Article:
Jang, R. and Collinge, W. orcid.org/0000-0003-3387-1649 (Cover date: November 2020) Improving BIM asset and facilities management processes: A Mechanical and Electrical (M&E) contractor perspective. Journal of Building Engineering, 32. 101540. ISSN 2352-7102

https://doi.org/10.1016/j.jobe.2020.101540

Improving BIM asset and facilities management processes: a Mechanical and Electrical (M&E) contractor perspective

Mr Ryan Jang

College of Science and Engineering, Flinders University, Australia.

Email: ryan.jang@flinders.edu.au

Dr William Collinge

Programme Director Construction Project Management,

Dept. of Mechanical Aerospace and Civil Engineering, Univ. of Manchester,

Manchester M1 7JR, UK.

Email: william.collinge@manchester.ac.uk

Abstract

Despite BIM asset information management processes having advanced to globally recognised standards, facilities and asset integration remains problematic for many companies engaged in the construction project lifecycle. Challenges typically stem from deficiencies in the BIM regulations and standards, inaccurate information exchanges, software interoperability issues and unclear requirement definitions that ultimately result in higher project costs and poorer operational efficiencies. An exploration of these challenges and their potential solutions is therefore important if BIM-FM integration issues are to be improved. Few studies have systematically investigated this subject from the perspective of a BIM-accredited Mechanical and Electrical (M&E) company engaged on projects. This paper combines a literature review with an empirical case study of a BIM-accredited Mechanical and Electrical (M&E) contractor to explore the critical issues surrounding facilities and asset management integration; this combination of evidence providing a distillation of the issues surrounding BIM/FM asset integration and its` resolution. 15 key issues from the literature were classified under 4 broad themes (Informational, Technological, Organisational and Industrial) as being of primary concern; the case study analysis verifying the findings and also providing a series of bespoke recommendations for improving industry practice. The paper clarifies the problem issues (both negotiable and systemic) afflicting the industry, indicating how individual companies can develop their own processes for improving BIM-based asset integration. It may be concluded that although BIM asset integration processes have reached globally recognised standards, systemic characteristics of the industry result in persisting problems that impact the BIM-FM asset management journey.

Keywords: BIM standards; building information modelling; facilities management; asset management; mechanical and electrical engineering.

1. Introduction

The paper examines the challenges faced by Mechanical and electrical (M&E) companies aiming to deliver assets in BIM compliant projects. It reveals the current deficiencies in BIM regulations and standards for Tier 2 contractors, such as M&E contractors, and uses a comprehensive literature review and case study analysis to scope out solutions and approaches to these issues. The work adds to the growing literature concerning BIM-FM integration by exploring current BIM work processes, information requirement issues and the role of standards (i.e. BS EN ISO 19650-2).

Whilst it is recognised that BIM adoption can lead to a wide range of efficiency and productivity benefits [7], it is also noted that 85% of total project costs are ultimately related to FM issues [37]. For instance, annual costs through waste caused by operating issues from inaccurate information and interoperability was reported as 10.6 billion USD in the United States [22]. Other scholars [e.g. 25; 17] have also identified unclear information requirements and software interoperability as issues affecting smooth asset management processes. Therefore, whilst BIM adoption can theoretically reduce operating costs by providing information accurate assets to clients and facility managers [40], 2017), BIM-FM integration issues need to be robustly addressed and resolved early to improve delivery in the FM phase. Although extensive studies have addressed BIM adoption in design and construction, there has been less focus on the FM phase [24]. Additionally, few studies have systematically investigated the subject from the perspective of a BIM accredited Mechanical and electrical (M&E) company; scholars commenting that there are not enough studies specifying the complex relationship amongst clients, TIER 1 and TIER 2 contractors in the BIM asset integration process [25; 47; 41]. Indeed, whilst [17] highlights how BIM asset integration in the design-

build phase can have significant effects on BIM-FM integration after handover, most previous studies have focused on the FM phase, not considering specific processes from the TIER 2 contractor's view.

The paper begins with a review of BIM, facilities asset management processes and a critique of the academic literature in this area. The literature review identifies a number of important issues relevant to the work of contractors aiming to work in BIM-enabled project environments. Details of the literature review together with the overall methodological approach are given in a following research method section. The work and experiences of a UK M&E contractor is then presented in a case study section. A discussion connects empirical insights with the issues and themes of the literature review, leading to a series of propositions and recommendations to assist BIM-FM integration work. The combination of empirical evidence and literature review gives practitioners and academics a distillation of the important issues around BIM/FM asset integration and directions for further research work.

2. BIM and FM Asset Management: Overview

Building Information Modelling (BIM) is an integrated, collaborative information-sharing process between project stakeholders that covers the design, construction and facility management (FM) phase of construction projects [40]. Information includes 2-dimensional (2D), 3-dimensional (3D) models, schedules, cost and building lifecycle data [45]. The advantages of BIM have resulted in its` widespread adoption, with surveys showing 75% of design professionals in developed countries believing BIM is a vital technology for the near future [32]. In the UK, which is a BIM-driven country, level 2 BIM adoption has been mandated on projects procured by the government since

2016 [32], with Level 3 BIM aiming to integrate digital design into the assets for facility management (FM), being a stated objective of the "Digital Built Britain" agenda [38].

BIM is predominantly adopted in the design and construction phase rather than the FM phase as its functions and options typically originate in construction support such as visualisation and construction management [34]. Liu and Issa [13] highlight that most practitioners in the design phase tend to focus on clash checking, neglecting operation accessibility. In their survey, Eadie et al. [10] highlight that only 10% of companies/projects focus on FM phase benefits of adopting BIM, the emphasis instead being on the cost benefits of BIM in the design phase. However, benefits of BIM can be significant in the FM phase as 85% of project lifecycle costs after construction can be traced to FM issues [37]. Additionally, more than 80% of FM working hours are spent on seeking accurate information, an issue often missed by practitioners during design phase work [4]. BIM implementation in FM can alleviate these issues by providing reliable BIM-based data and accurate as-built information to facility managers [3; 40]. Case studies, such as that observed by Dempsey (2009) and cited in [40] emphasise that 98% of operation time is likely saved through BIM-FM integration. Also, BIM adoption in FM enables rational decision making regarding FM activities [13].

On the other hand, due to its relative novelty, BIM-FM integration issues are largely under- recognised in the current market. Issues such as unclear scope, software interoperability and unclear information requirements continue to hinder BIM-FM integration [25]. So whilst McArthur [17] emphasise that early consideration of FM is vital to capture specific information requirements, there is usually very little

collaboration between clients and facility managers in design phase works, with various constraints to BIM-FM integration [40] existing. Official standards and guidance relating to BIM and asset management information has also evolved in tandem with industry familiarity with BIM.

In 2019, British Standards Institution (BSI) developed the standard 'BS EN ISO 19650-1/2' to improve the quality of BIM delivery processes; the original BIM standard 'PAS 1192 series' being replaced by 'ISO 19650 series' with global recognition [6]. BS EN ISO 19650-2 focuses on "project delivery, where the majority of graphical data, non-graphical data and documents, known collectively as the project information model (PIM), are accumulated from design and construction activities" [8]. Furthermore, BSI provides diverse training with these standards, leading to accreditation and awards to qualified organisations who achieve successful BIM asset delivery. These processes and accreditations have contributed to a gradual standardisation process of the BIM industry, with iterations of the standards aim to improve and clarify processes for industry. However, there have been few studies examining the utility of these standards from the perspective of a Tier 2 M&E contractor. Moreover, there has been little exploration of the issues and challenges commonly encountered by M&E companies aiming to deliver work to BIM standards. A closer critique of the BIM information delivery cycle and academic literature highlights a number of issues of relevance.

