors | Design | Covering Type | Shared Parameter | Text | CD | 100% |
| 62 | Architectural | Doors | Design | Door Edge Protection | Shared Parameter | Yes/No | CD | 100% |
| 63 | Architectural | Doors | Design | Door Edge Protection Type | Shared Parameter | Text | CD | 100% |
| 64 | Architectural | Doors | Design | Door Material | Shared Parameter | Text | CD | 100% |
| 65 | Architectural | Doors | Design | Door Signage | Shared Parameter | Yes/No | CD | 100% |
| 66 | Architectural | Doors | Design | Door Signage Label | Shared Parameter | Text | CD | 100% |
| 67 | Architectural | Doors | Design | Electromagnetic Lock | Shared Parameter | Yes/No | CD | 100% |
| 68 | Architectural | Doors | Design | Electronic Access | Shared Parameter | Yes/No | CD | 100% |
| 69 | Architectural | Doors | Design | Emergency Breakout | Shared Parameter | Yes/No | CD | 100% |
| 70 | Architectural | Doors | Design | Exit Door | Shared Parameter | Yes/No | CD | 100% |
| 71 | Architectural | Doors | Design | Finish | Built in Revit | Metadata | CD | 100% |
| 72 | Architectural | Doors | Design | Fire Label - SP | Shared Parameter | Number | CD | 100% |
| 73 | Architectural | Doors | Design | Fire Rating | Built in Revit | Metadata | CD | 100% |
| 74 | Architectural | Doors | Design | Frame Type | Built in Revit | Metadata | CD | 100% |
| 75 | Architectural | Doors | Design | Function | Built in Revit | Metadata | CD | 100% |
| 76 | Architectural | Doors | Design | Glazing Area | Shared Parameter | Area | CD | 100% |

**Figure 8.** Screenshot of DGS with examples of data parameters required for the Revit category 'Doors'.

Since some geometric information, such as the shape of an object, cannot be efficiently described through alphanumeric parameters, geometric requirements were defined using the LoD matrix concept (Figure 9), which was adopted following the BIMForum Level of Development Specification guidelines [56].

| | A | B | C | D | E |
|---|---|---|---|---|---|
| 1 | | Discipline | Category | Project Phase | BIM Forum LOD (Geometry) |
| 2 | | Architectural | Areas | Design | |
| 3 | | Architectural | Casework | Design | LOD200 |
| 4 | | Architectural | Ceiling | Design | LOD200 |
| 5 | | Architectural | Columns | Design | |
| 6 | | Architectural | Curtain Panels | Design | LOD300 |
| 7 | | Architectural | Curtain Systems | Design | LOD300 |
| 8 | | Architectural | Curtain Wall Mullions | Design | LOD300 |
| 9 | | Architectural | Doors | Design | LOD300 |
| 10 | | Architectural | Floors | Design | LOD300 |
| 11 | | Architectural | Furniture | Design | LOD300 |
| 12 | | Architectural | Furniture Systems | Design | LOD300 |
| 13 | | Architectural | Generic Models | Design | LOD300 |

**Figure 9.** Partial screenshot of the DGS spreadsheet showing the expected LoD for each category of object at a certain phase of the project.

b. *Model development observing BIM requirements (Creation of a digital asset in BIM)*

In this step, the digital versions of the assets are created as objects in a BIM environment. Regardless of the BIM requirements for FM, this step is an intrinsic part of any project authored in BIM. Whenever an object is placed in a model, some information is automatically generated and associated with this object as a consequence of the parametric nature of BIM authoring tools. Location, classification, identification, geometry, and relational information are examples of types of information generated when a virtual object is placed in a model. What differentiates this step in an FM-oriented BIM process is the observation of certain rules by the design team to ensure that the asset data can be later extracted from the models by other teams without losing data quality.

These rules were described in both the modeling requirements established in the OSR and the modeling strategies defined in the BEP. The modeling requirements specified rules to be followed during the creation of content using the BIM authoring tool (Revit). The modeling strategies stipulated how the designers would coordinate the collaboration between different models for each discipline.

c. *Validation of the Asset information in BIM (compliance with BIM Requirements)*

Current workflows employed by designers during BIM development do not necessarily result in asset information that can be used by the asset owners. This misalignment between the conventional way designers use BIM for their own purposes and how they are expected to use BIM to deliver asset information creates the need for a validation process involving the asset owner. This validation process occurs concurrently with the model development to ensure that the owner's information requirements are met and prevent the accumulation of issues at the end of design.

In project A, this validation process was conducted by the BIM consultants. The models were periodically reviewed against the BIM requirements, and a compliance report was provided to the design team with a list of issues that required their attention. Figure 10 shows the timeline of project A with seven model reviews and five BIM-related meetings that took place during design. Figure 10 also shows when each of the five versions of the models were submitted relative to the scheduled design development milestones.

To improve the QA/QC of the models, the design team employed the Autodesk model checker plugin for Revit. This tool was used for (a) General model checks covering file characteristics, model settings, and restricted elements, (b) Discipline-specific category checks to verify elements that should or should not exist in each category, (c) Checking discipline-specific parameter requirements per the DGS, and (d) Family and type naming checks covering mandatory and restricted terms.

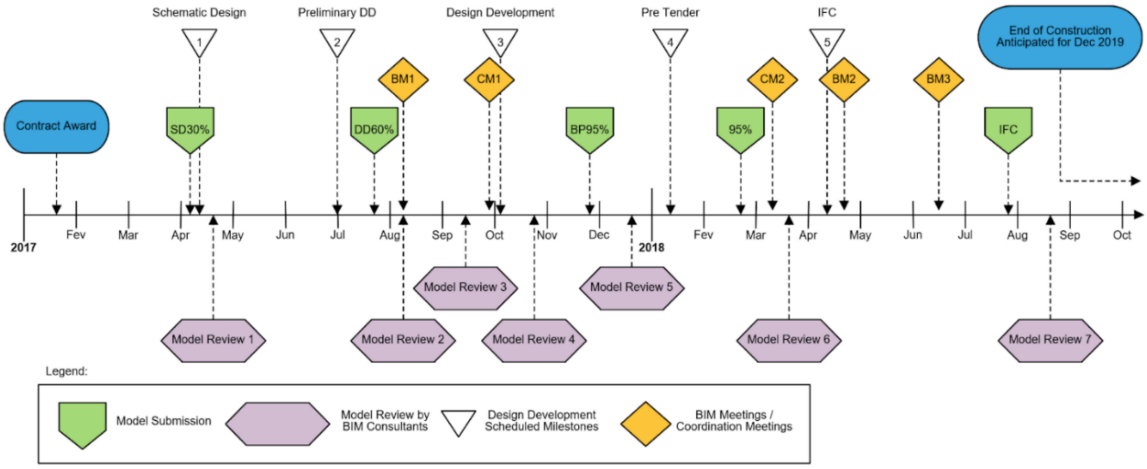


**Figure 10.** Timeline of the BIM compliance process during design.

The DGS spreadsheet was fundamental for this step, during which specific data requirements were defined for each category of BIM object. Figure 11 shows an example of different data parameters required in the DGS being incorporated in the respective categories of objects in BIM. Ideate BIMLink, a plugin for Revit, was used to create and export schedules with parametric data, which allowed data import using Excel spreadsheets. The Autodesk Classification Manager plugin for Revit was used to populate classification information that was difficult to access in Revit, such as the assembly code and OmniClass number. As well as supporting FM activities, the additional information required in the DGS enabled BIM to be used as a tool for the design reviews.

