Integration of facility management and building information modeling (BIM)

A review of key issues and challenges

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Received 18 March 2018
Revised 12 June 2018
19 August 2018
Accepted 22 August 2018

Abstract

Purpose – The purpose of this study is to investigate factors that impede the integration of facilities management (FM) into building information modeling (BIM) technology. The use of BIM technology in the commercial construction industry has grown enormously in recent years. Its application to FM, however, is still limited. The literature highlights issues that hinder BIM–FM integration, which are studied and discussed in detail in this paper.

Design/methodology/approach – A review of literature is conducted to identify and categorize key issues hampering the application of BIM to FM. This paper has also designed a questionnaire based on a literature review and surveyed FM professionals at two industry events. Using the collected responses, these issues are analyzed and discussed using non-parametric statistical analyses.

Findings – A total of 16 issues are identified through the literature review of 54 studies under the four categories of BIM-execution and information-management, technological, cost-based and legal and contractual issues. The results of the survey of FM professionals (with 57 complete responses) reveal that the single most important issue is the lack of FM involvement in project phases when BIM is evolving.

Originality/value – The findings of this study could assist the construction industry (e.g. building-material and equipment manufacturers, design professionals, general contractors, construction managers, owners and facility managers) with creating guidelines that would help in BIM–FM integration. BIM is a virtual database that contains important design and construction information, which can be used for effective and efficient life cycle management if building data are captured completely and accurately with a facility manager's involvement.

Keywords Facilities management, Building information modeling, BIM and life cycle management, BIM challenges, BIM issues, BIM–FM integration

Paper type Research paper

1. Introduction

In recent times, the use of building information modeling (BIM) has increased tremendously in the construction sector, having significantly improved the efficiency, productivity and quality control of construction operations throughout a building's life cycle (Azhar, 2011; Arayici *et al.*, 2011). Essentially, BIM is a virtual database of a building's information that enables various stakeholders to effectively communicate and collaborate with each other (Naghshbandi, 2017). BIM can be used for many purposes such as visualization, code reviews, estimation, construction scheduling, clash detections and facility management (FM)

Facilities
Vol. 37 No. 7/8, 2019
pp. 455-483

0263-2772
DOI 10.1108/F-03-2018-0043

(Azhar, 2011). FM refers to the building phase that involves the financial management of funds to operate and maintain a facility (Kelly *et al.*, 2013). During this phase, BIM data can be useful in commissioning, space management, locating building components, quality control, energy management, security management and maintenance and repairs (Becerik-Gerber *et al.*, 2011).

While several studies have established the usefulness of BIM for design and construction purposes, its use for FM remains unexplored (Kiviniemi and Codinhoto, 2014; Kelly *et al.*, 2013). This was further substantiated by the Smart Market Report by Dodge Data and Analytics (Jones, 2015), which showed that over 86 per cent of building owners require BIM data from general contractors; however, only 17 per cent use it for FM. Even though BIM includes rich building design and construction data, why is it still not used for FM decision-making? Answers to this question may be found in peer-reviewed studies that discuss a variety of issues and challenges impeding BIM's use in the FM industry. For instance, owners are mostly concerned with the initial project cost of a building, failing to envision subsequent costs incurred during the operations and maintenance (O&M) phase of the building (Love *et al.*, 2014). In addition, during the design phase, when BIM starts evolving, inputs from facility managers are not included. This results in an information model with inadequate data for FM decision-making (Dixit and Venkatraj, 2017; Becerik-Gerber *et al.*, 2011). A thorough study of issues and challenges influencing BIM–FM integration is crucial to the FM industry. Most research papers investigated BIM–FM integration through case studies (Arayici *et al.*, 2011; Kassem *et al.*, 2015; Borhani, *et al.*, 2017), interviews (Lindkvist and Whyte, 2013; Korpela *et al.*, 2015), Delphi methods (Mayo and Issa, 2015), focus groups (Hosseini *et al.*, 2018) or survey methods (Mayo *et al.*, 2012; Liu and Issa, 2013). However, either their scope was limited to a facility, organization, city or a construction project or their focus was on BIM–FM process effectiveness, information exchange or data requirements. In addition, most studies surveyed either non-FM professionals or a mix of construction professionals, including those from the FM industry. A thorough survey of FM professionals to investigate what issues and challenges impede the integration of FM into BIM can provide a more insightful FM perspective on the BIM–FM topic.

In this paper, relevant literature is explored to identify issues and challenges hindering BIM–FM integration. Based on the findings of the literature review, a questionnaire survey was formulated and administered; responses were collected from FM professionals to validate these issues. In addition, key players (manufacturers of building materials, assemblies and equipment; design professionals; general contractors; construction managers; clients/owners; and facility managers) are also identified who may help address these issues. The results of this study are expected to help FM professionals generate a standardized BIM–FM integration framework to resolve issues and ensure complete usage of BIM for FM decision-making.

2. Research objectives and methods

2.1 Research objective

The main goal of this study is to investigate key issues and challenges impeding a successful integration of FM into BIM. The goal will be reached through the following research objectives:

- Identify key issues that hinder the BIM–FM integration by conducting a systematic review of literature.
- Design and administer a questionnaire survey to FM professionals based on the results of literature review, and collect, analyze and discuss their responses.
- Determine the sources of these issues and discuss suitable measures to address them.

2.2 Research methods

A survey-based approach is applied to collect data from FM professionals. We first conducted a review of literature to study the state-of-the-art of BIM–FM integration and create a knowledge base for generating survey questions. A questionnaire survey was generated based on the results of the literature review. A questionnaire-survey approach was preferred because it allows anonymity and freedom of participants and ensures the uniformity of responses (Visser *et al.*, 2000; Akbayrak, 2000; Bird, 2009; Mathiyazhagan and Nandan, 2010). The survey was administered in person to ensure higher and complete responses (Akbayrak, 2000; Bird, 2009). Figure 1 illustrates the research method schematically.

2.2.1 Literature review. A literature search was performed on the Google Scholar search engine using keywords such as Revit, BIM, FM, BIM for O&M, Construction Operations Building Information Exchange (COBie), dynamic maintenance of BIM, fragmentation, FM information transfer formats, interoperability and key players. These terms were also combined to find more studies. For instance, we combined terms such as Revit and BIM with FM and building maintenance and operations. Likewise, terms such as BIM and FM were searched with words such as "issues" and "challenges" to identify studies discussing or examining BIM–FM integration issues. We used both the acronym FM and the term "facility management" to search for relevant literature. This search resulted in a collection of over 54 research papers (n = 54) between the years 2008 and 2017 (focusing on studies published during the past decade kept the results relevant). In a rigorous review of literature, Volk *et al.* (2014) found that most papers on BIM were "published after 2008 with a considerable intensification in the latest years." Figure 1 illustrates the process of literature review schematically. We reviewed and analyzed the information obtained from the referred journal papers, conference proceedings, government documents, industry reports and other online articles. Studies that considered and discussed the use of BIM during the FM phase and not during the design and construction phases were included. Such cases were particularly selected to understand the key issues and barriers that prevent the implementation of BIM mainly for the O&M phase that relates closely to FM. This analysis led to formulating a matrix that helped us identify BIM–FM issues highlighted in various studies.

2.2.2 Survey. Once a matrix of key issues and challenges to BIM–FM integration was developed from the literature review, a questionnaire survey was designed to collect responses from FM professionals. These responses were categorized based on their years of experience in FM and area of expertise in the field of FM (FM delivery or FM consultancy). FM delivery is a

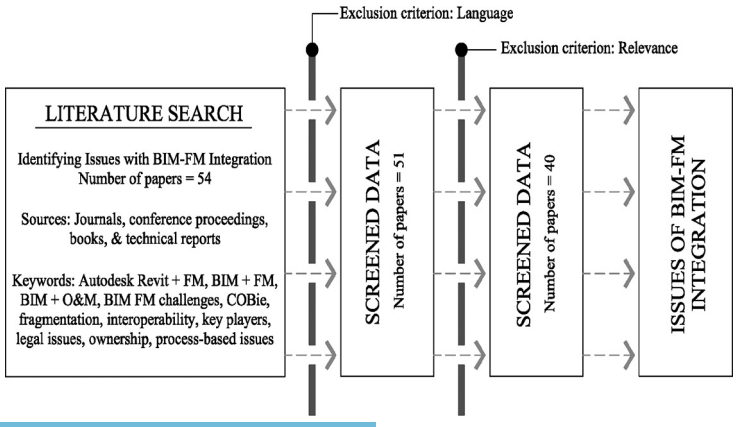

Figure 1. Research methodology

term that refers to professionals who are involved in delivering FM services during the O&M phase. On the contrary, the term FM consultancy refers to professionals who provide consultancy services (developing comprehensive maintenance plans, condition assessment studies, etc.) during the buildings' life cycle. The issues and challenges were assigned to four categories, each of which was represented by three to four questions in the questionnaire. Table I lists the survey questions under the four categories, along with the scales to measure responses. In addition to the questions related to BIM–FM integration issues, we asked respondents for their years of experience in the FM industry and their level of proficiency with BIM, to explore whether these factors influenced their responses. A non-random convenient sampling was used to administer the survey and collect responses. The survey was conducted at the 2017 International Facility Management Association (IFMA) World Workplace, Stockholm, Europe, and the 2017 IFMA World Workplace, Houston, USA. A total of 57 responses were collected from professionals in academia and industry.