2.1 BIM Information Delivery Cycle

Ideal BIM information management processes for the operational phase of assets are clearly stated by BSI [9]. At a high level, client's needs should be derived from the Organisational Information Requirements (OIR). According to the OIR, Asset

Information Requirements (AIR) are generated to determine any data and assets to be captured including technical aspects of data production [9]. The AIR is used to define Employer Information Requirements (EIR), which determine the final information requirements to be delivered from provider (Contractor) to receiver (Client). These three steps are defined as the "Information requirement" phase [33] (see figure 1). As soon as the information requirement step is complete, graphical and non-graphical data, called Project Information Model (PIM), start to be created and integrated after setting up the BIM Execution Plan (BEP). At handover, final data is integrated to an Asset Information Model (AIM) [9]. These processes are shown in figure 1.

However, because the design phase has a significant impact on the whole project lifecycle [42], many scholars highlight the importance of fundamental specification of information requirements at the initiation stage [18]. As already noted, appropriate planning and design can significantly save FM costs, as design phase decisions and consequent actions determine almost 80% of the FM cost [23], so less interaction among key stakeholders in early phase can negatively affect later stages due to unidentified risks [1].

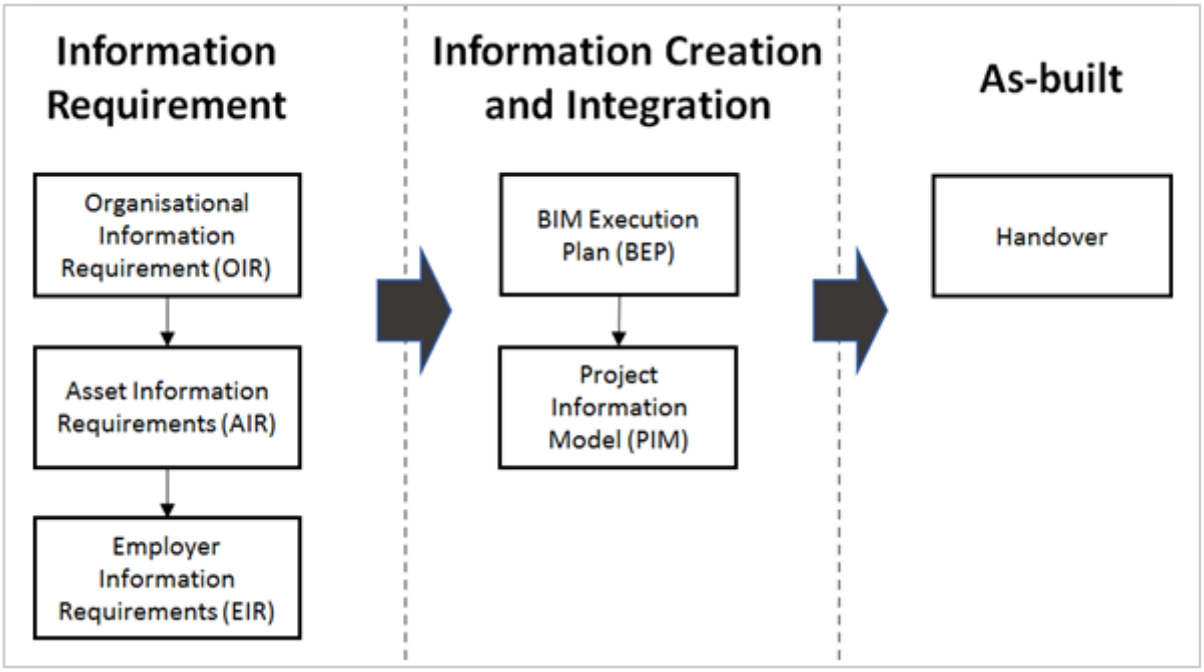

Figure 1: Information Requirement steps

Two international standards, ISO 19650-1 and 2, were published in 2019, themselves derived from PAS 1192-1/2. ISO 19650-2 focuses on "project delivery, where the majority of graphical data, non-graphical data and documents, known collectively as the project information model (PIM), are accumulated from design and construction activities" [8]. However, although BSI and ISO provide industry recognised standards, stakeholders in construction generally have limited knowledge of standards such as PAS 1192 to satisfy informational requirements for BIM [24]. Also, many tend to develop their own standard or processes for their own needs [36].

ISO 19650-2 emphasises that a clear definition of client OIR and AIR is the most important factor in achieving successful BIM asset delivery [8]. However, many clients tend to request just COBie or Industry Foundation Class (IFC) files without careful consideration about what they really need in the FM phase [45]. A critical issue here is

the difficulty in identifying salient information for BIM-FM integration [41]. Level of detail (LOD) is about how detailed BIM models and assets convey the essential information for each stage; LOD being determined between the client and contractor. Ideally, the LOD should only include essential information that will be used for construction and facility management rather than containing irrelevant information [45]. This is because over-specification of LOD requires extra effort, whilst over-simplification can miss important information [45]. Additionally, it is recognised that reviewing and updating thousands of assets with diverse parameters can be labour-intensive and time-consuming [43]. The study conducted by [24] shows that although owners and FM teams recognize long-term benefits of BIM, the standards or governmental guidance do not provide detailed methodology to gain the benefits. As a result, in reality, project teams face difficulties in defining the LOD of BIM assets as they do not have detailed standard settings including terms and classification of the BIM-based assets [41]. As noted by [25], BIM asset integration needs precise standard or guidance for information requirements.

Furthermore, a lack of IT competency in client and FM teams is another critical issue identified by scholars [25]. Key stakeholders of the project tend to have little experience and knowledge of BIM-FM integration [24]. In a study, [47] found that most of the 2,100 internal and external practitioners surveyed in FM phase do not have IT experience, which will limit their knowledge of information requirements issues [25]. As a result, FM teams often take lower priority for clients, as reflected by one client interviewee from the study of [11] who said “I was supposed to meet with them … in a week’s time, but I’ve had to push it out about three weeks because of other priorities”.

Additionally, FM teams and designers often have different knowledge and perspectives towards FM assets because their scope of work is different. FM teams can give designers operational perspectives such as space management and operating conditions [35], but often, relevant information is ignored because designers do not know how to specify the detailed data requirements due to lack of designer operational experience [35; 41]. The study of [28] shows that designers create models for the construction purposes rather than producing as-built drawings because modelling and drawings are required only for construction. As a result, information that FM teams need may be missing in the design phase [30], highlighting the importance of collaboration between designers and FM teams to specify what should be updated and what FM needs.

As soon as the information requirement process is finished, requested assets begin to be created and integrated by designers and engineers. COBie is an important non-graphical asset format that includes digital information about operational assets such as equipment lists and preventive maintenance schedules [19]. Although COBie data is usually successfully transferred to FM teams, they tend to find difficulty in the integration with AIM [43]. In the study conducted by [41], COBie was not fully operational, being replaced by a customised spreadsheet; a crucial issue being that non-standardised information is gathered [43]. Also, [16] found that 74% of FM practitioners did not receive appropriate information from contractors for FM stage work. Often, clients or FM teams tend to rely on designers with the belief that designers will provide details in compatible formats [11]. Thus, if FM teams were more fully engaged in the design phase, they would not experience issues with federating COBie data with AIM (COBie data initially being created in the design phase).