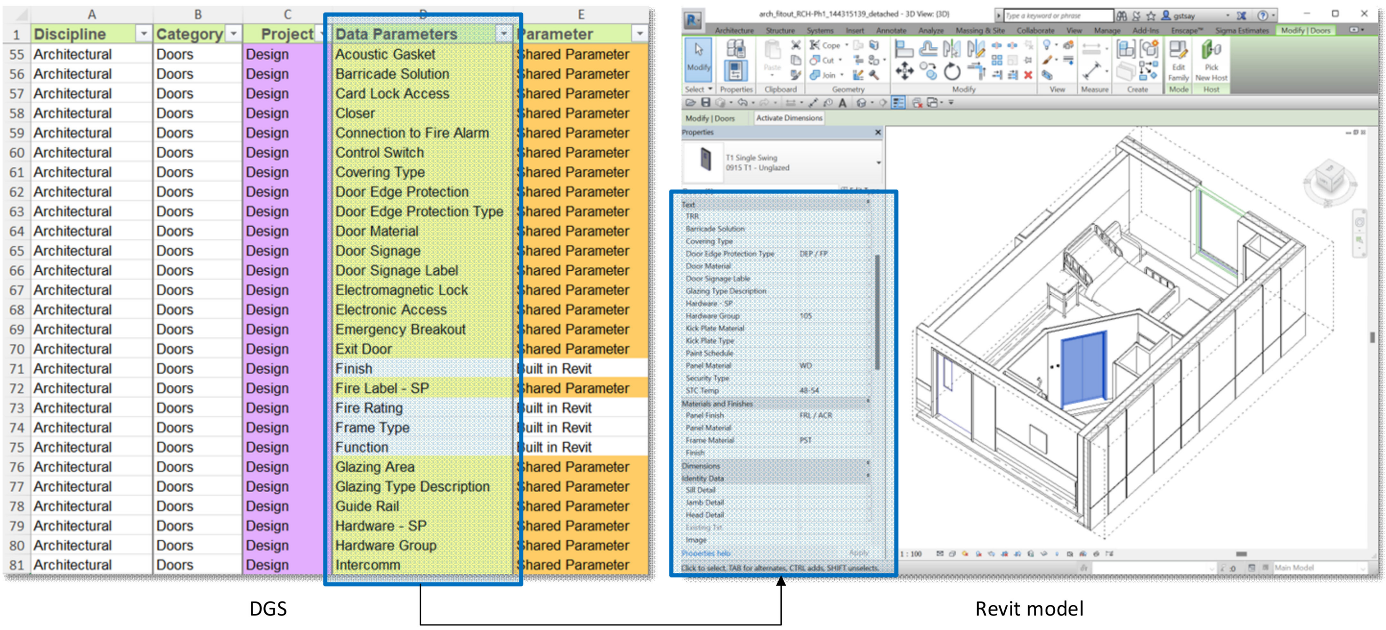


**Figure 11.** Schematic example of the asset information required in the DGS being incorporated into the Revit models during design.

d. *Model updates based on design changes during construction*

The deviations from design that happen during construction that affect the required asset information need to be captured and incorporated into the design models in an ongoing manner. This is to ensure the accuracy of the asset information in BIM for downstream use. To define what changes are sufficiently relevant to be incorporated into the design models, the BIM consultants provided an accuracy table that defined the tolerance of acceptable deviations between the fabrication models, as-built conditions, and design models. When the deviation exceeded the defined tolerance, the contractor was required to provide the designers with red lines that were used to update the design models.

As part of the BIM-enabled asset information development process, it was expected that the trades would produce fabrication models that could complement the asset information from the design models. Although these fabrication models provided an additional level of detail in terms of geometric information for specific systems, which was useful for virtual coordination, there was no additional semantic information captured. Therefore, these fabrication models were not used directly to provide asset information.

e. *Data extraction from design models into an external database (Creation of an asset registry)*

The creation of a database with information from the design models, structured by assets, is necessary to facilitate the provision of information during construction. Figure 12 shows the data parameters for a specific asset in BIM being imported into the BIM-FM platform that served as an external database. Although the models are databases themselves, there are a few reasons why they are not used to collect O&M information directly. First, the need for access to software such as Revit, and the necessary familiarity with it, can be a barrier for the general contractor (GC) and trades that limits their ability to associate O&M information with the assets. Furthermore, BIM authoring tools are not well suited to incorporate large number of PDFs. Finally, design models often contain large amounts of information that are not required or useful for FM, which can be overwhelming and end up compromising the access to the required asset information.

In project A, proprietary BIM-FM platform software developed by the BIM consultants was employed to facilitate the stakeholders' collaboration and access. This software, BIMFMi, served as a consolidated external building data repository. It also had a cloud-based interface in which the contractors and subcontractors were trained and granted access to upload documents and semantic information to specific model objects related to their activities.

A key aspect of this phase is the data format used to manage the information, especially outside the BIM authoring tool environment. COBie has been proposed as a standard data exchange format in the industry. However, the BIM consultants opted for a bespoke solution that worked well with their external database software, BIMFMi. Although this specific software was used in this project, other solutions are available for managing BIM data externally, such as Autodesk BIM 360 Ops, VueOps, EcoDomus, and even Excel spreadsheets.

f. *Association of asset information from the construction phase with respective digital assets in the external database*

In this step, the GC and trades provide both semantic information and PDF documents to the external database. A fundamental aspect of this step is the association of the information with specific assets in a structured way. Figure 13 shows the different types of asset information that can be accessed in the external database. This differs from what happens in a traditional handover in which the asset information is delivered in O&M binders that are organized by a classification system, such as Omniclass. In project A, the information provided at this point was directly uploaded into the external database, meaning that this information was not necessarily incorporated into the models.