2.2.3 Data analysis. Two types of scales were used to measure professionals' opinions:

(1) ordinal scale; and

(2) nominal or categorical scale.

The five-point Likert scale was used on some questions that were treated as an ordinal scale in the analysis. The three-choice nominal or categorical scale was used for the remaining questions (Table I). The two-sample T-test was used on nominal variables as a means of

Category	Question/statement	Scale type
BIM execution and information-management issues	Post-construction, BIM workflow stops because a BIM execution framework is absent	Five-point Likert, ordinal
	Including FM professionals during initial BIM will help in collecting O&M data	Five-point Likert, ordinal
	Capturing and updating FM data in BIM can be improved by: (1) developing guidelines; (2) using automated FM systems; (3) both	Three-choice, nominal
Technological issues	Incompatible file exchange formats are caused by multiple: (1) software applications; (2) software versions; (3) both	Three-choice, nominal
	Data incompatibility between BIM tools will be resolved by: (1) interoperable BIM software platform; (2) plug-ins; (3) both	Three-choice, nominal
	File size hinders information exchange between on-site and off-site personnel	Five-point Likert, ordinal
	Creating small work-packages, usable on mobile devices, will enhance information exchange	Five-point Likert, ordinal
Cost-based issues	The owners refrain from investing in BIM because of: (1) high training costs; (2) unperceived cost benefits; (3) both	Three-choice, nominal
	Pre-planning and allocating funds initially will help in managing BIM costs	Five-point Likert, ordinal
	FM industry will generate a better return on investment by using BIM for O&M	Five-point Likert, ordinal
Legal and contractual issues	Lack of clarity on the ownership of the BIM model delays decision-making	Five-point Likert, ordinal
	Assigning ownership and responsibility of the BIM model during the initial stages of construction will improve decision-making	Five-point Likert, ordinal
	FM professionals refrain from electronic transfer of confidential information because of issues of cyber security, authenticity and other risks	Five-point Likert, ordinal

Table I.
List of survey questions

statistical analysis to evaluate the hypothesis that there is no statistically significant difference between the responses of three pairs of demographically different subgroups. They were "participants with less than 10 years of experience in FM delivery" and "participants with 10-30 years of experience in FM delivery"; "participants with a third to fifth level of proficiency with using BIM for FM" and "participants with a first to second level of proficiency with using BIM for FM"; and "participants with less than 10 years of experience in FM consultancy" and "participants with 10-30 years of experience in FM consultancy." However, the two-sample T-test was rejected for the subgroup "participants with less than 10 years of experience in FM consultancy" and "participants with 10-30 years of experience in FM consultancy," as the data set had a small sample size (less than 25). In addition, this data set was not normally distributed, as verified by the Shapiro–Wilk test. Therefore, the Mann–Whitney U-test was used on the three pairs of subgroups to analyze the hypothesis as it does not rely on distributional assumptions and is a non-parametric test of the null hypothesis. We used a rigorous analysis of collected data for any differences across different subgroups because the mean score of one survey item was considerably higher than the other items. This item examined participants' opinion on "Including FM professionals during initial BIM will help in collecting O&M data."

2.2.4 Limitations. The review of literature was based on 54 studies published between the years 2008 and 2017. The identified BIM–FM issues may be limited to these studies. Also, the questionnaire survey was administered to the participants of the two conferences. The survey results and conclusions are, therefore, limited to their opinion and may not be generalized to the broader FM professional population.

3. Literature review

3.1 Existing studies on building information modeling–facilities management integration

Existing studies used a wide range of methods, such as literature reviews (Volk *et al.*, 2014; Pärn *et al.*, 2017; Edirisinghe *et al.*, 2017), case studies (Cavka *et al.*, 2015), focus groups (Hosseini *et al.*, 2018), interviews (Lindkvist and Whyte, 2013), Delphi method (Mayo and Issa, 2015) and surveys (Mayo *et al.*, 2012; Liu and Issa, 2014), to discuss advantages, disadvantages, key issues and challenges to BIM–FM integration. Most studies, such as Arayici *et al.* (2011); Kelly *et al.* (2013), Kasprzak *et al.* (2013), Kiviniemi and Codinhoto (2014), Kassem *et al.* (2015), Cavka *et al.* (2015), Korpela *et al.* (2015), Borhani *et al.* (2017), Lin and Su (2013), Parsanezhad and Dimyadi, 2013 and Wang *et al.* (2013), presented case studies to reveal a wide range of BIM–FM issues, such as a lack of BIM–FM integration benefit awareness, a lack of interoperability between FM and BIM authoring tools, poorly defined FM data requirements, unclear roles and responsibilities for data management, a lack of contractual and liability framework, inadequate BIM skills and low motivation to adopt BIM technologies. Hosseini *et al.* (2018) used a focus-group approach to not only discuss key challenges but also outline data and information typology (operational, tactical and strategic) and typology matrix for data and information to help capture needed data during project handover stage. Lindkvist and Whyte (2013) interviewed 18 participants, including client representatives, delivery partners and FM professionals, to discuss challenges and opportunities of FM involvement during project handover. Miettinen *et al.* (2018) conducted interviews of 11 FM practitioners with "a limited familiarity of BIM" to discuss key issues impeding the use of for FM. Mayo and Issa (2015) applied a four-round Delphi approach to identify important information needs (content of closeout information) and the frequency and format of FM data to be captured. Mayo *et al.* (2012) conducted a 29-question survey of the members of the Construction Owners Association of America, FL Chapter to identify major obstacles to BIM use for FM. The survey revealed that a lack of

interoperability, misunderstanding of information handover requirements and a general lack of software knowledge required to use BIM deliverables were the key challenges to BIM–FM integration. Table II lists some of the studies on FM–BIM integration, which conducted a survey, interview, focus group, case study or a literature review to investigate issues hindering specifically BIM–FM integration. While most studies used a case study approach to investigate or discuss FM–BIM integration process, some applied interview and survey approaches. Other methods, such as focus groups and Delphi method, are also used by some studies to identify and discuss mostly BIM data needs for FM decision-making. Some studies, such as Mohanta and Das (2017) and Volk *et al.* (2014), used literature review to synthesize published knowledge and identify key issues that hinder the use of BIM for FM. Volk *et al.* (2014) discussed how a limited focus of BIM functionalities on FM tasks hampers the effective use of BIM for FM. They further argued that this could be owing to the non-participation of facility managers during the BIM evolution phases. Other issues such as the interoperability of BIM and FM tools as well as the inaccurate and insufficient capture and processing of BIM data needed for FM decision-making were also discussed. Mohanta and Das (2017) also discussed the importance of defining the standard level of

Study	Research methods	Scope	Focus
Pishdad-Bozorgi *et al.* (2018)	Interview	Project-specific	FM–BIM process effectiveness; lessons learned
Parsanezhad and Dimyadi (2013)	Case study	Project-specific	FM–BIM issues
Mohanta and Das (2017)	Literature review	Literature	Abilities of BIM as an FM tool
Miettinen *et al.* (2018)	Interview and literature review	City-specific	FM–BIM integration needs and impediments
Mayo and Issa (2015)	Delphi method	Organization-specific	BIM information needs for FM
Mayo *et al.* (2012)	Survey	Organization-specific	FM–BIM obstacles
Liu and Issa (2013)	Survey	Industry professionals	BIM information needs for FM
Korpela *et al.* (2015)	Interview	Project-specific	FM–BIM information needs, tools and challenges
Kelly *et al.* (2013)	Case study	Project-specific	FM–BIM challenges
Lindkvist and Whyte (2013)	Interview	Project-specific	Challenges of FM data handover during project closeout phase
Kassem *et al.* (2015)	Case study and literature review	Project-specific	FM–BIM challenges; value of BIM for FM
Volk *et al.* (2014)	Literature review	Literature	BIM for existing building: challenges
Kasprzak *et al.* (2013)	Case study	Organization-specific	BIM information needs for FM; value of BIM for FM
Hosseini *et al.* (2018)	Focus group	Association-specific	Data and information typology and needs
Cavka *et al.* (2015)	Case study	Organization-specific	Owner challenges to adopt BIM
Bosch *et al.* (2015)	Interview and literature review	Association-specific	BIM bottlenecks form BIM use in operation stage
Borhani *et al.* (2017)	Case study and literature review	Organization-specific	BIM workflow and information exchange for sustainable facility management
Arayici *et al.* (2011)	Case study	Project-specific	BIM contribution to FM improvement

Table II.
Studies on BIM–FM integration

development/details (LOD) and information requirements of FM decision-making so that needed data can be captured accurately and completely when BIM is developing. The scope of these studies mainly included a project, professional association, organization or a city. In other words, data were collected mainly from participants associated to or from these groups, limiting the generalizability of the studies. Also, the focus of studies was on FM–BIM process, its data requirements or challenges and barriers. This study includes a survey of FM industry professionals to identify what issues are impeding BIM–FM integration.