Previous studies highlight the importance of effective communication for capturing as-built processes. Although FM teams obtain as-built models at handover, there can be many differences between the models and BIM models specifically relating to FM [14]. This can be because the as-built data and models are not accurate. Causes include miscommunication between designers and site engineers [15]. Despite its` collaborative features, producing a BIM as-built model may be more demanding for communication than producing a non-BIM as-built model. For instance, [15] argue that non-BIM as-built data can proceed directly to site, whereas BIM as-built necessarily requires collaboration between BIM engineer in office and site engineer on site during the integration work. Collecting and updating site data on BIM is time-consuming [21]. Some solutions have been introduced to alleviate these issues [20], including Image [2], Image-based clouds [21] and 3D laser scanning [5]. Each one has its own limitations. For example, although 3D scanning technology is denser and more accurate, its process requires extensive skills, expensive equipment and various personnel [2]. Also, this process can also be time-consuming and malfunction in bad weather [12]. Although various as-built BIM software packages have been launched, the purpose of such software is mostly about saving different versions of as-built data, which does not support communication between stakeholders. Field BIM is currently being adopted to improve site communication. For example, Autodesk's BIM field provides data management that accelerates field communication between BIM engineers and site engineers. This development can improve the as-built miscommunication between stakeholders. The above review of BIM Information Delivery issues derives from a review of the literature, presented in Table 1, and detailed below.

3. Research Method

The study set out to understand what issues must be addressed by a BIM-accredited engineering company for successful BIM asset integration. A combined literature review with empirical case study investigation was deemed appropriate as previous studies have adopted such an approach to good effect [25; 26; 30; 35].

Although the paper offers a single empirical case study with a relatively small number of interviewees, it contributes to existing understandings of BIM-FM integration; the empirical case approach enabling study of a "particular contemporary phenomenon within its real-life context using multiple sources of evidence" [44]. Specifically, the case study allows issues associated with the standard 'BS EN ISO 19650-2' to be a focus of critical attention and reflection, providing "an opportunity to observe and analyse a phenomenon that few have considered before" [46].

The overall methodological approach is illustrated in figure 2.

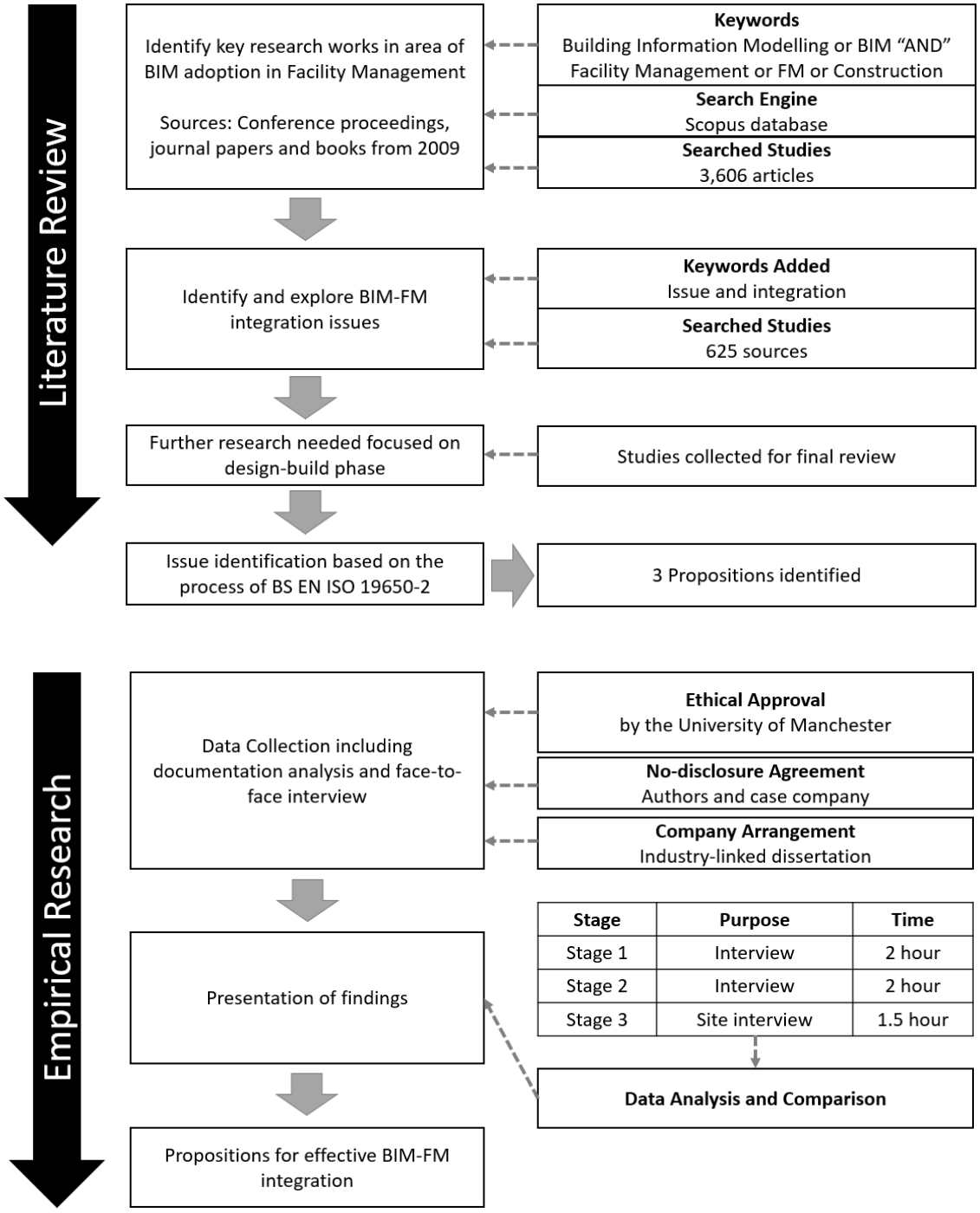

Figure 2: Methodological approach

A literature review identified 3,606 studies; this number being refined to 625 following further keyword searches and abstract review. Other inclusion criteria included peer-

reviewed conference or journal papers because they validate the reliability of the resources [46]. Sources published after 2009 in BIM-driven countries (UK, USA, Korea, Australia, New Zealand, Netherland, Finland, Swiss, Singapore, Taiwan, Pakistan and China) were selected to collect recent issues in BIM-leading countries. The resultant collection of 26 sources are presented in Table 1. 15 recurring issues were identified from the literature regarding BIM-FM integration, the 15 issues occurring 108 times in total in the corpus. These issues were discussed in the previous literature review, and can be classified into 4 broad categories: Informational, Technological, Organisational and Industrial. When dividing these issues by phases, it was notable that Technological and Industrial issues did not occur before handover, with fewer issues identified in the design-build phase. The survey of the literature provides a foundation for future interpretations [31] and a basis from which examination of the case study could be approached.