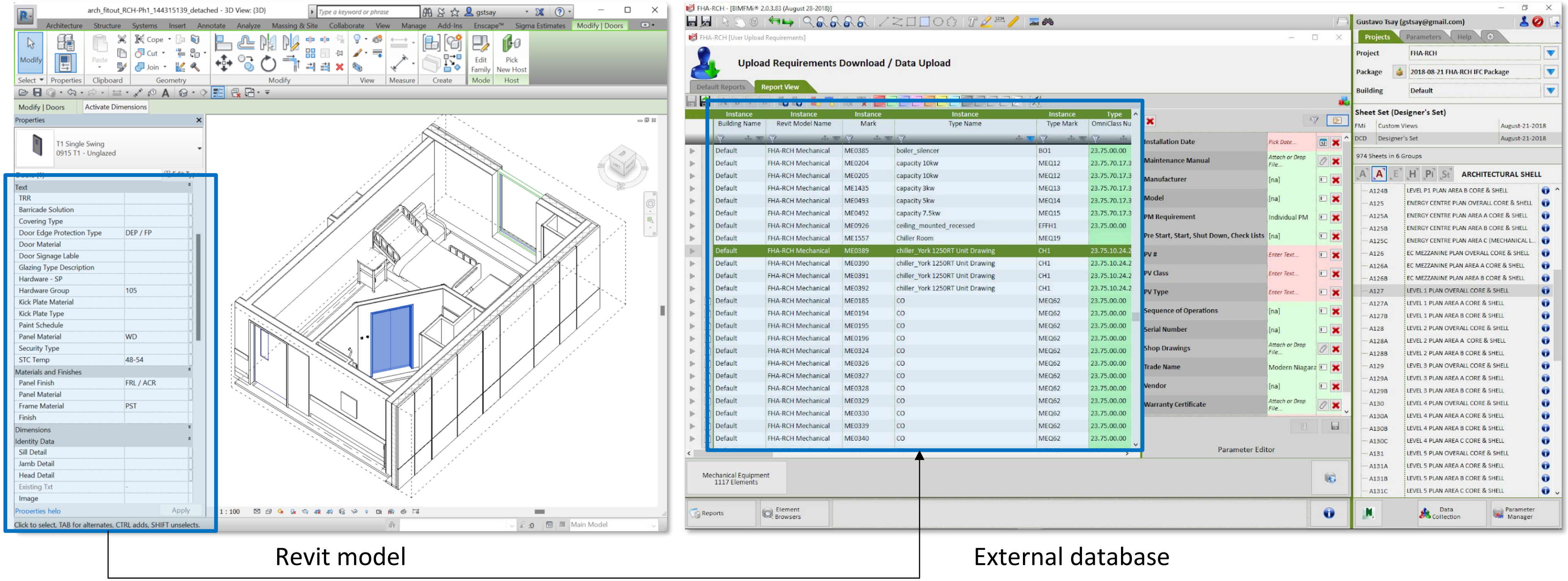


**Figure 12.** Schematic example of the information developed in the design models being incorporated into the external database (BIMFMi).

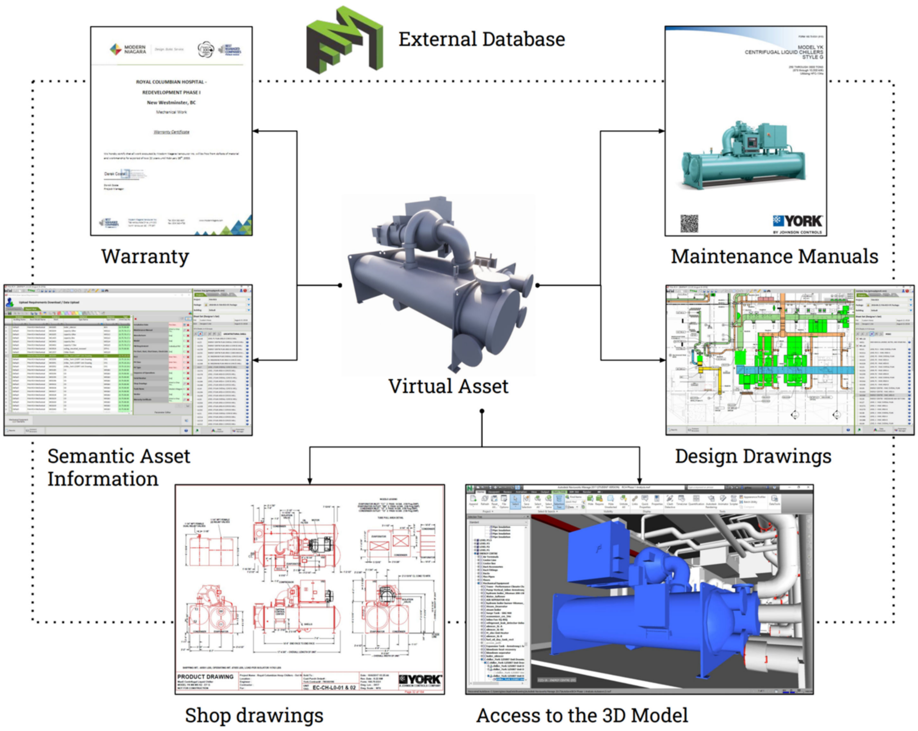


**Figure 13.** Representation of asset information available (Chiller) in the external database.

g. *Validation of the Asset Information in the External Database*

Concurrently with the previous step, the semantic information and PDFs provided in the external database are validated against the information requirements. In project A, the GC was in charge of overseeing the asset information uploaded by the trades and making sure that it was accurate. The BIM consultants were responsible for verifying whether the information uploaded to the external database was complete and reporting this to the owner.

h. *Asset information upload into FM systems*

Finally, the information collected in the external database is uploaded into the CMMS, Maximo in project A. As part of this step, the Owners and CMMS Consultant parsed and complemented the asset information collected in the BIM process using Excel spreadsheets. Once the data was properly formatted, it was uploaded into Maximo using .csv files. It is important to note that not all of the asset information available in the external database was necessarily imported into Maximo because BIMFMi remained as a source of information available to the owners.

The main purpose of a CMMS is to manage maintenance work orders, but it is also used to record and track all maintenance, see the asset history, ensure the performance of critical equipment, keep track of asset inventory, define priority in the maintenance schedule, and use the data to spot trends and make well-informed decisions. The information created in Maximo revolves around the assets and the work orders. While the asset information comes from the BIM process, information about the work orders is built up as work orders are created during the operations phase. These two sources of information are then connected through an asset number provided when a work order is created, which creates the possibility of different analyses. Figure 14 shows examples of the different types of asset information available per asset in the CMMS as result of the BIM process integrated with work order information.