3.2 Building information modeling–facilities management integration: key issues

The literature review helped us classify the issues into four categories:

(1) BIM execution and information management;

(2) technological;

(3) cost-based; and

(4) legal and contractual.

Figure 2 presents the matrix of BIM–FM issues under the four categories along with referred studies discussing them. These issues are discussed in detail in the subsequent sections.

3.2.1 Building information modeling-execution and information-management issues. BIM-execution and information-management issues occur owing to:

- unclear BIM workflow;
- improper information capture;
- failure to update BIM information; and
- lack of client demand.

3.2.1.1 Unclear building information modeling workflow. The successful implementation of BIM requires an exchange of information between various stakeholders (Eadie *et al.*, 2013). Unclear roles, undefined responsibilities, unstandardized BIM workflow structure, reluctance to share information with other teams and a lack of guidelines to control or verify BIM data result in building personnel working redundantly (McAuley, 2016; Elmualim and Gilder, 2014; Kelly *et al.*, 2013; Kasprzak *et al.*, 2013; Eadie *et al.*, 2013; Lin and Su, 2013; Wang *et al.*, 2013; Becerik-Gerber, 2011). For example, the current BIM workflow structure does not include FM personnel until the O&M phase, such a workflow structure suddenly exposes FM personnel to large amounts of data that overwhelm them (Kang and Hong, 2015; Teicholz, 2013). In such cases, gathering useful FM information or outsourcing BIM to external service providers becomes difficult, particularly when the construction phase is over (Beach, 2017). Hiring a BIM coordinator to assign responsibilities to the individuals working in a team may significantly influence the use of BIM and how efficiently the team can be organized to enhance the use of BIM.

3.2.1.2 Improper information capture. The volume of information progressively increases from the design phase to the O&M phase, making it crucial to capture building information such as manufacturing data, specifications, operational instructions, procedures and warranty information (Liu and Issa, 2013; Becerik-Gerber *et al.*, 2011). At present, no specific guidelines exist regarding the LOD, nomenclature, numbering style, semantics, syntax and schema to be used while gathering this information (Liu and Issa, 2013; Parsanezhad and Dimyadi, 2013; Becerik-Gerber *et al.*, 2011). These factors eventually lead to delays in information processing, loss of information and data disintegration and fragmentation over the building's life cycle (Liu

STUDY	ISSUES															
	BIM execution and information management				Technological						Cost based			Legal and contractual		
	Unclear BIM workflow	Improper information capture	Failure to update BIM information	Lack of client demand to use BIM for FM	Incompatible file exchange formats	Availability of multiple software platforms	Interoperability between BIM-FM technologies	Large file size	Software issues	Long adaptation time towards using new technology	Cost associated with training BIM personnel	Cost associated with information management	Unperceived cost benefits of using BIM	Ownership and responsibility of BIM data	Contractual & compliance	Cyber security & privacy
Azhar, 2011		✓									✓			✓		
Azhar *et al.*, 2015									✓			✓				
Becerik-Gerber *et al.*, 2011	✓	✓	✓		✓	✓										
Goedert & Meadati, 2008					✓											
Jung *et al.*, 2011					✓											
Kasprzak *et al.*, 2013	✓															
Kelly *et al.*, 2013	✓		✓				✓							✓	✓	
Kiviniemi & Codinhoto, 2014									✓							
Liu & Issa, 2013		✓	✓													
Liu & Zetterson, 2016		✓	✓		✓	✓			✓							
Naghshbandi, 2017			✓													
Parn *et al.*, 2017	✓		✓													
Talebi, 2014											✓		✓	✓		
Volk *et al.*, 2014														✓		
Anderson *et al.*, 2012							✓		✓	✓						
Beach *et al.*, 2017			✓							✓	✓		✓	✓		
Eadie *et al.*, 2013	✓										✓			✓		✓
East & Brodt, 2007												✓				
Elmualim & Gilder, 2014	✓			✓						✓		✓	✓			
Kang & Hong, 2015			✓									✓				
Kivits & Furneaux, 2013						✓		✓		✓			✓	✓		✓
Lin & Su, 2013	✓		✓					✓								
Lin *et al.*, 2014			✓					✓								
Liu & Issa, 2014					✓		✓									
Liu, 2010			✓								✓			✓		
Love *et al.*, 2014	✓		✓				✓						✓			
Manning & Messner, 2008			✓						✓							
Mayo *et al.*, 2012			✓		✓											
McAuley, 2016	✓		✓			✓	✓						✓			
McAuley *et al.*, 2015				✓									✓			
Mignard & Nicolle, 2014			✓													
Mishra & Mishra, 2014											✓					
Parsanezhad & Dimyadu, 2013		✓				✓										
Utiome, 2015		✓					✓		✓							
Vanlande *et al.*, 2008			✓													
Arayici *et al.*, 2011			✓													
Steel *et al.*, 2012		✓			✓											
Wang *et al.*, 2013	✓		✓	✓												
Arayici *et al.*, 2012			✓	✓												

Figure 2.
List of studies included in literature review, highlighting the issues discussed in them

and Zettersten, 2016). Increasing transparency among building stakeholders and developing a standard protocol for information capture during the design and construction phases would enhance the decision-making process.

3.2.1.3 Failure to update building information modeling information. A BIM needs to be constantly updated to ensure that the quality of information present in the model is useful for FM personnel (Naghshbandi, 2017; Beach *et al.*, 2017; McAuley, 2016; Kelly *et al.*, 2013; Liu and

Issa, 2013; Becerik-Gerber *et al.*, 2011; Vanlande *et al.*, 2008). However, data entry into a BIM is a manual and time-consuming process. This might cause inaccuracies in updating BIM information owing to data duplication or data modification. Additionally, the limited ability of mobile devices to update necessary information in a BIM causes delays and errors in performing key FM tasks (Kang and Hong, 2015; Lin and Su, 2013; Lin *et al.*, 2014; Teicholz, 2013) As a result, FM personnel lack the motivation to provide continuous feedback to the owner with an updated BIM (Liu and Zettersten, 2016). Updating FM information in BIM during the design, construction and O&M phases would significantly improve decision-making and problem-solving (Mignard and Nicolle, 2014; Wang *et al.*, 2013).

3.2.1.4 Lack of client demand to use building information modeling for facilities management. At present, there is a lack of sufficient information and case studies of built assets that show the benefits of using BIM for FM. Therefore, clients fail to demand the use of BIM for FM as they are unaware of its implications (McAuley, 2016; McAuley *et al.*, 2015; Talebi, 2014; Wang *et al.*, 2013; Arayici *et al.*, 2012). As a result, BIM models are not managed or maintained throughout a building's life cycle (Elmualim and Gilder, 2014). In this case, creating an information database of previous case studies would provide some motivation for owners to use BIM for FM.

3.2.2 Technological issues. Technological issues mainly occur because of:

- incompatible file exchange formats;
- availability of multiple software platforms;
- interoperability between BIM–FM technologies;
- large file sizes;
- software issues; and
- long adaptation times when using new technology.

3.2.2.1 Incompatible file exchange formats. During the design and construction phases, incompatible file formats are created because of building professionals working on a mixture of digital and paper-based media. Updating paper-based information on BIM becomes a tedious process (Goedert and Meadati, 2008). In addition, the existence of different application formats and middleware programs leads to information loss, miscommunication and liability while data are being transferred from one application to another (Teicholz, 2013; Mayo *et al.*, 2012). For example, while information is transferred from Solibri Model Checker to Autodesk Revit, the information is converted from one format to another, causing loss of data (Liu and Zettersten, 2016; Liu and Issa, 2013). Establishing standard protocols such as Industry Foundation Classes, information delivery manuals or adapting to completely digitalized formats might help resolve this issue (Jung and Joo, 2011).

