# Building information modeling for facilities management: A literature review and future research directions

Sandra T. Matarneh[a, *]

sandra.matarneh@port.ac.uk

Mark Danso-Amoako[a]

Salam Al-Bizri[a]

Mark Gaterell[a]

Rana Matarneh[b]

[a]University of Portsmouth in the UK, United Kingdom

[b]Al Ahliyya Amman University in Jordan, Jordan

*Corresponding author.

**Abstract**

Although a considerable number of studies on building information modeling (BIM) for facilities management (FM) have been conducted during the past ten years, a lack of consensus remains among academics and practitioners concerning the successful and practical information exchange process between BIM and FM systems. There is a need to establish an up-to-date synthesis on the current status of information exchange and interoperability between BIM and FM systems. After an in-depth review of 113 journal articles published from 2008 to 2018, this study systematically presents (1) a holistic review and critical reflection on the current status of BIM implementation in FM with a focus on information exchange and interoperability, (2) research trends and patterns and (3) research gaps and a future agenda in this area. Through a bibliometric and content review analysis, this paper concludes that the process of information exchange between BIM models and FM systems is not a straightforward process, as software interoperability remains a significant challenge. Bridging this gap requires standardized practical processes to integrate different information sources related to maintenance management, health & safety management tasks and BIM data, to provide a rich semantic database to support FM systems. Finally, it is hoped that this paper will advocate further developing a seamless information exchange process between BIM and FM systems to overcome interoperability issues and facilitate BIM implementation in FM.

**Keywords:** Building information modeling (BIM); Facilities management (FM); Information exchange; Interoperability; Information management; Literature review; Bibliometric analysis; Content analysis

# 1 Introduction

During the operations and maintenance phase, Facilities Management (FM) teams often spend considerable time and effort collecting information from various combinations of electronic data and hardcopy documents. There is a constant redundant activity searching for, sorting, validating, and recreating information [1]. The “National Institute of Standards and Technology” (NIST) reported that two-thirds of the projected $15.8 billion lost in the United States capital facilities industry are associated with inadequate interoperability during the Operations and Maintenance (O&M) phase. Losses associated with inadequate interoperability result from expenses related to manual data re-entry, data verification, redundancy and idle labour time searching for relevant data that is often unavailable. Minimizing the impact of interoperability problems requires a seamless electronic data exchange to provide FM teams with a comprehensive and accurate database [2].

The concept of extending Building Information Modeling (BIM) implementation through the O&M phase is simply to reduce the O&M costs and reap the real benefits of BIM's capabilities as a data conduit. However, in most current practices, where BIM is implemented to support FM operations, FM teams do not normally use BIM data models, either because these models do not include the required FM data [3], or because FM teams lack understanding of how to transfer information from BIM models to FM systems. This makes the information exchange process between BIM and FM operations tedious and overwhelming [4]. There are still technical issues to be overcome, mainly standardizing the information exchange process and resolving interoperability issues between BIM and FM systems [5]. Both Becerik-Gerber et al. [6] and Wetzel & Thabet [7] acknowledge that, although BIM easily enables data flows between facility's lifecycle stages, using an interoperable data format, data exchange and interoperability between BIM and FM systems still remain problematic. This paper aims to provide a comprehensive discussion concerning recent advances in the field of information exchange and interoperability between BIM and FM systems.

Recent reviews of BIM implementation and research approaches in FM either covered digitisation in FM, where BIM was presented among other technologies [8,9]; or BIM implementation in FM, where the reviews analysed the existing research on BIM for FM and established trends [10]. Some of the reviews concentrate on specific aspects of BIM implementation in FM such as: BIM for FM with specific focus on refurbishment and maintenance [11]; energy retrofitting [12], knowledge management [13,14]; existing buildings [15], and as-is BIM model surveys [16]; Burno et al., 2018). Although topics regarding data exchange and interoperability between BIM and FM systems were covered in some reviews and identified as a research trend [11]; [8,9,12,14], the existing research in this field requires more work to be done to investigate the current status of data exchange and interoperability between BIM and FM systems and to recommend future work. As there is no specific overview, to our knowledge, of data exchange and interoperability between BIM and FM systems, we try to close this gap partly with the present contribution. This paper aims to address the following objectives: first, to assess the literature in academic journals concerning developing data exchange and interoperability between BIM and FM systems by mapping trends according to the reviewed articles' content and contribution. Secondly, we aim to map the literature by identifying the research focus of each reviewed article and organizing them accordingly in relevant domain topics. Thirdly, it is intended to shed the light on the current status of information exchange and interoperability between BIM and FM systems and propose a future agenda for each domain area.