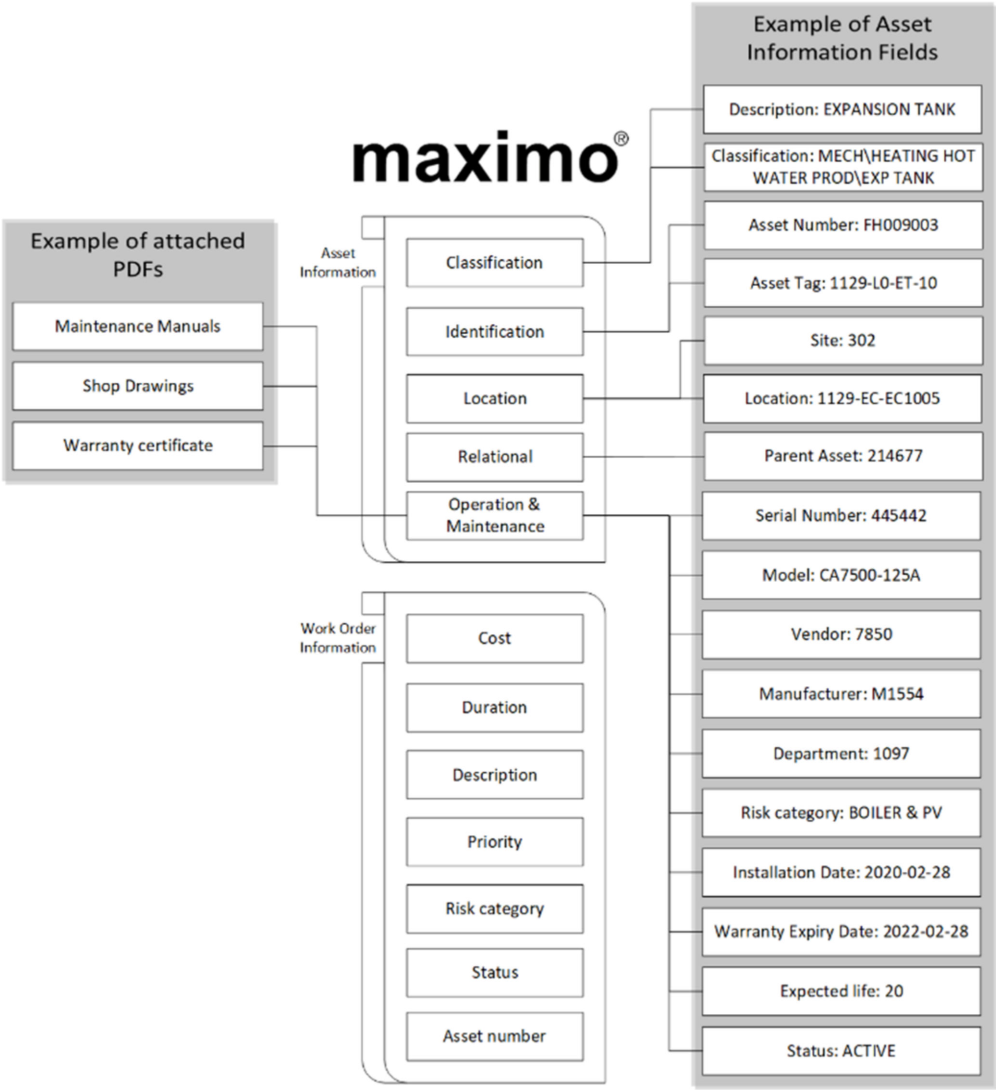


**Figure 14.** Representation of different types of information available per asset in the CMMS in the operations phase.

This section summarized the key steps in the BIM-enabled asset information delivery process. The next section will describe the challenges observed in this process and map these challenges across the industry, organization, and project levels.

## 6. Synthesizing, Verifying, Mapping, and Establishing Connections between the Challenges in BIM-Enabled Asset Information Delivery

### *6.1. Synthesis and Verification of Challenges*

As previously mentioned, several challenges prevent the efficient implementation of a BIM process to support FM activities. Although project A had comprehensive information requirements and BIM consultants to guide the whole process, many challenges previously mentioned in the literature were observed. Table 5 describes how these challenges manifested in project A.

**Table 5.** Synthesis of challenges identified in the literature with examples and description of how they were observed in practice.

| Observed Challenge/Issue Identified in the Literature | Example of Challenges/Issues Observed in Project A |
|---|---|
| Limited interoperability (lack of integration between BIM and FM systems) | • Although the issue of difficult interoperability was mentioned, interviews with the CMMS consultant and an analysis of the spreadsheets containing data from the BIM models revealed that the challenge of exchanging information between the BIM and FM systems was not software related. Instead, it was due to the lack of adequate structure in the asset information that is created in BIM during design, which is further discussed as part of another issue—lack of information quality in BIM for FM. |
| Unclear BIM requirements for FM at early project stages | • An assessment of the developed asset information demonstrated that the asset information requirements initially developed were significantly changed throughout the project. The changes affected the type of assets and the information that were tracked, naming conventions, and the classification of the assets in groups or categories. As a first project to have asset information requirements as part of a BIM process, it was not clear to the owners what, and how much, data was reasonable to request. Moreover, the BIM requirements were established based on potential uses of the model not currently employed by the owners. The project team agreed that a better understanding of the projected model uses could help define more useful information requirements and minimize the data collection scope. |
| Lack of consolidated guidance, protocols and standards for BIM FM (industry level) | • Although there are standards such as COBie and ISO 19650 that provide guidance for the asset information delivery process, there is still uncertainty among practitioners about their viability. For example, the BIM consultants mentioned that one reason not to use COBie as a data specification format was the level of complexity and level of additional effort required to initially input the mapping for the COBie export into Revit. Regarding ISO 19650, the framework was partially aligned with the proposed process outlined in the requirements. However, the BIM consultants opted to not adopt the terminology suggested in ISO 19650 because it is still not widely known or understood among stakeholders and could create unnecessary confusion. |
| Lack of end-user involvement in the definition and validation of the requirements (internal buy-in) | • Although the asset information requirements were developed in collaboration between the owners and the BIM consultants, the input from the FMO team was limited due to their lack of familiarity with the BIM process. It was also hard for them to define detailed requirements because they were not used to relying on this information being thoroughly delivered at handover.<br>• Most of the compliance assessment against the asset information requirements was performed by the BIM consultants who verified whether the required data was being provided in the right format. However, the more technical aspects of the asset information provided, and the accuracy of this information were not fully verified. |
| Lack of delivery team's input in the definition of the process | Limited use of the BEP:<br>• Stakeholders can provide input in the definition of process during the planning phase or during project execution. Ideally, this involvement should happen early on, as is the case in Integrated Project [44]. Given that the delivery method in project A was a Design-Build, the delivery team's input in the definition of the process and requirements occurred through documenting their own approaches in the BEP. As part of the required collaboration between different parties, the BEP should be a living document that is updated periodically as a record of the agreed workflows observed during a project's design and delivery. However, as of the most recent reviewed data upload report created by the BIM consultants, the delivery team had still not provided complete updates in the BEP to reflect how the data was being collected.<br>Establishment of clear scopes among stakeholders:<br>• As stated in the BIM requirements, "It is important to note that using a BIM process introduces additional scopes of work not present in traditional workflows." Because the implementation of a BIM process, especially for FM, is not yet a mainstream process in the industry, it requires a significant amount of time and effort to clearly communicate the objectives and methods of this process to the stakeholders. This early communication is critical to align expectations and clarify each stakeholder's responsibilities. Although several BIM meetings were conducted in early phases of the project, the different teams among the stakeholders still had different understandings about the proposed process of using BIM for asset information delivery. |