[insert Table 1]

3.1 Case Study

The case company is a UK Mechanical and Electrical (M&E) contractor with more than 240 employees. It provides various engineering services mostly in design and build systems. In 2018, the company developed its own BIM processes (in accordance with the PAS 1192-2 standard), obtaining BIM accreditation Part 2: "Delivery phase of the asset of PAS 1192-2" from the British Standards Institution (BSI). Moreover, in 2019, as PAS 1192-2 was being replaced by BS EN ISO 19650-2, the company was audited

and accredited by BSI again with newly revised BIM processes. Most of the company`s turnover is comprised of M&E components, the company engaging in project work ranging in cost from £50,000 to £20 million. In 2018, most projects were from the educational and commercial sectors.

The company's contractual position in projects is that of a Tier 2 appointed party: the company having direct relationship with TIER 1 and supply chain contractors, but being typically distant from the client and facility management. In practical terms, this means communication with the client is not typical. When the company has questions to ask, they must speak with the TIER 1 contractor. In addition, 97% of contracts are delivered within a design-build framework, the remaining 3% being traditional contracts related to minor maintenance contracts. The design-build framework is generally considered better for internal collaboration.

Data collection was based on company documentation analysis, face-to-face interviews and site visits. Unstructured and semi-structured interviews were conducted with practitioners involved in BIM asset integration from the company. The position and experience of each interviewee are detailed in Table 2; interviews being designed to obtain perspectives on BIM-based asset integration.

No	Interviewees	Position	Years of working in the company	Years of working with BIM process

1	Interviewee A	Design Manager	23	4
2	Interviewee B	Managing surveyor	12	4
3	Interviewee C	Mechanical Design Engineer	6	0.5
4	Interviewee D	Electrical Design Engineer	16	4
5	Interviewee E	Revit Engineer	4	3
6	Interviewee F	Project Engineer	10	2
7	Interviewee G	BIM Coordinator	2	11
8	Interviewee H	Revit Engineer	5	3
9	Interviewee I	Site Manager	Subcontractor (Undefined)	
10	Interviewee J	Mechanical Engineer	15	4

Table 2**:** Interviewees position and experience

4. Case Study Analysis

The following case study highlights the significance of the issues previously discussed and reveals how the M&E contractor is addressing them. As a TIER 2 company, the M&E contractor receives a specified BIM Execution Plan (BEP) from the TIER 1 contractor, typically generated by the client and TIER 1 contractor together based on Asset Information Requirements (AIR) and Exchange Information Requirements (EIR) information. This is appraised using a bespoke BEP appraisal form, being returned to the Tier 1 contractor. The TIER 1 contractor then reviews the appraisal form, revising the BEP accordingly. According to interviewees, the BEP is the primary source of BIM

Information for the TIER 2 contractor. However, because information in the BEP is derived from the AIR and EIR, the BIM coordinator may need to query the documents,

"As a TIER 2 contractor, we would not necessarily appraise the EIR… we typically appraise only the BEP. If there was an element missing from the BEP, then we look into the AIR or EIR because the whole point is for us is to appraise the BEP to be clear and concise" (Interviewee G).

As the company is only involved in the BEP process (not in AIR and EIR, due to contractual relationships), the disconnection with the client and their FM needs brings risks that can affect the quality of BIM information requirements. Thus, during BEP appraisal, the case company aims to identify specific risks and missing contents related to asset requirements or information beyond typical requirements. However, it can be difficult to measure the time and cost of such risks, as a Revit engineer noted:

"This morning, we had a meeting to develop a standard document, a pre-tender document that includes what level of COBie we deliver as standard, the asset information register we deliver as a standard, and the information requiring additional costs. We are currently tasked with what that additional cost is, but I am not sure how to measure it. Within the BEP processes, tender stage, sometimes some parts of asset information registers are marked with "to be agreed" to consider the time and cost later" (Interviewee H).

During the BEP appraisal process, many comments can be made by the M&E company, due to imprecise information in the AIR and EIR, sometimes almost doubling the page number of BEP documents. A design manager noted:

"BIM Execution Plan Appraisal is key to meeting a clear information requirement for us, but we don't really get involved in facility management so we cannot comment on something related to FM on the BEP. Also, in reality, the client and FM are not really involved in the AIR and BEP, so these requirements are not specified in the BEP" (Interviewee A).

This emphasises the significance of understanding BIM information requirements between the client and TIER 2 contractor. The interviewee related how on a recent project, the client had a professional BIM team that highlighted everything they needed in the Asset Information Register which resulted in successful BIM adoption in the FM phase. In contrast, in a recent commercial project, a TIER 1 Contractor was in major control of the AIR, EIR and BEP development, resulting in multiple information requirement changes due to less efficient communication. A root cause of this is client disinterest in BIM assets as they tend to believe the builder or designer to know better than they.

Supply chains are critically important for the M&E contractor; the company having approximately 600 supply chains in total, including 250 (active) and 100 (design responsible). These contractors often have little or no BIM knowledge, tending not to provide BIM-related data. In order to address this problem, the M&E contractor has adopted a supply chain assessment process. A BIM coordinator explained:

"We have two assessment forms for suppliers; one for those with design responsibility and another for those that do not have design responsibility. Through assessment, we identify what knowledge our supply chains have. Questions are scored and maintained in our database. If our supply chains don't have a very good score, it doesn't mean that

they will not get any work from us. It identifies training requirements. We don't want to lose our supply chains and we want to make them more knowledgeable about BIM. Our supply chains are trained every 2 months and assessed every 12 months. So, on our database, we should see the score go higher and higher. We offer training and our supply chains pay for our time to train them" (Interviewee G).

Such training and learning work with suppliers are considered fundamental and part of the BIM process for the M&E company. However, if a large number of supply chains require training, the company may not be able to train them due to a lack of manpower. As the M&E contractor is effectively responsible for ensuring their supply chains have a mutual understanding about BIM processes, a BIM supply chain assessment form is produced to be completed by supply chain contractors. The TIER 1 contractor will duly receive a copy of all such supply chain BIM documents at the end of the tender process. These activities align with a number of the issues highlighted in the literature review (Table 1) and indicate how the M&E contractor is addressing them: unclear requirements for BIM adoption and inaccurate level of detail (c.f. bespoke BEP appraisal form; supply chain database; supply chain assessments); need for specific guidance/templates (c.f. training and learning; assessment forms); technical competency (c.f. training and learning). The insights also highlight the need for company flexibility and how BIM preparation and training have time and cost implications (marked under Organisational and Industrial themes on Table 1).

Following the post-contract award, all design information to be acquired is fully examined by the M&E project team. Subsequently, models begin to be produced from consultant models containing architectural details and fundamental design. A Common Data Environment (CDE) is then established to compile, manage and share

documentation, including graphical and non-graphical assets for stakeholders in the project. All deliverables of BIM-related assets are then determined with a Task Information Delivery Plan (TIDP) template; any changes to the template being discussed with the BIM coordinator before it is documented. These processes from tender to post contract award are illustrated in Figure 3.