# 2 Research methodology

This study analyses and categorizes the existing research on BIM for FM with a focus on information exchange and interoperability for the last decade and until 2018 by conducting a quantitative and qualitative research method. The bibliometric analysis in this study aims to provide a quantitative analysis by using statistical methods to analyse trends of academic publication and citation to evaluate the existing research performance and understand the patterns. The bibliometric analysis in this study consists of six steps, as shown in Fig. 1.: (1) a keyword search in the Scopus database; (2) applying filters to include articles that discuss BIM for FM, journal articles, and English language; (3) journal selection with CiteScore greater than one; (4) journal databases search; (5) combining the two search methods' results in one list to avoid any duplication; (6) categorizing articles according to their keywords.

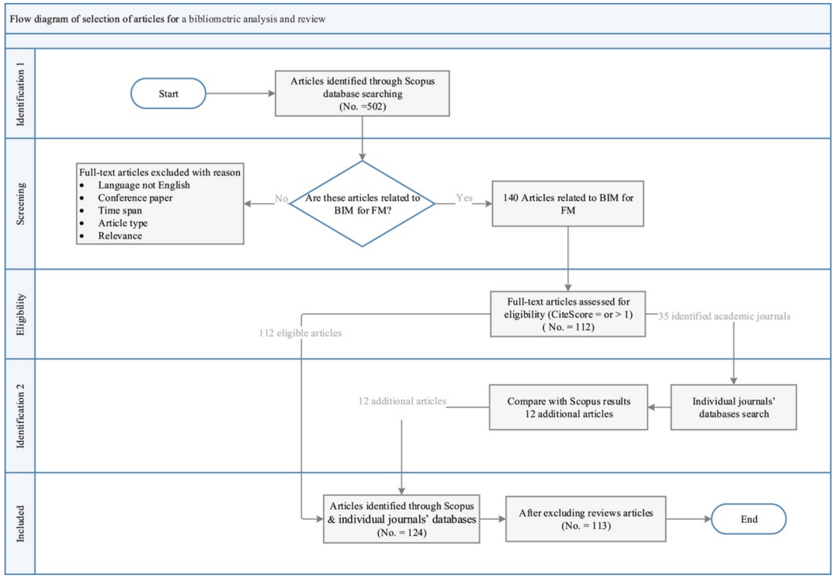



**Fig. 1** Flow diagram of selection of articles for bibliometric analysis on BIM for FM.

alt-text: Fig. 1

Firstly, we conducted a keyword search in the Scopus database using different keywords: (1) “BIM”; (2) “Building Information Modeling”; (3) “Building Information Modeling”; (4) “FM”; (5) “Facility Management”; (6) “Facilities Management”; (7) “Operations and Maintenance” and (8) “Asset Management”, which resulted in 502 articles. Secondly, we filtered all articles to select only journal articles related to BIM implementation in FM and published in the English language, which resulted in 140 articles. Thirdly, we identified the journals by filtering articles that were available in journals with a CiteScore greater than one (CiteScore: “is the number of citations received by a journal in one year to documents published in the three previous years, divided by the number of documents indexed in Scopus published in those same three years”). The fourth step was conducted using the individual selected journals' databases in the previous step to overcome any limitation in the Scopus database related to the search method. Then, in the fifth step, we combined the two search results, excluded any duplicated articles and organized them in one list, which resulted in 124 academic articles fitting our criteria. Of the 124, eleven are general reviews on BIM for FM and were already discussed in the research introduction. Accordingly, we excluded the literature review articles and considered only 113 articles for the sixth step of the keywords clustering.