**Table 5.** *Cont.*

| Observed Challenge/Issue Identified in the Literature | Example of Challenges/Issues Observed in Project A |
|---|---|
| Lack of delivery team's engagement in the process | Regarding the collection of asset information from the GC and trades, it was observed that a large part of the required information (PDFs and semantic information) was not provided as expected. This missing information had to be collected separately by the CMMS consultant and during the labeling process. According to the interviews, the main reasons for not providing the information were:<br>• Low priority of asset data collection compared to actual construction.<br>• Lack of understanding of the BIM-enabled asset information development process and its value.<br>• Inconsistencies between the asset data in the drawings and the actual assets installed were observed. As mentioned by the BIM consultants, there were inconsistencies in the data extracted from the design models, which prevented the trades from providing asset data correctly. It was expected that the trades would provide feedback to indicate discrepancies between the assets in the database and what was actually installed. However, such feedback was often not provided.<br>• Lack of a responsible person for asset data management on the DB team was also pointed out as a contributing factor for this issue.<br>• The GC mentioned that not enough time was allocated to perform the required asset data collection. |
| Impact on current processes (increased complexity, scope, cost, schedule) and lack of awareness about this impact | Impacts of BIM requirements for FM:<br>• Since it was the first time the design team was dealing with this level of BIM requirements for FM, the implications and required changes in the design processes were unknown. Multiple design team members mentioned that the BIM requirements implied significant changes in the way designers use Revit to create content in the models. These changes are subtle and not necessarily evident in the drawings. Therefore, an in-depth QA/QC process was necessary to ensure information quality in the model, which was significantly time-consuming.<br>• A similar issue was observed on the GC side: According to the BIM consultants, the GC and trades did not fully understand the need for the BIM process. They thought that BIMFMi was simply a platform for them to upload the asset-related documents (manuals, PDFs, etc.), i.e., a PDF repository. It was their understanding that somebody else would go through all of the data to find the required information and associate it with the digital assets in an organized way, because this was never part of their conventional scope. As mentioned by the asset information specialist, the GC and trades needed to understand that they were also hired to provide the information necessary to maintain the building.<br>Lack of awareness about the impacts of the BIM requirements for FM:<br>• The interviews and the survey revealed different perceptions of additional effort involved in the BIM-enabled asset information delivery process. It was initially expected by the owners that there would be a minimal increase in the delivery team's scope, which was perceived differently by the DB team. |
| Lack of top management support for innovative BIM processes | • Although the ARQTS team in organization A was able to efficiently drive the implementation of a BIM process, other departments within organization A that were important for the process did not have the same level of priority dedicated to BIM and the development of the digital assets. A director of organization A mentioned that if the value of this process was better established, it would be easier to build a business case around it and increase the buy-in from different departments in the organization. |
| Contractual barriers | Lack of contractual leverage to enforce the BIM requirements:<br>• The implementation of a penalty clause, or some form of contractual constraint to enforce compliance with BIM requirements, was mentioned several times during the meetings and interviews. The fact that the owners can withhold payment in case of defectiveness, incompleteness, or a failure to render the service according to the agreement provides leverage to ensure proper execution of the delivery team's duties. However, the inclusion and understanding of BIM and the asset information as contractual deliverables were still immature. |

**Table 5.** *Cont.*

| Observed Challenge/Issue Identified in the Literature | Example of Challenges/Issues Observed in Project A |
| --- | --- |
| Lack of information quality in BIM for FM | Quality control of the information in the models:<br>• Design practices not supported by the BIM standard requirements, such as creating content outside of Revit, still occurred, which compromised certain aspects of the information quality in the design models. Examples of such issues are: missing or duplicated information, inconsistencies between data fields in Revit, and unclear descriptions of assets.<br>• According to the assessment of the information in the design models, and the CMMS consultant, the data provided in the design models were not always accurate. During construction, the purchase and installation of equipment can often deviate from design; this requires additional effort to register the corrections in BIM, which was not fully observed in project A. |
| Limited evidence of value | Understanding the value of the BIM implementation process for FMO:<br>• According to the director of the ARQTS team, few people in the organization were familiar with BIM processes, and the value of BIM implementation was not clear to the FMO team. The ability to measure the value or benefits of the BIM process is essential to its implementation. A better understanding of this value in later stages can help justify adequate incentives for the additional work scope during design and construction and to ensure high engagement of the different teams involved in the project.<br>• Although it was part of the BIM requirements, the collection of Key Performance Indicators to assess the benefits of the BIM process was not carried out by the GC, who did not agree to share their costs.<br>• As pointed out by the asset information specialist, there was still not enough data to support a complete assessment of the value of the BIM process for FMO. It can take years of operating a building and a comprehensive record of work order data to allow for a full understanding of the benefits. |
| Limited BIM maturity and/or capability | Limited BIM maturity among stakeholders:<br>• The survey with the design team found that many people working on the project were not entirely familiar with the BIM requirements or the strategic goals behind them. Although these goals were broadly explained in the BIM requirements documentation, the primary purpose of utilizing the BIM data for facilities management was still not completely understood. The survey answers indicated that people had to do additional work to comply with the requirements, often without knowing how it would add value to the design. For them, it was unclear whether and how the additional information required was going to be utilized. Furthermore, the fact that a lot of time was spent adding content to the models that was not shown in the drawings was not perceived as a positive contribution to the quality of the design in general.<br>• According to the BIM consultants, the BIM maturity level in the local industry was overestimated during the planning phase. Reassessing local and current BIM practices could help identify achievable value without causing excessive disruption to current processes.<br>Limited internal capability of the owners to fully benefit from the model:<br>• The project leader of the facilities systems and support team mentioned that although there was a large amount of information in the BIM models, it was still a challenge for other teams less familiar with BIM to extract only the needed information.<br>• During the data collection process, the owners were highly dependent on the BIM consultants to access the asset information due to limited access to BIM software and familiarity with it.<br>• Although having BIM consultants during the procurement phase was mentioned as very advantageous due to their general expertise, it was also mentioned that it would be helpful to have dedicated asset management personnel with BIM capabilities in-house to streamline the process and conduct specific information retrieval from the models. |
| Limited project resources allocated to support innovation | • The resource allocation required for BIM activities, in general, was underestimated. The level of BIM requirements in this project was unprecedented for all of the teams involved, and both the design and construction teams revealed in the interviews that one of the main challenges was insufficient time allocated for the additional activities. |