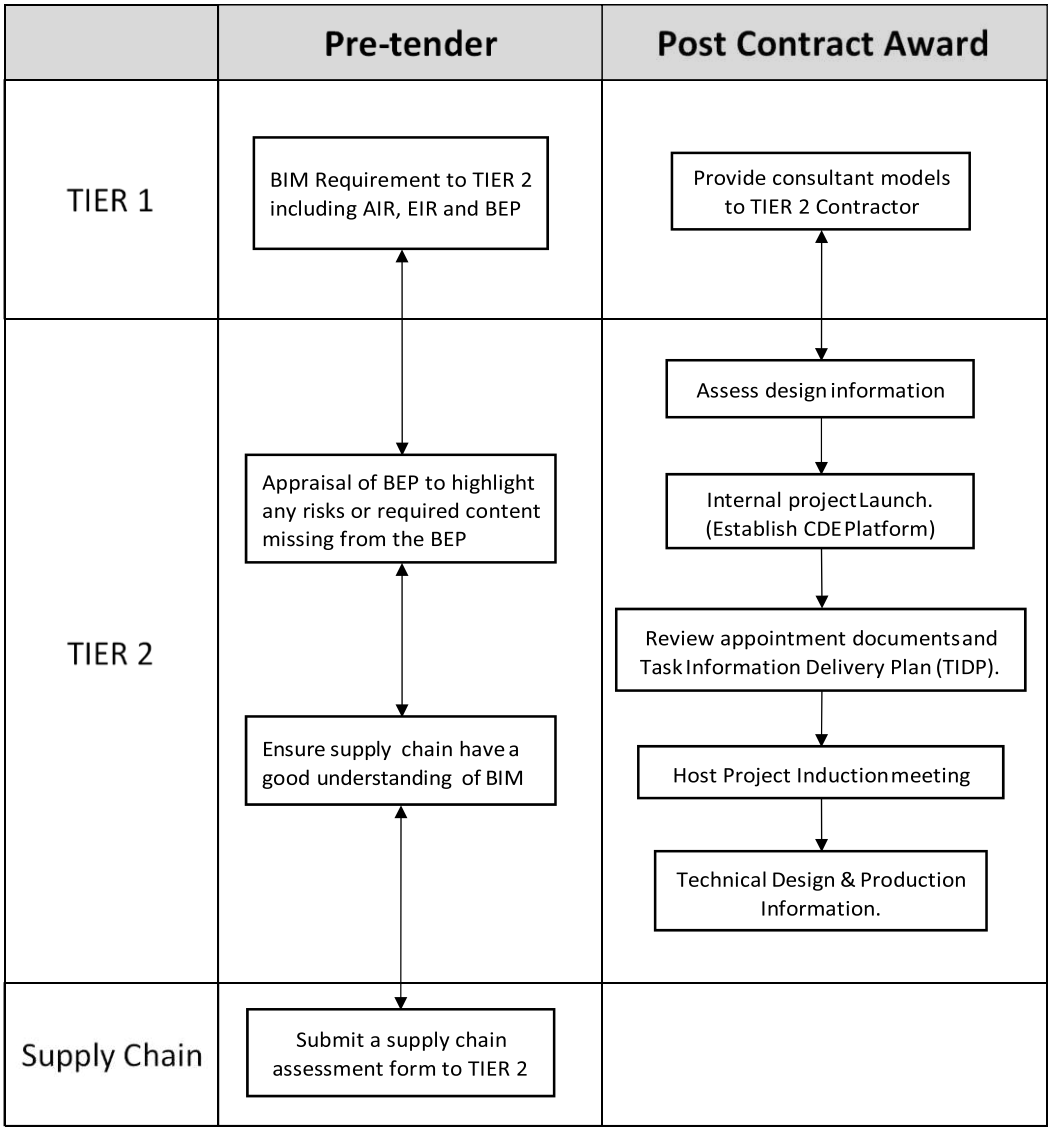

Figure 3**:** Pre-tender and post contract award processes

Following agreement over the BEP with the TIER 1 contractor, a COBie database (based on Asset Information Register) is created and populated into Project Information Models (PIMs). This is considered a fundamental asset for BIM-FM integration. In order to ensure all requirements embedded in the BEP are being met, a task manager conducts various tasks for accurate technical design and information production, including model status, stage completion, Information production procedure, COBie completeness and technical content examination procedures. These activities need a significant amount of time, cost and workload resources, as well as IT software and knowledge (issues highlighted as significant in Table 1). Design information is commonly modified during and after construction, with missing information often occurring. Recording as-built activities are vital to providing accurate BIM assets at handover, with communication being through CDE, mark-up drawings by site engineers and 3D scanning. Figure 4 shows the overall BIM integration processes for the M&E contractor.

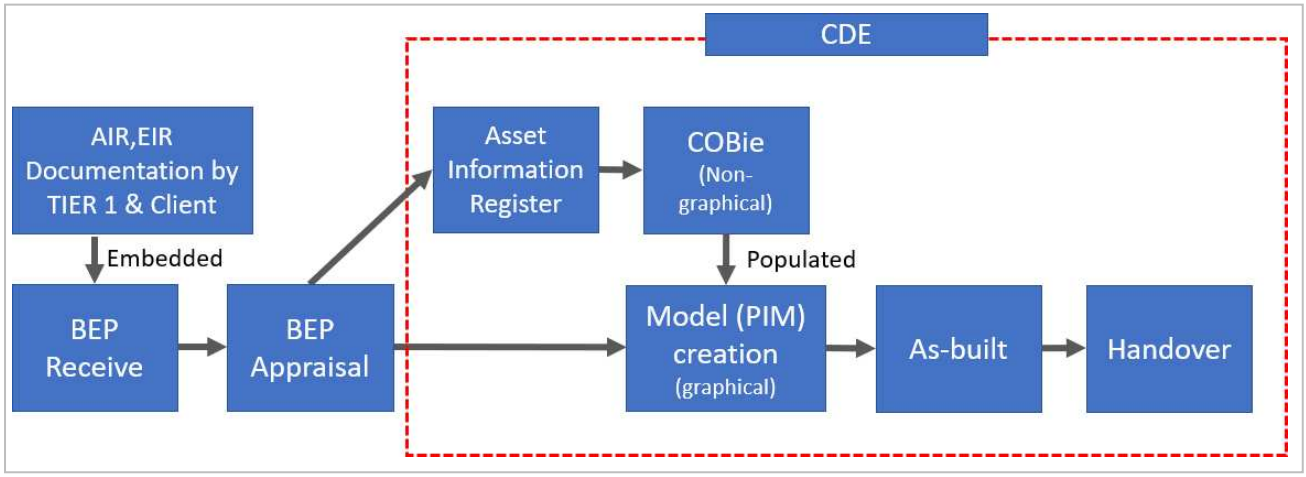

Figure 4: BIM asset integration process in the case company

In the M&E company, COBie data is created by a Revit engineer (called Information Originator in ISO) based on the received Asset Information Register. COBie information is continuously added to models throughout the project lifecycle, because if COBie is not regularly populated to models, it may lead to project delay. However, missing COBie information is always an issue throughout the project lifecycle, as a Revit engineer related:

"COBie data is continuously added throughout the project lifecycle but there is always going to be missing information related to COBie that we receive during the project. We try to fill out as much information on the models with regards to COBie as earliest as we can. In addition, we adopt a BIM-link that helps minimise the need to revisit certain elements as effective plug-in software. However, this is a lot of work and things can become late" (Interviewee E).