The content analysis in this study was adopted to derive qualitative data analysis of the 113 articles based on the technical aspect of each article to derive patterns and propose future research directions as detailed in section 4.

# 3 Bibliometric analysis results

The bibliometric analysis results reveal that over the last decade there has been a noticeable growth in the number of publications on BIM for FM, from three in 2008 to 28 in 2018 (Fig. 2 and Table 1). Interestingly, 75% of the publications were published during the last five years, which means that BIM implementation in FM is a new domain with increasing interest, especially during 2018.

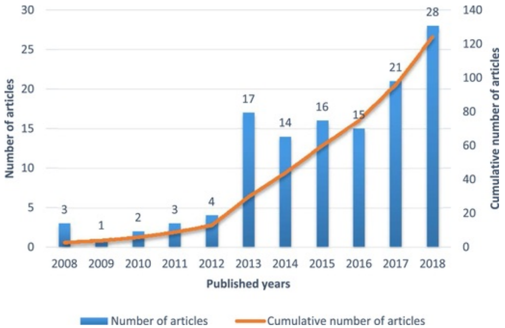



**Fig. 2** BIM for FM articles published over the last decade.

alt-text: Fig. 2

**Table 1** Review sources of 34 academic journals and the identified articles during 2008–2018.

alt-text: Table 1

| Journals | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Automation in Construction | 1 | 0 | 0 | 1 | 2 | 5 | 6 | 3 | 1 | 6 | 7 | **32** |
| Advanced Engineering Informatics | 1 | 0 | 1 | 1 | 0 | 3 | 0 | 1 | 1 | 1 | 4 | **13** |
| J. of Computing in Civil Engineering | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 3 | 2 | 1 | **8** |
| Built Environment Project and Asset Management | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 1 | 0 | **7** |
| J. of Information Technology in Construction | 0 | 1 | 0 | 0 | 0 | 2 | 0 | 1 | 1 | 1 | 1 | **7** |
| Facilities | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 0 | 2 | 0 | 1 | **6** |
| J. of Management in Engineering | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 0 | 1 | **4** |
| Building and Environment | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | **3** |
| Buildings | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 0 | 0 | **3** |
| J. of Building Engineering | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | **3** |
| J. of Construction Engineering and Management | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | **3** |
| Structural Survey | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | **3** |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| The Scientific World Journal | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | **3** |
| Advances in Engineering Software | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | **2** |
| Applied Energy | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | **2** |
| Computers in Industry | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | **2** |
| Engineering, Construction and Architectural Management | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | **2** |
| International Journal of Building Pathology and Adaptation | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | **2** |
| J. of Architectural Engineering | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | **2** |
| J. of Performance of Constructed Facilities | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | **2** |
| Renewable & Sustainable Energy Reviews | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | **2** |
| Architectural Engineering and Design Management | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **1** |
| Advances in Civil Engineering | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | **1** |
| Applied Sciences | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | **1** |
| Building Research and Information | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | **1** |
| Construction Management and Economics | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | **1** |
| Energies | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | **1** |
| Expert Systems with Applications | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | **1** |
| J. of Corporate Real Estate | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | **1** |
| J. of Facilities Management | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | **1** |
| KSCE Journal of Civil Engineering | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | **1** |
| Science and Technology for the Built Environment | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | **1** |
| Sustainable Cities and Society | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | **1** |
| Energy and Buildings | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | **1** |
| **Total per year** | **3** | **1** | **2** | **3** | **4** | **17** | **14** | **16** | **15** | **21** | **28** | **124** |

Over the ten-year period under review, and based on our selection criteria, the largest number of publications in the field of BIM for FM were published in “Automation in Construction” with 32 of the total selected articles. This was followed by “Advanced Engineering Informatics” (13 articles), and “Journal of Computing in Civil Engineering” (8 articles). Interestingly, these three journals published 43% of the total selected articles and from 2013 they all started to focus more on this field. Meanwhile, the other two journals, namely: Built Environment Project & Asset Management” and “Journal of Information Technology in Construction” published 7 articles for each, followed by “Facilities”, (6 articles) and “Journal of Management in Engineering” (4 articles), as shown in Table 1 and Fig. 3. The remaining journals' publication rate varied between one to three articles only during the ten-year period.