## *6.2. Mapping and Establishing Connections between Challenges*

In Figure 15, the challenges mentioned in the literature and observed during the project are analyzed and mapped across the different project phases and across different levels. The levels used in the analysis were the industry level, organizational level, and project level. The challenges at an industry level are challenges that happen across different projects and organizations but within the same industry (i.e., the AECO industry in this case). The challenges at the organizational level are challenges that happen across projects but within the same organization (e.g., owners, design companies, GCs). The project-level challenges happen within a single project. This distinction between levels is relevant because it suggests that there are different magnitudes of the scope of action required to deal with each type of challenge. For example, as an industry-level challenge, "limited evidence of value" cannot be fully addressed by a single organization, much less by a single project. Figure 15 also provides a holistic overview of the different challenges mentioned in the literature by indicating causal links between them based on the observations in the case study. The causal links indicate the influence through which one challenge contributes to other challenges (to different degrees), where the cause is partly responsible for the effect, and the effect is partly dependent on the cause.

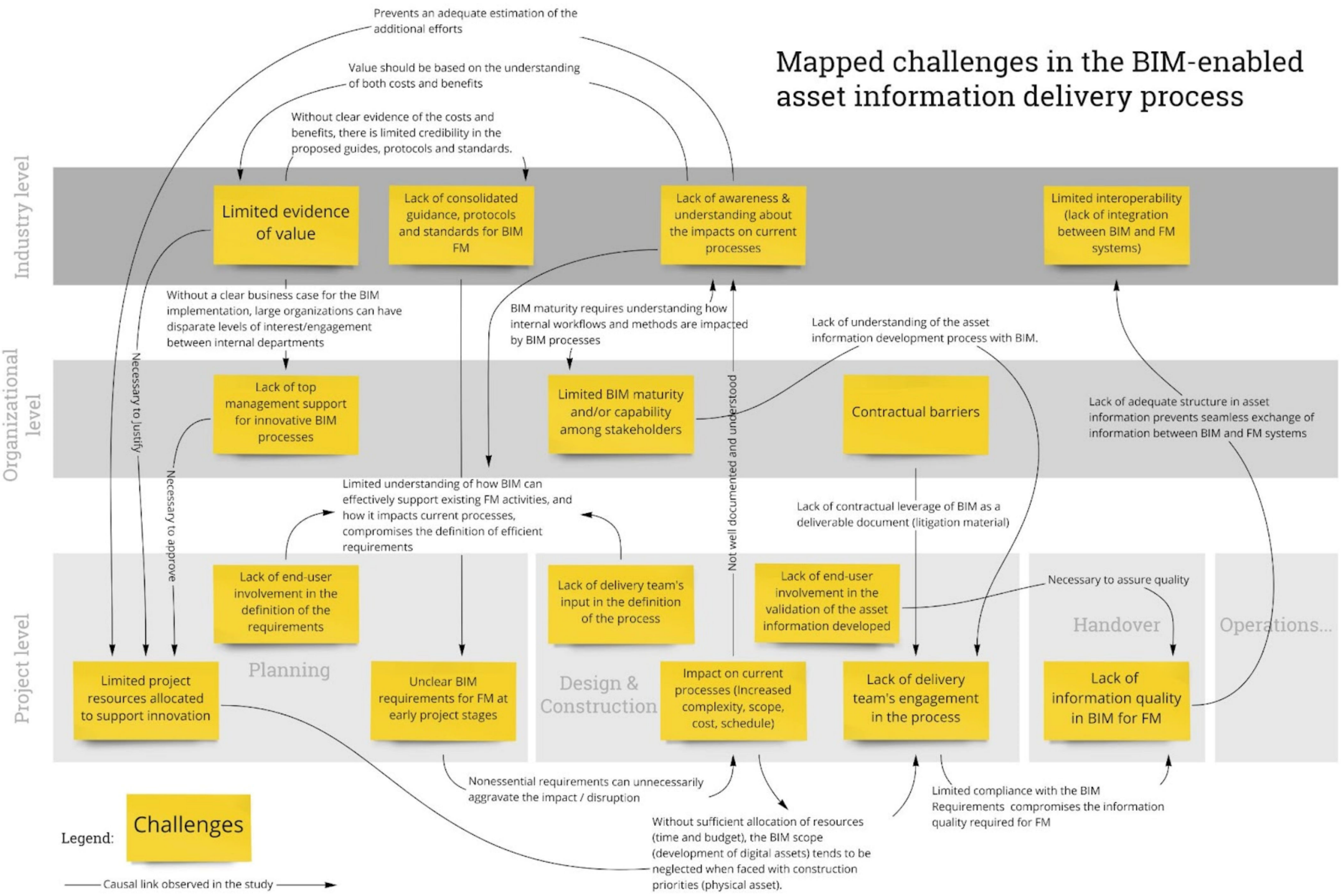


**Figure 15.** Mapped challenges in the BIM-enabled asset information delivery process.

## *6.3. Verification of Challenges*

The feedback obtained from the experts during validation was positive and reinforced the relevance of the challenges, their mapping, and the causal links between them. Figure 16 shows the average level of perceived influence of each challenge for the successful implementation of BIM for FM.

| Observed challenge: | Average level of perceived Influence | |
|---|---|---|
| | Project A | Industry in general (Other projects) |
| Limited interoperability (Lack of integration between BIM and FM systems) | 2 | 2 |
| Unclear BIM requirements for FM at early project stages | 4.5 | 5 |
| Lack of consolidated guidance, protocols, and standards for BIM FM (Industry Level) | 4 | 4 |
| Lack of end-user Involvement in the definition and validation of the requirements | 4 | 4 |
| Lack of delivery team's input in the definition of the process | 4 | 4 |
| Lack of delivery team's engagement in the process | 5 | 5 |
| Impact on current processes (Increased complexity, scope, cost, schedule) | 3 | 2 |
| Lack of top management support for innovative BIM processes | 5 | 5 |
| Contractual barriers | 4 | 4 |
| Lack of Information Quality in BIM for FM | 5 | 5 |
| Limited evidence of Value | 4 | 4 |
| Limited BIM maturity and/or capability | 3 | 3 |
| Limited project resources allocated to support innovation | 4 | 3 |

Legend:

| | |
|---|---|
| 1 | Not influential |
| 2 | Slightly influential |
| 3 | Somewhat influential |
| 4 | Very influential |
| 5 | Extremely influential |

**Figure 16.** Average level of perceived influence of each identified challenge for the successful implementation of BIM for FM.