BIM assets and models are integrated based on the BEP previously reviewed with the TIER 1 contractor. However, because information tends to continuously change, appraisals and revisions are needed to determine whether changes raise the project cost or not. If COBie requirements are frequently revised, it may result in reducing the quality of BIM asset integration. This is a chronic problem due to the difficulty of specifying the BIM assets and understanding what the client wants. Such issues relating to interoperability between BIM and FM technologies have been previously identified by scholars (Table 1).

In terms of software interoperability, the M&E contractor receives fundamental models and designs from architect contractors. Although BEP specifies an Industry Foundation Classes (IFC) file, the file received may not be compatible due to interoperability issues, as an engineer explained:

"On a recent project, we tried to bring in architect models to our Revit environment, but it did not recognise spaces or certain elements, so we sat down with the architect to solve the problem. Luckily, they had a BIM specialist. I would not say architectural companies are necessarily competent in delivering models. In ideal world, everybody is using Revit, but architects tend to use other platforms." (Interviewee D).

In this case, the BIM specialist played a crucial role in solving the interoperability problem. As the TIER 1 contractor is responsible for federating the models from different TIER 2 contractors, it could be argued that solutions to software interoperability problems should be provided by the TIER 1 contractor, but in practice, this does not always happen. A wide range of changes and modifications are commonly seen during construction, but the M&E contractor is contracted to work within tolerances. The importance of how data on site is managed and how information gets relayed back to the M&E contractor was relayed through the interviews. Field BIM has been recently recognised in the company to provide accurate digital assets in BIM models, a project engineer emphasising its significance:

"We are looking at Field BIM to capture all information on site and to put it back into BIM models. We have been getting site information from site engineer's marking up drawings, but are finding out we need to rely more on technology to capture information such as via 3D scanning. I have recently asked our director to purchase a 3D scanner.

That will enable us to capture as fitted services on-site and put that into a model" (Interviewee F).

Capturing site information can be difficult due to miscommunication and countless changes made on site. The communication between site engineers and designers is considered most crucial, which is why the contractor is trying to improve communication between stakeholders by adopting new technologies such as 3D scanning.

A site mechanical engineer said:

"We are supposed to fully use BIM and 3D models, but, in reality, 2D drawings are used more on site because of accuracy. For example, 3D drawings don't show the sockets between pipes or, sometimes, panels don't show up in models. Also, people on site tend to use 2D drawings for convenience. But 3D scanning will surely help us communicate with designers or engineers more quickly and efficiently. But I am not sure how to overcome the issues of inaccuracy and also it will require additional training" (Interviewee C).

The above insights reveal how tensions remain around introducing new technologies to sites that disrupt established ways of working; the empirical evidence also aligning with literature review findings (Table 1) relating to interoperability, cost and time implications.

5. Discussion

The empirical insights from the case study supplement findings of the literature review, illuminating a number of issues and improvement strategies for effective asset management from an M&E company perspective. The paper findings align with recent

discussions of an industry roundtable on digitising the asset at the Centre for Digital Built Britain [48]. Key takeaways of the roundtable included:

- FM needs to be involved in specifying information requirements from the start of a build.
- The whole supply chain, including manufacturers, should use a standard taxonomy for describing assets.
- A proactive asset management strategy, rather than reactive maintenance, will reap maximum benefits from BIM.

Figure 5 visualizes the primary integration issues, disconnections between stakeholders and main points in the BIM asset integration journey for a Tier 2 M&E contractor. It also highlights the bespoke work undertaken by the M&E contractor with its` supply chains (i.e. annual assessments of ability; training and learning activities; database of suppliers).

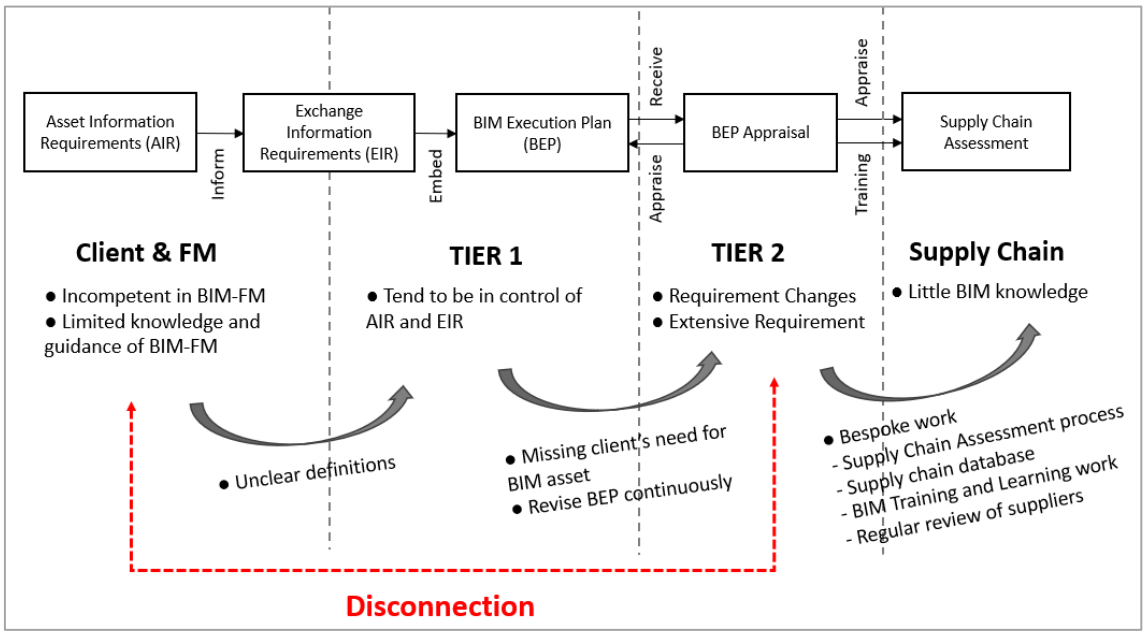

Figure 5: Integration issues and disconnections

A key insight of the paper is how the M&E contractor, which was successfully audited and accredited by BSI in 2019, revises its` BIM processes and supplements them with further necessary activities. These bespoke BIM processes address the deficiencies in the BIM asset management work stream. Such bespoke BIM processes (e.g. BEP appraisal form; supply chain database) assist the Tier 2 contractor in their work, by there remain more fundamental challenges. The need for better communication between the client and contractor remains an issue. Communication is inhibited by the contractual boundaries, so that although British Standards Institution [8] highlights the importance of clear understanding of OIR and AIR and an accurate EIR to deliver successful BIM assets, the disconnection between client and TIER 2 contractor is significant.

Although clear descriptions of OIR and AIR is emphasised for successful BIM information requirements [8], identifying essential information for BIM-FM asset integration can be difficult [41]. A lack of IT competency and understanding of BIM from the client is a crucial issue in defining the essential information required for asset management [25; 24]; unclear information requirements issues [45] being evident from the M&E contractor evidence, highlighting the need for closer engagement between client and contractors.

Although the TIER 1 company may have extensive experience in this area, it is difficult to exactly develop what the client wants and what the TIER 2 contractor understands because different stakeholders have different responsibilities and interests towards the complete BIM assets [27]. The disconnection between clients and TIER 2 contractors

may pose various risks such as changes to asset components and resulting information changes. This argument is supported by the studies into the relationship between cost and potential changes on projects, which argue that cost of changes is more significant in latter stages of a project [29].