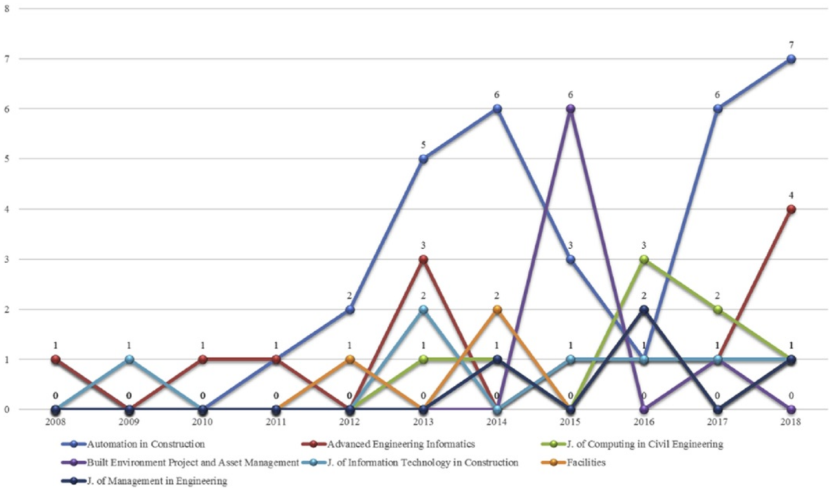



**Fig. 3** Articles per year per source (top 7 journals).

alt-text: Fig. 3

The bibliometric analysis also reveals that the largest number of journal publications over the last decade were conducted in the USA (40), UK (24), Canada (15), Australia (9), Taiwan (8) and China (7), as shown in Fig. 4. It was expected that the USA would have the largest proportion of publications in BIM research, since BIM was established in the USA. The analysis also shows that the interest in implementing BIM in FM has been growing over the last three years in the UK, due to the government's initiative in adopting BIM for its centrally procured projects.

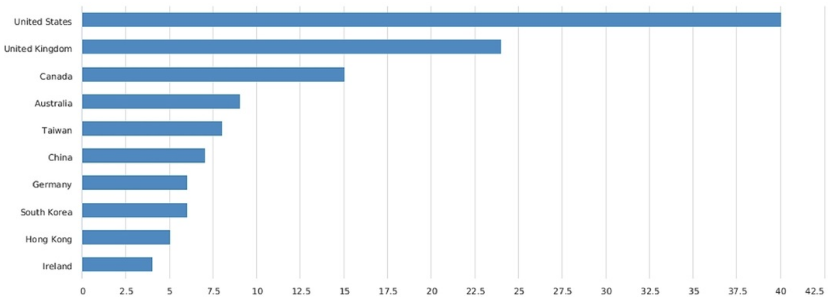



**Fig. 4** Articles by country or territory.

alt-text: Fig. 4

Furthermore, the bibliometric analysis reveals that six of the ten most cited articles were published in “Automation and Construction”. The top ten cited articles according to the Scopus citation metric are summarized in Table 2.

**Table 2** Top 10 cited articles in 2008–2018.

alt-text: Table 2

| Citations | Article | Author | Journal | Year |
|---|---|---|---|---|
| 357 | Building Information Modeling (BIM) for existing buildings - Literature review and future needs | Volk et al. | Automation in Construction | [15] |
| 201 | Application areas and data requirements for BIM-enabled facilities management | Becerik-Gerber et al. | Journal of Construction Engineering and Management | [6] |
| 171 | | | Advanced Engineering Informatics | [104] |