3.2.2.2 Availability of multiple software platforms. Various toolsets, such as Computer Aided Facility Management (CAFM), computer aided design, integrated workplace management systems and computerized maintenance management system) are used for BIM–FM integration. Building personnel use these different software platforms based on their availability and complexity. Additionally, the selection of a particular software platform is determined by the size, scope and geographic location of a project. This makes it difficult to use a single standard software platform while collaborating with multiple stakeholders across different regions of the globe (Liu and Zettersten, 2016; Kivits and Furneaux, 2013; Parsanezhad and Dimyadi, 2013).

3.2.2.3 Interoperability between building information modeling–facilities management technologies. Interoperability is defined as "the ability of a software program to exchange

data between various applications to facilitate automation and avoid data re-entry" (Azhar *et al.*, 2015). The issue of interoperability usually arises from incompatibility between the building automation systems, and other FM technologies with BIM (Teicholz, 2013). For instance, extracting information from a BIM causes an overload of information in the CAFM system (McAuley, 2016). To resolve this issue, COBie, a standardized format used for digitized information exchange is used to structure available data (Anderson *et al.*, 2012). However, "COBie does not provide details on what information is to be provided, when and by whom" (Kelly *et al.*, 2013). This lack of guidelines regarding the implementation of COBie limits its usage as a format for information exchange. As a result, data transfer becomes cumbersome and the overall interaction between stakeholders is restricted (Utiome, 2015). Developing plugins or application program interface (API)) for data transfer from standard software platforms to FM tools might help (Liu and Issa, 2013).

3.2.2.4 Large file sizes. The BIM–FM workflow requires data transfer between on-site and off-site personnel. As a BIM is designed to be used on desktop computers, downloading a BIM file can take 2-5 min, which limits their usage for FM tasks performed on-site (Lin *et al.*, 2014; Kivits and Furneaux, 2013; Lin and Su, 2013). For this, changing the BIM file into smaller data packets might help with the storage constraints of mobile devices. In addition, real-time updates of a BIM using mobile devices would improve the quality of FM data collected during the construction phase.

3.2.2.5 Software issues. New versions of a software are generally not compatible with older versions; this drastically restricts multi-user access to the model (Azhar *et al.*, 2015). For example, a model created using Revit 2017 will not open in the Revit 2015 version. The industry lacks software developers who understand the construction process or the end use of the product, making it difficult to design the software appropriately (Liu and Zettersten, 2016; Azhar *et al.*, 2015).

3.2.2.6 Long adaptation times when using new technology. As most of the BIM or FM software applications have a complex and non-intuitive interface, building professionals are apprehensive about investing time to understand and use these applications to manage data (Kivits and Furneaux, 2013). This has resulted in a mixture of electronic and paper-based media, making it difficult for personnel to access, track, authenticate or trust the source of information (Anderson *et al.*, 2012). Therefore, the value of using standard information exchange formats (e.g. COBie) is lost, as the construction industry lacks the motivation to use BIM–FM applications (Beach *et al.*, 2017; Elmualim and Gilder, 2014; Anderson *et al.*, 2012).

3.2.3 Cost-based issues. Cost-based issues include:

- costs associated with training BIM personnel;
- costs associated with information management; and
- unperceived cost benefits of using BIM.

3.2.3.1 Costs associated with training building information modeling personnel Apart from the initial investment cost, sufficient time and human resources must be allocated for training building professionals to use BIM (Mishra and Mishra, 2014). Therefore, the use of BIM is usually associated with additional administrative and training costs (Beach *et al.*, 2017; Talebi, 2014; Eadie *et al.*, 2013; Azhar, 2011; Liu, 2010). Investing and allocating sufficient funds during the preconstruction phase might help in eliminating the issue and saving costs in the long run.

3.2.3.2 Costs associated with information management. Annually, around $10bn is lost because of improper data access and interoperability issues (Beach *et al.*, 2017). Owing to an

owner's failure to invest in BIM, data are not managed properly (Elmualim and Gilder, 2014; East and Brodt, 2007). As a result, FM personnel spend considerable time verifying, locating and segregating useful data from the rest (Kang and Hong, 2015; East and Brodt, 2007). Also, because of the lack of a BIM workflow structure, building owners pay twice, once to the construction contractor for the set of complete documents at the end of construction and once to facility-maintenance contractors to capture updated as-built conditions (East and Brodt, 2007).

3.2.3.3 Unperceived cost benefits of using building information modeling. As building designers do not directly benefit from the use of BIM for FM, they fail to motivate the owner to invest in BIM for the post occupation evaluation of their assets. As a result, the as-built BIM of an asset is not updated with the most recent changes. This increases the time and cost required to perform FM tasks (Elmualim and Gilder, 2014; Kivits and Furneaux, 2013). A BIM also offers the flexibility of data storage by informing companies about the size of digital data storage required for the project's life cycle. This helps to significantly eliminate the need for fixed-size storage spaces for paper-based media. Companies can buy digital data storage using cloud services based on their current project requirements (Beach *et al.*, 2017). Being stored on the cloud, the information is readily available and accessible to the various stakeholders of a project (Beach *et al.*, 2017). In this case, the owner fails to perceive the potential cost benefits of using BIM to perform FM activities during the O&M phase of a project.

3.2.4 Legal and contractual issues. The key legal and contractual issues are:

- ownership and responsibility for BIM data;
- contractual and compliance issues; and
- cyber security and privacy.

3.2.4.1 Ownership and responsibility for building information modeling data. As a BIM is a single complex file created by the designer and edited by several other individuals involved in the construction process, assigning ownership and responsibility for a BIM is extremely challenging (Beach *et al.*, 2017; Azhar *et al.*, 2015; Talebi, 2014; Volk *et al.*, 2014; Elmualim and Gilder, 2014; Kelly *et al.*, 2013; Eadie *et al.*, 2013; Kivits and Furneaux, 2013; Azhar, 2011; East and Brodt, 2007). Ideally, only essential information would be transferred to the designated project participant to avoid risks associated with inaccurate data entry. However, categorizing information becomes cumbersome and time-consuming because of the lack of guidelines (Kivits and Furneaux, 2013; Teicholz, 2013; Azhar, 2011). Furthermore, an owner's licensing agreement will most probably include limited reuse. Based on the licensing agreement, a BIM can be reused or modified only a limited number of times. This makes it critical for project participants to understand liability and copyright concerns pertaining to data exchange or reuse (Volk *et al.*, 2014; Kelly *et al.*, 2013; Teicholz, 2013). Ownership of BIM data needs to be assigned during the pre-design and pre-construction phases to ensure smoother workflows.

3.2.4.2 Contractual and compliance issues. Contractual documents that include equipment lists, product data sheets, operations and maintenance manuals, warranties, spare parts sheets and specification lists are mostly paper-based documents that are reviewed, sealed and signed (Kelly *et al.*, 2013). On a few occasions, these contractual documents are generated from the BIM, resulting in accessibility concerns, confusion and misleading transfer of information (Kelly *et al.*, 2013; Teicholz, 2013). Office staff capturing this sort of information should be assisted by legal and contractual teams to capture the most precise as-built conditions and to avoid liabilities or legal consequences.

3.2.4.3 Cyber security and privacy. Electronic environments allow malicious hackers to corrupt, publicize or modify sensitive information (Kivits and Furneaux, 2013). Owing to this, cyber security becomes a major threat when an unauthorized user or hacker gains access to a BIM, as it contains sensitive information such as the location of the entry, exits, staircases and building layout. In addition, confidential information such as electronic signatures on contractual documents can be easily forged or replicated, thereby creating doubts about authenticity (Kivits and Furneaux, 2013). Furthermore, making the BIM a part of the extranet (using an external server, middleware software or cloud storage) might lead to an information security breach and legal repercussions (Eadie *et al.*, 2013). Developing cyber security policies or applications that would ensure safe and secure transfer of confidential information might motivate the construction industry to use completely digital environments.

Table III provides a summary of identified issues and challenges, along with a list of key players who may be able to address them. For instance, most issues of BIM execution and information management relate to players such as designers, manufacturers, general contractors and facility managers who are responsible for BIM work flow, as well as information creation, modification and transfer across project phases. Although most technological issues fall in the domain of software developers or service providers, owners may want their information technology staff to develop customized plugins for desired FM tasks. Cost-based issues can be addressed most effectively by owners. Informing owners about the business benefits of BIM, however, is crucial to securing a BIM budget. Issues of legal and contractual nature are more relevant to players involved in construction contracts (e.g. owner, designer and general contractor). Owners may have to get their legal advisors and contract personnel involved with the design and construction teams to establish liabilities of BIM data and to ensure the privacy and security of electronic data. The table also lists project phases in which a particular issue may occur. Suggestions to resolve these issues and resulting benefits to BIM–FM integration are also mentioned.