Theoretically, if the BEP is completely accurate in the early stage of the project, the risks of missing contents or extensive requirements can be avoided. However, the empirical findings show that clients are not fully engaged when it comes to BEP review. Furthermore, the TIER 2 contractor cannot be involved in AIR and EIR stages because they are not even assigned to a project at that stage. Therefore, in order to define information requirements clearly, clients should make an effort to clarify them with the TIER 2 contractor, which requires earlier engagement.

The findings generally reflect the complex communication relationships amongst client, TIER 1, TIER2 and supply chains; the case company playing a bridging role between TIER 1 and supply chains. To improve the quality of BIM-FM asset integration, better communication between key stakeholders is needed. For this to happen, contractual barriers to better communication must be overcome to improve the situation. Complete alliancing may not be necessary to address this: mutually beneficial memorandums of understanding or letters of intent may help in bringing M&E contractors into project discussions at an earlier stage.

Software interoperability is another persistent problem afflicting the industry, emerging as a significant issues in the empirical investigation as effecting asset creation/integration. Interviewees commented that clients should understand the fundamental problems of interoperability between software, ideally before the pre-

tender stage, to minimise interoperability issues in advance. Although the TIER 2 contractor is the BIM asset creator and integrator, as a passive contractor, interoperability issues cannot be solved without TIER 1 participation or client willingness towards BIM asset integration.

It was found that the M&E contractor plays a crucial role in bridging the TIER 1 and supply chain gap to make asset information accurate and precise; the M&E contractor taking the initiative to check supplier ability and keeping a database of suppliers with BIM knowledge. However, such processes are often accompanied by investment costs for training, software and infrastructure [4]. Although this increased work volume and project costs, the case company utilised its` supply chain database with suitable training in order to understand what the supply chain could supply, the company seeing such work as having long term investment value.

The empirical insights support the view that COBie data is often inaccurately received at handover, suggesting that data is neither standardised nor accurate [43]. Parsanezhad and Dimyadi [41] highlight that COBie is often not fully operational, leading to it being replaced by customised spreadsheets. The challenge around producing specific asset registers with related COBie requirements can result increased project costs and time, generating repetitive activities during the project lifecycle. For the M&E contractor, despite adopting a BIM-link as a plug-in to improve this situation, the whole asset information integration process including models and COBie data were time consuming. Interviewees maintained that early engagement from the client is considered the most important factor to produce accurate COBie information, as this can alleviate issues of continuous changes due to improved communication between key stakeholders during the BEP process.

6. Conclusions

The paper examined BIM asset management processes from the perspective of a fully accredited M&E contractor active in the UK construction market. A literature review identified several key issues of concern for BIM-FM integration; the case study analysis verifying the findings. As well as noting the significance of issues such as designer-client collaboration to set successful information requirements [41; 43], creation and integration of COBie data and software interoperability [43; 26] and as-built data management in the design-build phase [14; 21], the case study also revealed specific bespoke practices and processes to address deficiencies in the BIM asset management work stream. The insights can assist practitioners to develop their own standards or processes for improved BIM-based asset integration. It should also be noted that these bespoke processes were developed by a fully BIM-accredited M&E contractor.

It can be concluded that although BIM asset integration processes are now well developed to a globally recognised standard, certain characteristics of construction project management result in persisting problems that impact the BIM-FM asset management journey. These include organisational communication issues, software interoperability issues, contractual barriers to joined-up working and supply chain BIM awareness issues. The need for greater collaboration and more communication between key stakeholders at early project stages remains an issue for the Tier 2 contractors that provide a vital link to the supply chain.

Acknowledgements

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

7. References

[1] L.F. Alarcon, D.A. Mardones, Improving the design-construction interface, 6th International Group of Lean Construction Conference, Gunarya, Brazil. August 1998.

[2] K. Asadi, K. Han, Real-time image-to-BIM registration using perspective alignment for automated construction monitoring, Construction Research Congress 2018, ASCE 388–397, New Orleans, Louisiana, 2nd -4th April 2018.

[3] S. Azhar, M. Khalfan, T. Maqsood, Building information modeling (BIM): now and beyond, Australasian Journal of Construction Economics and Building 12 (4) (2012) 15–28.

[4] B. Becerik-Gerber, F. Jazizadeh, N. Li, G. Calis, Application areas and data requirements for BIM-enabled facilities management, Journal of Construction Engineering and Management 138 (3) (2012) 431–442.

[5] F. Bosché, M. Ahmed, Y. Turkan, C. T. Haas, R. Haas, The value of integrating scan- to-BIM and scan-vs-BIM techniques for construction monitoring using laser scanning and BIM: The case of cylindrical MEP components, Automation in Construction 49 (2015) 201–213.

[6] British Standards Institution, ISO 19650 Building Information Modelling. Available on-line at: https://www.bsigroup.com/en-GB/Building-Information-Modelling-BIM/bim-design-and-construction/iso- 19650-BIM/ (Accessed August 2019).

[7] P. Demian, D. Walters, The advantages of information management through building information modelling, Construction Management and Economics 32 (12) (2013) 1153-1165.

[8] British Standards Institution, PAS 1192-2:2013 - Specification for information management of the capital delivery phase of construction projects using building information modelling, British Standards Institution, London, 2013.

[9] British Standards Institution, PAS 1192-3:2014 Specification for information management for the operational phase of assets using BIM, British Standards Institution London, 2014.

[10] R. Eadie, M. Browne, H. Odeyinka, C. McKeown, S. McNiff, BIM implementation throughout the UK construction project lifecycle: An analysis, Automation in Construction 36 (2013) 145-151.

[11] R. Edirisinghe, P. Kalutara, K. London, An investigation of BIM adoption of owners and facility managers in Australia: institutional case study, Construction and Building Research Conference (COBRA 2016), Royal Institution of Chartered Surveyors, Toronto, Canada, 19th-22nd September 2016.

[12] M. Golparvar-fard, J. Bohn, J. Teizer, S. Savarese, F. Peña-mora, Evaluation of image-based modeling and laser scanning accuracy for emerging automated performance monitoring techniques, Automation in Construction 20 (8) (2011) 1143–1155.

[13] R. Liu, R.R.A. Issa, Design for maintenance accessibility using BIM tools, Facilities 32 (3/4) (2014) 153–159.

[14] Y.C. Lin, Y.P. Chen, W.T. Huang, C.C. Hong, Development of BIM execution plan for BIM model management during the pre-operation phase: A case study', Buildings 6 (8) (2016) 1-14.

[15] Y.C. Lin, H.Y. Lee, I.T. Yang, Developing as-built BIM model process management system for general contractors: A case study', Journal of Civil Engineering and Management 22 (5) (2016) 608–621.

[16] R. Liu, R.R.A. Issa, Issues in BIM for facility management from industry practitioners' perspectives, 2013 ASCE International Workshop on Computing in Civil Engineering, ASCE 411-418, Los Angeles, CA, USA, 23rd – 25th June 2013.

[17] J. McArthur, A Building Information Management (BIM) framework and supporting case study for existing building operations, maintenance and sustainability, Procedia Engineering 118 (2015) 1104–1111.

[18] A. Hamid, A. Bakar, M.R. Embi, Review on application of building information modelling in interior design industry, 4th International Building Control Conference 2016, Royal Institution of Surveyors Malaysia, Malaysia, 7th of March 2016.