| | | | | |
|---|---|---|---|---|
| | Building information modeling – Experts' views on standardisation and industry deployment | Howard, and BjÖrk, | | |
| 135 | Towards building information modeling for existing structures | Arayici, Yusuf | Structural Survey | [87] |
| 129 | IFC and building lifecycle management | Vanlande et al. | Automation in Construction | [51] |
| 110 | BIM implementation throughout the UK construction project lifecycle: An analysis | Eadie et al. | Automation in Construction | [103] |
| 98 | Building operation and energy performance: Monitoring, analysis and optimisation toolkit | Costa et al. | Applied Energy | [80] |
| 97 | A knowledge-based BIM system for building maintenance | Motawa, and Almarshad | Automation in Construction | [73] |
| 76 | Imaged-based verification of as-built documentation of operational buildings | Klein et al. | Automation in Construction | [88] |
| 73 | A benefits realization management building information modeling framework for asset owners | Love et al. | Automation in Construction | [69] |

The bibliometric analysis shows that BIM, FM and O&M, are the most frequently used keywords; this is not surprising since our search was specific in this field. This is followed by maintenance management, IFC, lifecycle information, information integration, building performance, COBie, handover, information requirements and interoperability, as shown in Fig. 5. The keywords' frequency helped us in clustering the selected publications in six clusters after combining the common interest of keywords as follows: (1) information management (includes: information integration, information requirements, information exchange, handover, data warehouse, data transfer, data mining, life cycle information and information systems), (2) maintenance management (includes: fault detection and diagnosis, and HVAC), (3) energy management (includes: building performance and energy efficiency), (4) refurbishment/retrofit, (5) existing building audits and surveys (includes: as-built BIM, laser scanning, and point cloud), (6) BIM for FM (includes: owners and BIM adoption). The clustering of the keywords shows that the majority of the selected publications fall under the first cluster “information management”. Generally, keyword analysis can help in mapping the literature, but is not enough when the topic is new and precise, because a keyword's occurrence will not exceed two or three times in some cases. Accordingly, we decided to conduct a content analysis in which we reviewed each article individually to generate patterns and trends of existing research, based on the article's content and contribution.

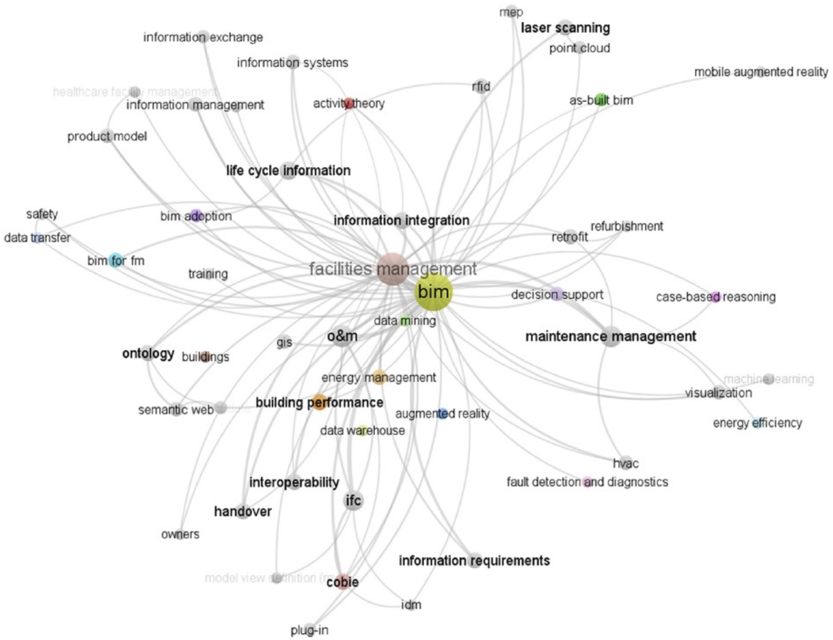



**Fig. 5** Keyword clustering.

alt-text: Fig. 5

# 4 Content analysis

In order to generate a more qualitative analysis of the reviewed articles and derive patterns to propose a future agenda, we mapped the selected articles and proposed a categorisation structure based on content analysis of the articles, as shown in Fig. 6. According to our content analysis, the selected articles for review were categorized into eight categories, based on their research focus and contribution, as detailed in Table 3.