4. Results

4.1 Participants' experience and proficiency

In the first question of the survey, participants were asked about their years of experience in two different areas of FM. As shown in Figure 3, roughly half of the respondents (52.7 per cent) stated that they had less than 10 years of experience in the field of FM delivery, while the rest reported that they had between 10 and 30 years of experience in this field. In addition, the cumulative percentage of the responses indicates that about half of the respondents (53.8 per cent) reported less than 10 years of experience in the area of FM consultancy, while the rest stated 10-30 years of experience (Figure 3). The second question inquired about their level of proficiency in using BIM for FM on a scale of five levels, with the first being the least proficient and the fifth being the most proficient, meaning the participant knows about BIM and could probably open a model. The second level of proficiency may indicate that the participants could also navigate through a model to find needed information. The third level indicates that the participant can also make changes to the model if needed. Participants at the fourth level can also create new models and use BIM database for a desired purpose (e.g. project planning and simulation). The most advanced BIM proficiency is the fifth level at which the participant could also organize BIM data as per life cycle management requirements and can use it for FM decision-making (e.g. maintenance management, space management). As shown in Figure 4, approximately half of the participants (49.1 per cent) rated their level of proficiency with using BIM for FM

Table III. Summary of prevalent issues hindering BIM–FM integration

Issue/category	Key player	Phase issue exists in	Suggestion	Benefits to FM
BIM-execution and information-management issues				
Unclear BIM workflow	Designer, contractor and facility manager	Design, construction, O&M	Develop framework to include a third-party BIM service provider	Increases accuracy of data quality of the BIM
Improper information capture	Manufacturer, designer, contractor and facility manager	Building's life cycle	Develop protocols and standard formats to capture information	Prevents information loss, enabling faster decision-making
Failure to update BIM information	Owner and facility manager	O&M	Automate the entry of FM data	Saves time required to manually enter FM data
Lack of client demand to use BIM for FM	Owner	O&M	Emphasize the importance of using BIM to the owner	Saves time and cost in the long run
Technological issues				
Incompatible file exchange formats	Software developer	Design and construction	Understand the requirements of the end user and offer easier format exchange	Prevents data disintegration over the building's life cycle
Availability of multiple software platforms	Software developer	Design and construction	Develop consistent software platform to perform all functions	Ensures standard information flow across FM players
Interoperability between BIM–FM technologies	Software developer, owner	Design, construction, O&M	Develop plugins/API for data transfer from BIM to FM tools	Will prevent data fragmentation
Large file size	Software developer	Construction, O&M	Increase the ability of mobile devices to update BIM data	Improves communication between stakeholders
Software issues	Software developer	Software development, design, construction	Develop consistent construction templates and ensure new software versions are compatible with older versions	Limits inconsistencies, increases efficiency and quality of data
Long adaptation times toward using new software	Designer, contractor and facility manager	Design, construction, O&M	Make the user interface less complex and easy to understand	Saves time required to access and track information

(*continued*)

Table III.

Issue/category	Key player	Phase issue exists in	Suggestion	Benefits to FM
Cost-based issues				
Cost associated with training BIM personnel	Owner	Pre-construction	Allocate funds during initial project phase	Ensures the use of BIM for the entire building's life cycle
Cost associated with information management	Owner	Building's life cycle	Develop guidelines regarding payment procedures	Adds value to the company
Unperceived cost benefits of using BIM	Owners and designers	O&M	Substantiate with information regarding the cost benefits of using BIM	Saves storage cost, enhances collaboration
Legal and contractual issues				
Ownership and responsibility of BIM data	Owner and designer	Design	Assign ownership during initial project phase	Ensures smoother workflows
Contractual and compliance issues	Owner, designer, contractor and facility manager	Design, construction, O&M	Develop documents in a completely digital environment	Faster verification process
Cyber security and privacy	Owner, designer, contractor and facility manager	Design, construction, O&M	Increase security by developing either cyber security policies or applications	Will help in eliminating paper-based media

between the third and fifth levels. The rest reported that they were proficient at either the first or second level.

The third question asked participants their opinion regarding issues that hindered the implementation of BIM for FM decision-making. The issues were categorized in four groups of questions as follows:

(1) BIM-execution and information-management issues;

(2) technological issues;

(3) cost-based issues; and

(4) legal and contractual issues.

The subsequent sections describe responses to the questions under the four groups by scale type.

4.2 Responses to survey questions

Table IV lists all responses to the survey questions on an ordinal scale. The first question regarding "BIM execution and information management issues" asked participants their opinion of the statement that "post construction, BIM workflow stops because a BIM-execution framework is absent." Only 3.6 per cent of respondents reported that they either "Completely Agree" or "Agree" with the statement, meaning that most participants disagreed in some way or another with the statement. The second question of this category asked participants their opinion of the statement that "including FM professionals during

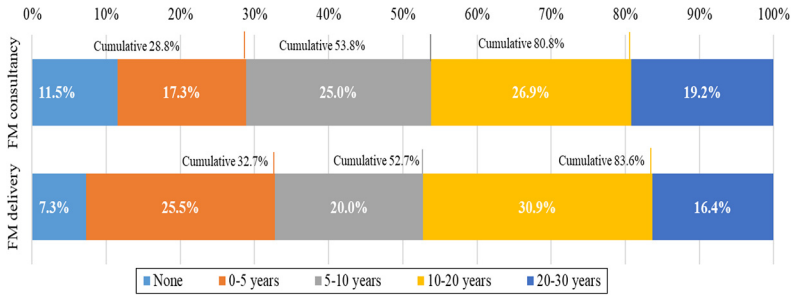

Figure 3.
Percentage of respondents with years' of experience in FM consultancy and delivery

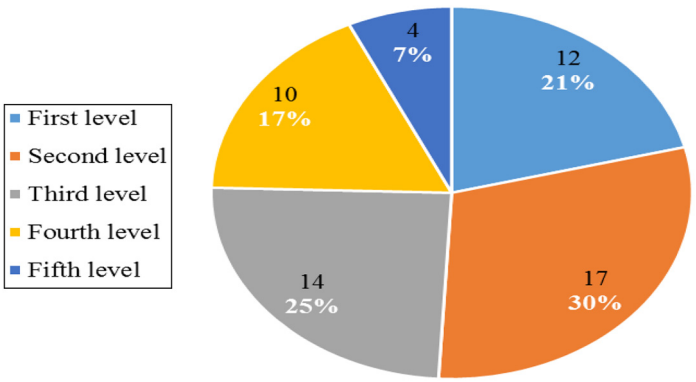

Figure 4.
Respondents' proficiency with using BIM (number of respondents)

Table IV. Number of responses on survey questions under each category of BIM–FM issues

Issues	Questions	Completely disagree	Disagree	Neutral	Agree	Completely agree	Weighted average
BIM execution and information management	Post-construction, BIM workflow stops because a BIM execution framework is absent	11	24	20	1	1	2.2
	Including FM professionals during initial BIM will help in collecting O&M data	1	1	20	24	11	3.8
Technological	File size hinders information exchange between on-site and off-site personnel	5	22	16	9	3	2.7
	Creating small work-packages, usable on mobile devices, will enhance information exchange	16	28	8	3	0	2.0
Cost-based	Pre-planning and allocating funds initially will help in managing BIM costs	16	26	14	1	0	2.0
	FM industry will generate a better return on investment by using BIM for O&M	11	28	15	3	0	2.2
Legal and contractual	Lack of clarity in ownership and responsibility of BIM model delays decision-making	11	29	13	4	0	2.2
	Assigning ownership and responsibility of the BIM model initially will improve decision–making	10	29	17	1	0	2.2
	FM professionals refrain from electronic transfer of confidential information owing to issues of cyber security, authenticity and other risks	5	23	17	9	2	2.6

initial BIM will help in collecting O&M data." Over half of the respondents (61.4 per cent) either "Completely Agree" or "Agree" with the statement. Only about 3.5 per cent of participants either "Completely Disagree" or "Disagree" with the statement. In other words, most participants agreed with the statement.

The third question of the "Technological issues" category asked participants their opinion of the statement that "file size hinders information exchange between on-site and off-site personnel." Only 21.9 per cent of the respondents reported that they either "Completely Agree" or "Agree" with the statement, while about half of the respondents (49.1 per cent) either "Completely Disagree" or "Disagree" with the statement (Table IV). The fourth question of this category asked participants their opinion of the statement that "creating small work-packages, usable on mobile devices will enhance information exchange." A majority of the respondents (80.0 per cent) either "Completely Disagree" or "Disagree" with the statement.