[19] S. Hamil, What is COBie?, available on-line at: https://www.thenbs.com/knowledge/what-is-cobie (Accessed June 2019).

[20] K. Han, J. Degol, M. Golparvar-Fard, Geometry- and appearance-based reasoning of construction progress monitoring, Journal of Construction Engineering and Management 144 (2) (2018) 1-12.

[21] K.K. Han, M. Golparvar-Fard, Potential of big visual data and building information modeling for construction performance analytics: An exploratory study. Automation in Construction 73 (2017) 184–198.

[22] Z. Hu, P. Tian, S. Li, J. Zhang, BIM-based integrated delivery technologies for intelligent MEP management in the operation and maintenance phase, Advances in Engineering Software 115 (2018) 1–16.

[23] ISO, ISO 15686-5:2008: Buildings and constructed assets-Service-life planning-Part 5: Life- cycle costing, available on-line at: https://www.iso.org/obp/ui/#iso:std:iso:15686:-5:ed-1:v1:en (Accessed April 2019).

[24] J. Jupp, R. Awad, BIM for FM and Information Requirements Management: Missing Links in the AEC and FM Interface, International Conference on Product Lifecycle Management (PLM 2017), Seville, Spain. 9th – 12th July 2017.

[25] M. Kassem, G. Kelly, N. Dawood, M. Serginson, S. Lockley, BIM in facilities management applications: a case study of a large university complex, Built Environment Project and Asset Management 5 (3) (2015) 261-277.

[26] G. Kelly, M. Serginson, S. Lockley, N. Dawood, M. Kassem, BIM for facility management: a review and a case study investigating the value and challenges, 13th International Conference on Construction Applications of Virtual Reality, London, United Kingdom. 30th – 31th October 2013.

[27] H. Kerosuo, R. Miettinen, S. Paavola, T. Mäki, J. Korpela, Challenges of the expansive use of Building Information Modeling (BIM) in construction projects, Production 25 (2) (2015) 289- 297.

[28] J. Korpela, R. Miettinen, T. Salmikivi, J. Ihalainen, The challenges and potentials of utilizing building information modelling in facility management: the case of the center for properties and facilities of the University of Helsinki, Construction Management and Economics 33 (1) (2015) 3- 17.

[29] I. Kovacic, V. Zoller, Building life cycle optimization tools for early design phases, Energy 92 (2015) 409–419.

[30] R. Miettinen, H. Kerosuo, T. Metsälä, S. Paavola, Bridging the life cycle: a case study on facility management infrastructures and uses of BIM', Journal of Facilities Management 16 (1) (2018) 2-16.

[31] S.G. Naoum, Dissertation research & writing for construction students. 3rd ed., Routledge, London, 2013.

[32] NBS, NBS International BIM Report 2016, available on-line at: https://www.thenbs.com/knowledge/nbs-international-bim-report-2016 (Accessed April 2019).

[33] UK BIM Alliance, Information management according to BS EN ISO 19650, available on-line at: https://www.ukbimalliance.org/wp-content/uploads/2019/03/Information-Management-according-to- BS-EN-ISO-19650-Guidance-Part-1-Concepts-1.pdf (Accessed August 2019).

[34] R. Volk, J. Stengel, F. Schultmann, Building Information Modeling (BIM) for existing buildings-Literature review and future needs, Automation in Construction 38 (2014) 109–127.

[35] Y. Wang, X. Wang, J. Wang, P. Yung, G. Jun, Engagement of Facilities Management in Design Stage through BIM: Framework and a Case Study, Advances in Civil Engineering 2013 (2013) 1–8.

[36] A.N. Wei, and M.A. Othuman Mydin, Potential and benefits of Building Information Modeling (BIM) during pre-construction, construction and post construction stage, Analele Universităţii "Eftimie Murgu" 24 (1) (2017) 429-438.

[37] A. Lewis, D. Riley, A. Elmualim, Defining high performance buildings for operations and maintenance, International Journal of Facility Management 1 (2) (2010) 1-16.

[38] Infrastructure and Projects Authority, Creating a digital built Britain: what you need to know, available on-line at: https://www.gov.uk/guidance/creating-a-digital-built-britain-what-you-need-to-know (Accessed February 2019).

[39] K. Asadi, H. Ramshankar, M. Noghabaei, K. Han, Real-time image localization and registration with BIM using perspective alignment for indoor monitoring of construction, Journal of Computing in Civil Engineering 33 (5) (2019) 1-15.

[40] E. Pärn, D. Edwards, M. Sing, The building information modelling trajectory in facilities management: A review, Automation in Construction 75 (2017) 45-55.

[41] P. Parsanezhad, J. Dimyadi, Effective facility management and operations via a bim- based integrated information system, CIB Facilities Management (CFM) 2014 Conference, Copenhagen, Denmark, 21th – 23th May 2014.

[42] B.C. Paulson, Designing to reduce construction costs, Journal of the Construction Division 102 (4) (1976) 587–592.

[43] P. Pishdad-Bozorgi, X. Gao, C. Eastman, A.P. Self, Planning and developing facility management-enabled building information model (FM-enabled BIM), Automation in Construction 87 (2018) 22–38.

[44] C. Robson, Real World Research, 2nd ed., Blackwell, Oxford, 2002.

[45] R. Sacks, P. Teicholz, G. Lee, C. Eastman, Bim handbook: A Guide to Building Information Modeling for Owners, Designers, Engineers, Contractors, and Facility Managers, 3rd ed., John Wiley & Sons, Inc, Hoboken, N.J, 2018.

[46] M. Saunders, P. Lewis, A. Thornhill, Research methods for business students, 5th ed., Financial Times Prentice Hall, Harlow, 2009.

[47] L. Shen, R. Edirisinghe, M.G. Yang, An Investigation of BIM Readiness of Owners and Facility Managers in Singapore: Institutional Case Study, CIB World Building Congress 2016. Tampere, Finland, 30 May – 3 June 2016.

[48] Centre for Digital Built Britain. Digitising the Asset. Digitising Construction 2020: Next steps towards a Digital Built Britain, February 2020.

[49] M. Munir, A. Kiviniemi, S. Jonesand, S. Finnegan, BIM business value for asset owners: key issues and challenges, International Journal of Building Pathology and Adaptation, Vol ahead-of-print (2020).

[50] B. Ali, H. Zahoor, A. R. Nasir, A. Maqsoom, R. W. A. Khan, K. M. Mazher, BIM-based claims management system: A centralized information repository for extension of time claims. Automation in construction, 110 (2020) 102937.

[51] E. Piaia, F. Maietti, R. Di Giulio, O. Schippers-Trifan, A. Van Delft, S. Bruinenberg, R. Olivadese, BIM-based Cultural Heritage Asset Management Tool:

Innovative Solution to Orient the Preservation and Valorization of Historic Buildings. International Journal of Architectural Heritage, (2020) 1-24.

[52] S. Ashworth, MP. Tucker, CK. Druhmann, Critical success factors for facility management employer's information requirements (EIR) for BIM, Facilities, 37 (1/2) (2019) 103-118.

[53] S. Lavy, N. Saxena, M. Dixit, Effects of BIM and COBie Database Facility Management on Work Order Processing Times: Case Study, Journal of Performance of Constructed Facilities, 33 (6) (2019).

Table / Figure Legend