Two of the challenges were perceived as only slightly influential. The reason for considering limited interoperability as slightly influential was that most of the issues related to transferring the data between software were associated with low data quality and not as a software-related issue. Regarding the impact on current processes, the experts expressed that there is, indeed, a required shift in the way things are done, which implies an increased scope for the delivery team. However, this can be seen as an opportunity for delivery teams with higher BIM maturity and not necessarily as a challenge when the expertise and the resources are available. The experts also noted that the teams are often not fully aware of their required input in the process, and how this lack of awareness affects their internal processes during initial project phases, which can ultimately impact the quality of the asset information delivery.

Their feedback was also important to validate the relevance of these findings across the industry. Based on their experience with other projects, the perceived challenges in project A are similarly relevant across the industry, as indicated by similar values between the two columns in Figure 16. Three challenges were perceived slightly differently when comparing project A with their other projects. The lack of clear BIM requirements for FM in the early project stages was a major challenge. However, the fact that the owners hired BIM consultants to help develop these requirements from the beginning reduced the relevance of this challenge in project A. The impact of BIM requirements for FM on current processes was perceived as a more relevant challenge in project A than in industry in general owing to the increasing BIM maturity of delivery teams across the industry. The limited resource allocation to support innovation was also perceived as a more relevant challenge in project A because there is a growing understanding about the asset information delivery process across the industry.

Other than the observations above, the experts generally agreed with the presented findings. Minor observations and other comments have been already incorporated as part of the findings of this research.

## 7. Discussion

Because using BIM for FM is relatively new to the AECO industry, the characterization of an FM-enabled BIM process is still unconsolidated. Moreover, as observed in practice, design and construction teams are often involved in FM-enabled BIM processes without fully understanding their required contributions. Although a considerable number of studies on BIM for FM have been conducted in the past years, few studies have documented the whole process of development and delivery of asset information using BIM following pre-established information requirements and its implications in real large-scale projects [10,11]. Therefore, empirical knowledge such as the common BIM data requirements for O&M, current BIM data delivery and presentation methods, use of new technologies, and hypothetical BIM–O&M use cases are still required as a foundation for the development of more powerful and generally applicable standards, guidelines and BIM-based solutions for facility O&M [2].

This gap was addressed by documenting the processes being adopted in the local industry through case studies, which captured knowledge such as information requirements, main activities, information workflow, scope of each stakeholder, and tools. Eight fundamental steps were identified across three different projects: a. Definition of the information requirements (BIM requirements), b. Model development observing BIM requirements (creation of digital assets in BIM), c. Validation of the asset information in BIM (compliance with BIM requirements), d. Model updates based on design changes during construction, e. Data extraction from design models to an external database (creation of an asset registry), f. Association of asset information from the construction phase with respective digital assets in the external database, g. Validation of the asset information in the external database, and h. Asset information upload into FM systems.

Different approaches towards the integration of BIM and FM systems have been studied. Ref. [11] categorized four of them: (1) using BIM model as an FM data repository [8,21,36,51,87]; (2) entering the required information to BIM models and transferring it to CMMS or computer-aided facility management (CAFM) systems [44,45,64,65]; (3) storing data from FM systems in a database and linking it with a BIM model to visualize and query it in BIM [27,30,33]; and (4) using BIM-FM platforms to integrate BIM models with FM systems [88].

This study demonstrates a mixed approach in which the required information is provided collaboratively by different stakeholders at different stages of the project using a BIM-FM platform as an external database, where all the geometric and non-geometric asset information produced during design and construction is gathered and organized per asset, and then transferred into the CMMS.

The approach discussed in this study differs from the first approach because no information related to FM activities is brought into the BIM models. Instead, the information flow through BIM is unidirectional, meaning that BIM data is used to feed other systems, but data from other systems are not brought back into the models for further analysis. This helps avoid the limitations related to the capacities of BIM authoring tools and large file sizes.

Although similar, the approach in this study differs from the second approach because a BIM-FM platform is employed and because not all the required information for FM is entered in BIM. Instead, different pieces of the required information are provided by different stakeholders at different stages of the project. While the information required from the design phase is generated in the models, the information required from the construction phase is fed directly into the BIM-FM platform. One of the limitations previously described in method two is the lacking capacity to visualize geometric information in the CMMS. However, by using the BIM-FM platform, CMMS users have access to the 3D model and all its geometric information via individual asset links. Similarly to the second approach, this approach aims to take advantage of the asset information conventionally provided by each stakeholder which, however, creates the need for additional validation efforts.

The approach discussed in this study differs from the third and fourth approaches because no data from CMMS or any other FM system is integrated or brought back into another database, or BIM-FM integration platform. While there are many potential benefits of visualizing and querying data from FM systems in a 3D environment, the owners did not envision any specific integrated use that justified the effort required to keep an updated system with integrated data from BIM and FM systems.

Compared with similar case studies in the literature [8,44,51,64,65], the observed BIM-enabled asset information delivery process in this study provides a deeper look into the actual asset information requirements. The study also contributes the following points to the related literature:

- Highlights the importance of validating the asset information produced in BIM during design given a misalignment between the conventional way designers use BIM for their own purposes and how they are expected to use BIM to deliver asset information.
- Provides a glimpse into the existence of an additional scope that this process implies for the delivery team compared with conventional project delivery.
- Demonstrates that the idea of having BIM as a central repository of all asset information is not necessarily relevant for FM. A large portion of the information relevant to FM is not actually incorporated in BIM.