The second question of the "Cost based issues" category asked participants their opinion of the statement that "pre-planning and allocating funds initially will help in managing BIM costs." A majority of respondents (73.7 per cent) either "Completely Disagree" or "Disagree" with the statement (Table IV). The third question of this category asked participants their opinion of the statement that "FM industry will generate a better return on investment by using BIM for O&M." Over half of the respondents (68.4 per cent) either "Completely Disagree" or "Disagree" with the statement, while only 5.3 per cent of the participants agreed with it (Table IV).

The first question regarding "Legal and contractual issues" asked participants their opinion of the statement that "lack of clarity in ownership and responsibility of BIM model delays decision-making." Most respondents (70.2 per cent) either "Completely Disagree" or "Disagree" with the statement, while only 7.0 per cent of the participants agreed with it (Table IV). The second question of this category asked participants their opinion of the statement that "assigning ownership and responsibility of the BIM model initially will improve decision-making." Over half of the respondents (68.4 per cent) either "Completely Disagree" or "Disagree" with the statement, while only 1.8 per cent of the participants agreed with it. The last question of this category asked participants their opinion of the statement that "FM professionals refrain from electronic transfer of confidential information due to issues of cyber security, authenticity and other risks." As shown in Table IV, half of the respondents either "Completely Disagree" or "Disagree" with the statement, while less than 20 per cent of the participants agreed with it.

Figure 5 illustrates survey responses measured on a nominal scale. The third question of the "BIM execution and information management issues" category asked participants which of the mentioned factors could improve capturing and updating FM data in BIM. As shown in Figure 5, more than half of the respondents stated that both "developing guidelines" and

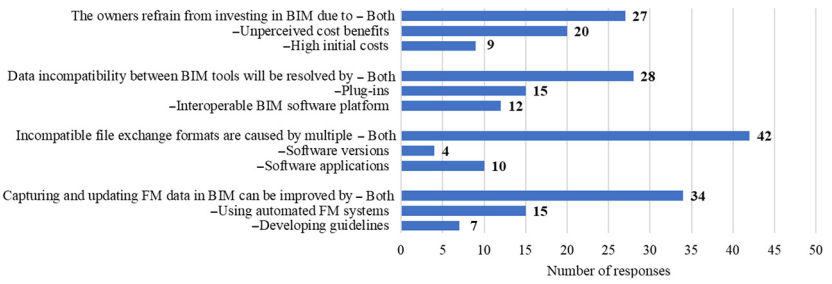

Figure 5. Number of respondents selecting the factors responsible for BIM–FM issues under study (nominal scale)

"using automated FM systems" could improve capturing and updating FM data in BIM. The first question regarding "Technological issues" asked participants their opinion of causes of incompatible file exchange formats. As shown in Figure 5, a majority of respondents (75 per cent) stated that incompatible file exchange formats are caused by both multiple software applications and multiple software versions. The second question of this category asked participants their opinion about solutions for data incompatibility between BIM tools. The highest percentage (50.9 per cent) belonged to those who reported that data incompatibility between BIM tools will be resolved by both interoperable BIM software platforms and plug-ins (Figure 5). The first question regarding "Cost based issues" asked participants their opinion about why owners refrain from investing in BIM. As shown in Figure 5, the highest percentage (48.2 per cent) belonged to those who reported that owners refrain from investing in BIM owing to both "software, training, and HR costs" and "unperceived cost benefits."

4.3 T-test and Mann–Whitney U-tests

Independent sample T-tests were conducted for nominal variables to evaluate the hypothesis that there is no statistically significant difference between responses of two pairs of subgroups:

(1) "Participants with less than 10 years of experience in FM delivery" and "Participants with 10-30 years of experience in FM delivery" (Table V); and

(2) "Participants with a third to fifth level of proficiency with using BIM for FM" and "Participants with a first to second level of proficiency with using BIM for FM" (Table VI).

As shown in Tables V and VI, all p-values were greater than 0.05, and so, the null hypothesis of the test cannot be rejected, meaning that there were no statistically significant differences between responses in the corresponding pairs of subgroups.

For samples smaller than 25 units, conclusions from an independent samples T-test can be trusted if the dependent variables follow a normal distribution in the population. As the number of participants with 10-30 years of experience in FM consultancy is 24 units, the normality of the distribution was checked by running a Shapiro–Wilk test. The Shapiro–Wilk test ($p < 0.05$) showed that responses were not approximately normally distributed for the two subgroups (Table VII). Hence, a non-parametric Mann–Whitney U-test was used to compare differences between responses of the two subgroups: "Participants with less than

Table V.
Independent samples T-test results for years of experience in FM delivery as a grouping variable

Variable (see Table I)	Years of experience in FM delivery	Mean	SD	t	df	Significance (two-tailed)
Capturing and updating FM data in BIM can be improved by.....	Less than 10	2.55	0.572	0.818	50	0.438
	10-30	2.39	0.839	0.784	37.257	
Incompatible file exchange formats are caused by multiple.....	Less than 10	2.59	0.780	0.572	49	0.570
	10-30	2.45	0.858	0.564	42.934	
Data Incompatibility between BIM tools will be resolved by.....	Less than 10	2.38	0.820	1.073	49	0.288
	10-30	2.14	0.774	1.082	46.623	
The owners refrain from investing in BIM owing to.....	Less than 10	2.31	0.806	−0.181	50	0.857
	10-30	2.35	0.647	−0.186	49.986	

10 years of experience in FM consultancy" and "Participants with 10-30 years of experience in FM consultancy." As shown in Table VIII, all p-values were greater than 0.05, and so, the null hypothesis of the test cannot be rejected, meaning that there were no statistically significant differences between responses in the two subgroups.

As an alternative for the independent samples T-test, Mann–Whitney U-tests were performed for ordinal variables to examine if there existed any statistically significant differences between responses of the three pairs of subgroups:

Variable (see Table I)	Level of proficiency with using BIM for FM	Mean	SD	t	df	Significance (two-tailed)
Capturing and updating FM data in BIM can be improved by.....	Third to fifth levels	2.54	0.576	0.559	54	0.579
	First to second levels	2.43	0.836	0.559	47.939	
Incompatible file exchange formats are caused by multiple.....	Third to fifth levels	2.61	0.737	0.339	54	0.736
	First to second levels	2.54	0.838	0.339	53.138	
Data Incompatibility between BIM tools will be resolved by.....	Third to fifth levels	2.29	0.810	−0.048	53	0.962
	First to second levels	2.30	0.823	−0.048	52.849	
The owners refrain from investing in BIM owing to.....	Third to fifth levels	2.14	0.891	−1.842	54	0.072
	First to second levels	2.50	0.509	−1.842	42.939	

Table VI. Independent samples T-test results for level of proficiency with using BIM for FM as a grouping variable

Variable (see Table I)	Years of experience in FM consultancy	Shapiro–Wilk Statistic	df	Significance
Capturing and updating FM data in BIM can be improved by.....	Less than 10 years	0.694	29	0.000
	10-30 years	0.675	21	0.000
Incompatible file exchange formats are caused by multiple.....	Less than 10 years	0.550	29	0.000
	10-30years	0.633	21	0.000
Data Incompatibility between BIM tools will be resolved by.....	Less than 10 years	0.705	29	0.000
	10-30years	0.812	21	0.001
The owners refrain from investing in BIM owing to.....	Less than 10 years	0.748	29	0.000
	10-30years	0.765	21	0.000

Table VII. Test of normality

Variable (see Table I)	Years of experience in FM consultancy	Mean rank	Exact significance (two-tailed)
Capturing and updating FM data in BIM can be improved by.....	Less than 10 years	27.12	0.722
	10-30years	25.72	
Incompatible file exchange formats are caused by multiple.....	Less than 10 years	26.84	0.583
	10-30years	24.89	
Data Incompatibility between BIM tools will be resolved by.....	Less than 10 years	28.03	0.235
	10-30years	23.32	
The owners refrain from investing in BIM owing to.....	Less than 10 years	25.93	1.000
	10-30years	26.09	

Table VIII. Mann–Whitney U-test results for years of experience in FM consultancy as a grouping variable

(1) "Participants with less than 10 years of experience in FM delivery" and "Participants with 10-30 years of experience in FM delivery";

(2) "Participants with less than 10 years of experience in FM consultancy" and "Participants with 10-30 years of experience in FM consultancy"; and

(3) "Participants with a third to fifth level of proficiency with using BIM for FM" and "Participants with a first to second level of proficiency with using BIM for FM".

Mann–Whitney U-test is a non-parametric test of the null hypothesis that two populations are the same against an alternative hypothesis that a particular population tends to have significantly different values than the other.

In the Mann–Whitney U-test, the results are interpreted by *p*-values. If the actual calculated *p*-value is less than the pre-determined significance level of 0.05, then the null hypothesis can be rejected. As shown in Tables IX, X and XI, all *p*-values were greater than 0.05. Therefore, the null hypothesis of the test cannot be rejected, meaning that there were no statistically significant differences between responses in the corresponding pairs of subgroups.

5. Discussion

Using the results of the literature review, the issues hindering BIM–FM integration were classified into four categories. A similar classification structure was used to design the questionnaire survey, with three to four questions in each of the four categories. The survey results do not validate certain findings of the literature review. For instance, in the category of BIM execution and information management, the survey results indicate that the predominant factor hindering BIM–FM integration is that FM professionals are not included in the initial BIM process to collect relevant O&M data (61 per cent). However, in the literature review, the majority of studies claimed that the failure to update BIM information is the most significant issue in this category (Table II). On the other hand, a failure to update BIM information could be owing to a lack of facility managers' input or involvement in the project-delivery process. In

Table IX.
Mann–Whitney U-test results for years of experience in FM delivery as a grouping variable

Variable	Years of experience in FM delivery	Mean Rank	Exact significance (two-tailed)
Post-construction, BIM workflow stops because a BIM execution framework is absent	Less than 10 years	29.66	0.393
	10-30years	26.15	
Including FM professionals during initial BIM will help in collecting Q&M data	Less than 10 years	26.34	0.393
	10-30years	29.85	
File size hinders information exchange between on-site and off-site personnel	Less than 10 years	29.83	0.148
	10-30years	24.06	
Creating small work-packages, usable on mobile devices will enhance information exchange	Less than 10 years	27.93	0.601
	10-30years	26.04	
Pre-planning and allocating funds initially will help in managing BIM costs	Less than 10 years	28.45	0.861
	10-30years	27.50	
FM industry will generate a better return on investment by using BIM for Q&M	Less than 10 years	27.31	0.719
	10-30years	28.77	
Lack of clarity in ownership and responsibility of BIM model delays decision-making	Less than 10 years	26.53	0.464
	10-30years	29.63	
Assigning ownership and responsibility of the BIM model initially will improve decision-making	Less than 10 years	28.66	0.761
	10-30years	27.27	
FM professional refrain from electronic transfer of confidential information owing to issues of cyber security, authenticity and other risks	Less than 10 years	28.46	0.626
	10-30years	26.46	

Variable	Years of experience in FM consultancy	Mean rank	Exact significance (two-tailed)
Post-construction, BIM workflow stops because a BIM execution framework is absent	Less than 10 years	25.10	0.433
	10-30years	28.26	
Including FM professionals during initial BIM will help in collecting Q&M data	Less than 10 years	27.90	0.433
	10-30years	24.74	
File size hinders information exchange between on-site and off-site personnel	Less than 10 years	26.50	0.554
	10-30years	24.12	
Creating small work-packages, usable on mobile devices will enhance information exchange	Less than 10 years	24.26	0.455
	10-30years	27.21	
Pre-planning and allocating funds initially will help in managing BIM costs	Less than 10 years	23.40	0.086
	10-30years	30.41	
FM industry will generate a better return on investment by using BIM for Q&M	Less than 10 years	26.69	0.915
	10-30years	26.26	
Lack of clarity in ownership and responsibility of BIM model delays decision-making	Less than 10 years	23.19	0.055
	10-30years	30.67	
Assigning ownership and responsibility of the BIM model initially will improve decision-making	Less than 10 years	24.31	0.198
	10-30years	29.26	
FM professional refrain from electronic transfer of confidential information owing to issues of cyber security, authenticity and other risks	Less than 10 years	25.36	0.714
	10-30 years	26.84	

Table X.
Mann-Whitney U-test results for years of experience in FM consultancy as a grouping variable

Variable	Level of proficiency with using BIM for FM	Mean rank	Exact significance (two-tailed)
Post-construction, BIM workflow stops because a BIM execution framework is absent	Third to fifth levels	32.00	0.159
	First to second levels	26.10	
Including FM professionals during initial BIM will help in collecting Q&M data	Third to fifth levels	26.00	0.159
	First to second levels	31.90	
File size hinders information exchange between on-site and off-site personnel	Third to fifth levels	29.00	0.653
	First to second levels	27.04	
Creating small work-packages, usable on mobile devices will enhance information exchange	Third to fifth levels	26.16	0.361
	First to second levels	29.91	
Pre-planning and allocating funds initially will help in managing BIM costs	Third to fifth levels	27.30	0.450
	First to second levels	30.64	
FM industry will generate a better return on investment by using BIM for Q&M	Third to fifth levels	27.34	0.433
	First to second levels	30.60	
Lack of clarity in ownership and responsibility of BIM model delays decision-making	Third to fifth levels	29.04	0.991
	First to second levels	28.97	
Assigning ownership and responsibility of the BIM model initially will improve decision-making	Third to fifth levels	27.71	0.554
	First to second levels	30.24	
FM professional refrain from electronic transfer of confidential information owing to issues of cyber security, authenticity and other risks	Third to fifth levels	29.20	0.749
	First to second levels	27.80	

Table XI.
Mann-Whitney U-test results for level of proficiency with using BIM for FM as a grouping variable

the category of technological issues, the survey results indicate that over half of the respondents (50 per cent) agreed with the assertion that file size hinders information transfer between on-site and off-site personnel. However, according to the literature review, incompatible file exchange formats was cited as the most important issue in this category

(Table II). For cost-based issues, a majority of the respondents (70 per cent) disagreed with both statements: "pre-planning and allocating funds initially will help in managing BIM costs" and "FM industry will generate a better return on investment by using BIM for O&M." Similarly, in the category of legal and contractual issues, only 7 per cent of the respondents agreed with the assertion that the lack of clarity in ownership and responsibility of BIM model delays decision-making. In addition, only 20 per cent of the respondents agreed that cyber security, authenticity and risk will increase because of the electronic transfer of confidential information. The survey results from the above two categories, i.e. cost-based issues and legal and contractual issues, indicate that none of the factors identified in the literature review significantly impedes BIM–FM integration. The Mann–Whitney U-test (Tables VI-IX) showed that there are no significant differences in the results obtained from the different demographic subgroups. This implies that the FM professionals' level of BIM proficiency, years of experience in FM consultancy or experience in FM delivery have no impact on the survey results.

5.1 Comparison with similar studies

The survey results substantiated that the most important issue hindering BIM–FM integration is the lack of FM professionals' involvement in pre-design, design and construction phases. A similar assertion was made by previous studies that concluded that involving a facility manager in BIM evolution process is crucial to identify and model right data in a right format compatible with FM-authoring tools used by an organization (Arayici *et al.*, 2011; Azhar, 2011; Alvarez-Romero, 2014; Cavka *et al.*, 2015; McAuley, 2016; Pärn *et al.*, 2017; Hosseini *et al.*, 2018). The survey responses indicate that it is not the cost, technology or legal issues, but the inability to capture the right information in an accurate and complete manner that may be the biggest challenge to BIM–FM integration. Similar conclusions were reported by studies such as Alvarez-Romero's (2014) that argued that there is a "mismatch" between information needed by FM staff and information actually delivered by the design and construction team. In an extensive and systematic review of literature, Volk *et al.* (2014) discussed the significance of involving FM professionals when BIM is evolving so that right information is accurately and completely captured to facilitate FM decision-making. Furthermore, what design and construction information must be captured and in what level of detail is also not clear, as asserted by studies by, among others, Kelly *et al.* (2013); Cavka *et al.* (2015); Naghshbandi (2017) and Hosseini *et al.* (2018). Other studies that specifically examined BIM–FM challenges revealed a wide range of issues. For instance, Parsanezhad and Dimyadi (2013) listed key issues as a lack of BIM guidelines for defining the process, terminology, taxonomy, data requirements and level of details, along with a lack of technologies. Kelly *et al.* (2013) revealed a lack of tangible BIM benefits for FM, clear requirements for BIM–FM integration, clear roles, responsibilities, contract and liability framework. Likewise, Mayo *et al.* (2012) found that software costs and a lack of training and BIM expertise are the biggest challenges to BIM–FM integration. Most of the studies, however, agreed that involving a facility manager in BIM process could resolve a majority of the issues. The results of this paper and other referred studies emphasize two key changes that must take place in both FM consultancy and delivery. First, the role of a facility manager must be extended to the planning, pre-design and design phases to include not only design review but also the review and verification of BIM. In the case of FM consultancy, this change could mean FM consultants offering BIM review and verification services. Second, standards to capture BIM data for FM decision-making must be established to define the LOD, format, structure and type of BIM data. Guidelines in such standards can be generic as well as specific to a desired FM activity or functionality. Future FM research can focus on outlining key FM functions, mapping them to BIM data requirements and

establishing a set of standards so that mapped BIM data can be captured properly during BIM creation, transfer and handover.