Another gap addressed in this study was the diffuse understanding of challenges related to BIM for FM, leading to the proposition of isolated solutions that often fail to consider the connections between these different challenges. As it was recently pointed out by [15], the current slow BIM adoption is caused by a series of combined reasons rather than a single cause. Therefore, the root causes of the barriers and any potential interrelations among them should be further explored [5]. Based on the asset information delivery process developed in this study, the challenges previously mentioned in the literature were contextualized, mapped across different levels of implementation (i.e., project, organization, and industry) and project phases, and causal links were established between them. Although these challenges had been previously identified in the literature, the way in which they were observed in this study provides additional insights:

- There is a significant emphasis on the lack of interoperability as one of the main challenges in BIM for FM in the literature [6,8,19,44,60,62,63]. There have been several attempts to address this issue through the development of technological tools to automate the exchange of building information between different software. However, in this project, it was observed that the challenge of exchanging information between BIM and other FM systems stemmed from the lack of an adequate structure in the asset information that is created in BIM, in other words, a lack of information quality in BIM for FM, as discussed by [89].
- Another highly emphasized challenge in the literature is the lack of clear BIM requirements for FM at early project stages [8,19,60,62–66]. Although increased owner involvement has been often given as a solution for this challenge [28,66], this study demonstrates that it can be very difficult for owners to identify adequate information requirements. Having adequate input from FM teams early on in a project is still a challenge. Furthermore, there is still a limited understanding of how BIM can effectively support existing FM activities and how it impacts current design and construction processes, which compromises the definition of clear and efficient information requirements. In that sense, the support provided by standards and guidelines remains limited.
- Although the impacts on current processes (increased complexity, scope, cost, schedule) have been mentioned in previous studies [51,60,62,65,66], there is still little information on exactly how the activities of design teams, general contractors, and trades will be impacted by this process. A lack of awareness about these impacts can prevent these stakeholders from making well-informed decisions during the Request for Proposal, and for the allocation of resources required for the project, which ultimately compromises the quality of the asset information achieved at the end of the process.
- Finally, it was observed that the limited evidence of value in the literature is a central challenge that directly affects important aspects of the asset information delivery process at the project, organization, and industry levels. Although some studies [6,64,90] provide estimates of value based on surveys and interviews, the evidence of value is not sufficiently robust to provide adequate support for decision making.

Notably, there are limitations in establishing generalizable causality when using a case study. Nevertheless, providing this mapped understanding of challenges based on empirical data from a few case studies can still be useful. Understanding the sometimes compounding influences among challenges across different project phases and levels can help to identify root causes of issues and potential bottlenecks in this complex process. Most importantly, a holistic understanding of the proposed process and its challenges highlights the importance of developing more integrated solutions instead of trying to solve each challenge individually.

With regards to limitations, this research studied the BIM-enabled asset information delivery process using only three projects and without substantial data from the operations phase. More case studies are necessary to establish better references for this process and its value in different contexts (e.g., considering different delivery methods and building types).

For future research, additional studies similar to [89] are required to understand what exactly constitutes information quality in BIM for FM and how to achieve it considering the potential impacts that it might have on current design practices. These impacts on current practices should also be further investigated. Although the word "disruption" is constantly used with a positive connotation in the discussions of disruptive technological innovations, the level of disruption implied in using BIM processes for FM can be a significant barrier if not well managed. Finally, more studies are necessary to capture the actual value of the asset information in the operations phase.

## 8. Conclusions

Technological advances are creating many possibilities for the use of construction data. However, adequate processes and practices supporting the development of useful information with BIM are still in the early stages. The current utilization of BIM tools for different purposes and by different stakeholders needs to be aligned among project stakeholders to provide useful asset information for owners. Although owners are pushing for this alignment through the establishment of information requirements within a BIM process, the role of each stakeholder in the development of a unified source of asset information in BIM is still a subject of debate.

The research presented in this paper contributes to a better understanding of the process and challenges involved in the BIM-enabled delivery of asset information in a real-world setting. Given the lack of empirical data from case studies in which stringent BIM requirements for FM were included in the supplier contracts from the early stages, this paper provides unique insights into the impacts and challenges in formulating and complying with these requirements. Specifically, this research provides:

- A detailed analysis of the relevant literature on owner-driven BIM requirements, implementation for FM purposes, and the associated challenges;
- A detailed ethnographic longitudinal analysis of the asset information delivery process on a complex project with stringent BIM requirements for FM; and
- Synthesis and confirmation of relevant challenges in the literature, augmented by a detailed mapping of these challenges overlaid against the observed asset information delivery process.

While there is a learning curve for the organizations that implement BIM for FM, the lessons learned in this case study can help new owners to prevent inefficiencies and unrealistic expectations and prepare the designers, contractors, and owners for the challenges involved in the transition to this new process. As a practical contribution, the lessons learned in this case study should encourage design and construction teams to understand their own BIM-enabled information delivery process. The owners, in turn, should have a clear understanding of their asset information requirements, account for additional resources required for this process, and ensure that the selected teams are aware of their compliance criteria and equipped to meet them.

**Author Contributions:** Conceptualization, G.S.T. and S.S.-F.; methodology, G.S.T., S.S.-F. and É.P.; software, G.S.T.; validation, G.S.T., S.S.-F. and É.P.; formal analysis, G.S.T., S.S.-F. and É.P.; investigation, G.S.T., S.S.-F. and É.P.; resources, S.S.-F.; data curation, G.S.T., S.S.-F. and É.P.; writing—original draft preparation, G.S.T.; writing—review and editing, G.S.T., S.S.-F. and É.P.; visualization, G.S.T., S.S.-F. and É.P.; supervision, S.S.-F.; project administration, S.S.-F.; funding acquisition, S.S.-F. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by Natural Sciences and Engineering Research Council of Canada (NSERC), and Fraser Health Authority, grant numbers F18-05090 and F19-04525.

**Institutional Review Board Statement:** The study was conducted in accordance with the Declaration of Helsinki and approved by the UBC Office of Research Ethics (protocol code H19-01461 7/10/2019).

**Informed Consent Statement:** Informed consent was obtained from all subjects involved in the study.

**Data Availability Statement:** Not applicable.

**Acknowledgments:** This article was developed as a part of the UBC BIM Topics Lab in collaboration with industry partners. The authors would like to thank the owners in projects A, B, and C, the design team in project A, and all other participants involved in this research for sharing their knowledge to their best and for fostering genuine interest in scientific research.

**Conflicts of Interest:** The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

## Abbreviations

| | |
|---|---|
| AECO | Architecture, Engineering, Construction, and Operations |
| AIR | Asset Information Requirements |
| ARQTS | Asset Risk and Quality Technical Services (Department of owner organization in projects A and B) |
| BEP | BIM Execution Plan |
| BIM | Building Information Model or Modeling |
| COBie | Construction Operations Building information exchange |
| CMMS | Computerized Maintenance Management System |
| DGS | Data and Geometry Specification (Part of BIM requirements on projects A, B, and C) |
| EIR | Exchange Information Requirements |
| FM | Facilities Management |
| FMO | Facilities Management and Operations (Department of owner organization in projects A and B) |
| IFC | Industry Foundation Class |
| GC | General Contractor |
| LOD | Level of Development |
| MVD | Model View Definition |
| O&M | Operations and Maintenance |
| OIR | Organizational Information Requirements |
| OSR | Owner Standard Requirements (Part of BIM requirements in projects A and B) |

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