5.2 Building information creation, transfer and handover

The three stages of design, construction and handover are critical to capturing geometric and non-geometric building information needed for completing desired FM tasks (Cavka *et al.*, 2015).

5.2.1 Design stage. Involving a facility manager at this stage could help organize geometric and non-geometric design information, such as construction drawings, details and schedules pertaining to life cycle management decision-making (Cavka *et al.*, 2015; Hosseini *et al.*, 2018). The facility manager could actually help set up a FM data transfer template to define the type, format and attribute of data to be retained and added during the construction and handover stages.

5.2.2 Construction stage. The facility manager at this stage can guide the general contractor and subcontractors to document any changes or adjustments made to the design during construction (Alvarez-Romero, 2014). Because multiple parties are involved, the efficiency, accuracy and consistency of documentation are important for updating the model (Alvarez-Romero, 2014). The facility manager could actually act as a project integrator, as defined by the BIM guidelines established by the USA General Services Administration (GSA, 2017), who could ensure compliance with data requirements and format.

5.2.3 Handover stage. The most crucial stage from the facility management standpoint is the handover stage when a project is handed over to the client as a building. Along the project, all as-built drawings, specifications, manuals and as-built BIM are also turned over to the client (Ghosh, 2015; Miettinen *et al.*, 2018). It is extremely important for a facility manager to get involved in the data-handover process and verify if as-built construction documents and BIM are complete and accurate (Kassem *et al.*, 2015; Naghshbandi, 2017). BIM data can be used for a variety of FM domains, including, but not limited to, asset management, space management, maintenance management, replacement and retrofit management, security and emergency management, energy and utility management, personnel management, inventory management, occupancy planning and performance monitoring (Alvarez-Romero, 2014; Cavka *et al.*, 2015; Mayo and Issa, 2015; Nicał and Wodyński, 2016; Hosseini *et al.*, 2018). However, to effectively use BIM for these domains, prior planning to define data requirements and LOD is very important (Borhani *et al.*, 2017; Hosseini *et al.*, 2018). Both geometric and non-geometric information must be captured and verified. Geometric information includes site layouts, campus plan, discipline-specific construction drawings, details, shop drawings, interior layouts and three-dimensional views organized by either UniFormat or MasterFormat, as suggested by the GSA guidelines. Non-geometric information includes technical specifications, commissioning information, test and inspection reports, operations and maintenance manuals, schedules for equipment and fixtures, door and window schedules, room and department schedules, warranties and guarantees, equipment and fixture details (manufacturer and vendor information, model, serial numbers/bar codes, installation dates, service life, etc.), egress information and MSDS information. Note that this list is not exhaustive and may include more data types based on the intended FM tasks.

5.3 Facility managers' involvement in building information modeling development

Facility managers can participate in BIM development, which, however, would require them to have prerequisite BIM knowledge to provide meaningful input. Two important questions

relate to FM experience and technology: what information to capture and how? A facility manager having good FM experience can provide input about what information to capture. How to model that information may require excellent proficiency with BIM-authoring tools. Unfortunately, those who create BIM may not be well versed with the data requirements for life cycle management; those who know the requirements may not be able to model.

Three models exist to help resolve these issues, as illustrated by Figures 6-8. BIM is created during the initial design phases and evolves through the construction and management phases. Between each phase, the building information is either filtered out, modified or added when a BIM is transferred from a design team to construction and eventually to an FM team. In the first model, facility managers are not conventionally motivated to participate in the design and construction phases of a project, resulting in important O&M data missing from an as-built BIM submitted to the client. In the second model, owners or clients motivate facility managers to get involved in the design and construction phases of a project, and provide services such as design reviews, life cycle cost analysis and project feasibility. Their involvement ensures that important design and construction data, along with any O&M information, are included accurately in an as-built

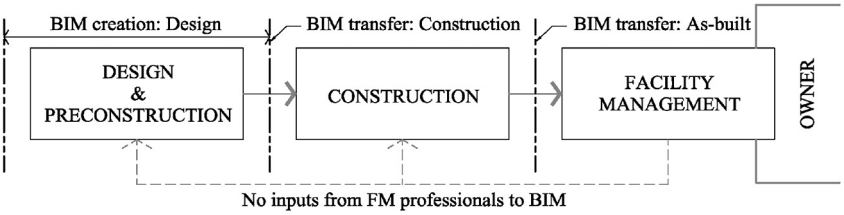

Figure 6.
Linear BIM workflow model (business as usual)

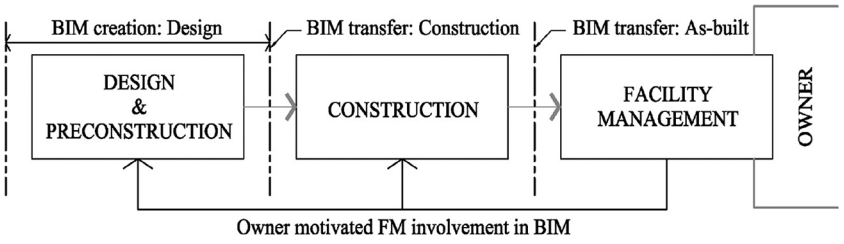

Figure 7.
Integrating FM professionals with all project phases

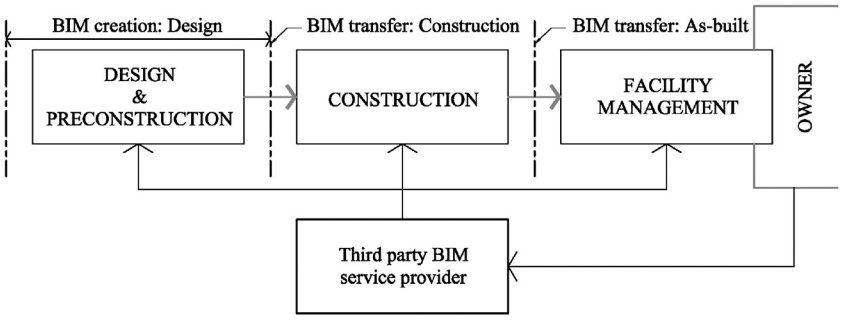

Figure 8.
Hire a third-party BIM service provider for information capture during the three project phases

BIM. This model requires that the facility manager knows BIM-authoring tools to a reasonable degree.

In the third model, owners may prefer to hire a third-party BIM service provider who reviews building information added to a BIM throughout the phases of pre-design, design, construction and management. The third-party BIM service provider can also facilitate information transition across these life cycle phases, ensuring that only required information transfers to a particular phase. For instance, when a BIM is transferred from a design to construction phase, design details irrelevant to the construction phase could be filtered out by applying a construction BIM template. Any modification or addition of building information may also be required during this BIM transfer. Similarly, the third-party service provider could review the as-built BIM for accuracy and completeness, while simultaneously adding any missing information required for FM by using an FM–BIM template. This model necessitates that the BIM service provider has the required design, construction and FM experience to identify and model the data requirements of each project phase.

6. Conclusions

The use of BIM technology has several positive implications for construction and the FM industry, as discussed above. However, its application for FM tasks and decision-making specifically seems limited because of multiple issues relating to BIM execution and information management, technology, cost and legal and contractual aspects. On the basis of a literature review, these issues were identified and a questionnaire survey of FM professionals was conducted at two industry events to further study the issues. The responses were collected from FM professionals and their opinions were analyzed using statistical methods. Although we found that, in most cases, the participants' opinions did not align completely with literature review findings, some observations from the literature review were confirmed by the survey responses. For example, like the literature review, 75 per cent of respondents agreed that interoperability owing to multiple software applications and versions disrupts BIM workflow. Additionally, the single most important issue stemming from the survey responses was the exclusion of FM professionals from project-delivery phases crucial to BIM creation. The involvement of FM professionals, therefore, is instrumental to creating complete and accurate building information that can be used for life cycle management. It is important to understand that the results of this study are based on a limited number of responses. A larger data set might be needed to further validate issues hindering BIM–FM integration. The results of this study will guide the construction industry in taking appropriate steps that would help in integrating BIM with FM decision-making. Future research could be conducted to formulate suitable templates and guidelines for information transfer. The guidelines or a template could help standardize the type, format and the LOD of building information that must be captured in an as-built BIM to be used for life cycle management. Agencies such as the USA General Services Administration have established BIM guidelines (GSA, 2017) for not only capturing complete, accurate and specific information, but also logging, reviewing and approving as-built BIMs. Such guidelines can be used to create a BIM data-transfer template.

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