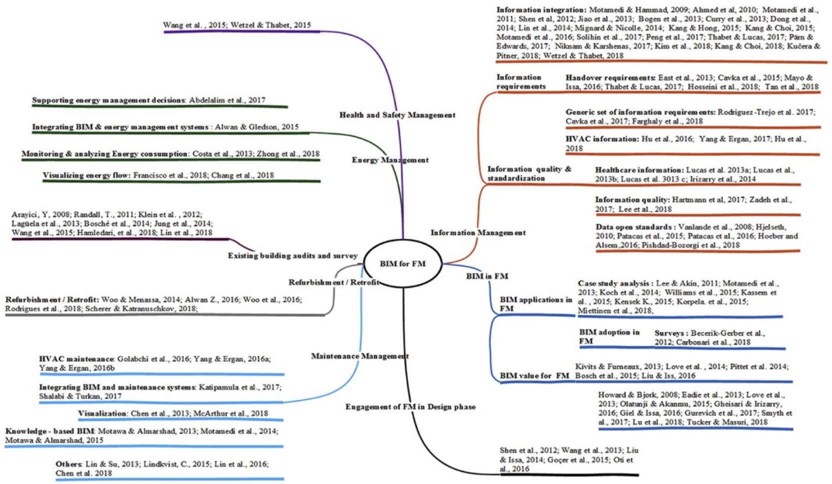



**Fig. 6** Content analysis results.

alt-text: Fig. 6

**Table 3** Articles content themes of BIM research for FM 2008–2018.

alt-text: Table 3

| Themes | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Information Management | 1 | 1 | 2 | 1 | 1 | 7 | 4 | 4 | 5 | 11 | 10 | **47** |
| BIM in FM | 1 | 0 | 0 | 1 | 1 | 4 | 3 | 6 | 3 | 2 | 4 | **25** |
| Maintenance Management | 0 | 0 | 0 | 0 | 0 | 3 | 1 | 2 | 4 | 2 | 2 | **14** |
| Energy Management | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 3 | **6** |
| Existing Buildings' Audits & Surveys | 1 | 0 | 0 | 1 | 1 | 1 | 2 | 1 | 0 | 0 | 2 | **9** |
| Engagement of FM in Design Stage | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | **5** |
| Refurbishment/Retrofit | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 0 | 2 | **5** |
| Health & Safety Management | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | **2** |
| **Total** | **3** | **1** | **2** | **3** | **4** | **17** | **12** | **17** | **15** | **16** | **23** | **113** |

# 5 Research gaps and future agenda

This section provides an overview of the research patterns identified in section 4, and suggests areas where further research is required within the scope of each pattern.

## 5.1 Category: information management

It is critical for FM teams to have accurate, comprehensive and available information to support effective and efficient building operations and maintenance activities [17,18]. However, the FM teams continue to struggle with information management, mainly because of the various FM information systems, which lack interoperability between each other [19]. BIM offers opportunities to improve facility information management by providing a unified platform for various data sources needed for daily O&M activities. Among many unresolved issues that need to be addressed for successful BIM implementation, information exchange and interoperability remain the main issues [5,6,20]. Our review shows that the last three years have been productive in the BIM-based FM information management field: 27 out of the 47 reviewed articles in this category were published during the last three years only, recording the highest growth rate among all categories identified in this review. Our review of published articles in this area reveals that the existing research used several methods to manage lifecycle information as discussed in the following subsections.

### 5.1.1 Sub-category: life cycle information integration

The sub-category that is most investigated in this area is information integration, using different techniques, such as data warehouse [21], agent-based web services [22], linking data in the cloud [23,24], a relational database and real-time data [25,26], a semantic web ontology [27,28], and using data mining techniques to extract useful information from BIM models to support FM activities during the O &M phase [29,30]. Other studies focused on integrating different technological systems rather than integrating the required FM information, for instance, integrating BIM with RFID tags to capture lifecycle information (Motamedi and Hammad 2009); [31,32], applying machine learning concept and raw sensor data [33], 2D barcode and mobile devices [34], a BIM/GIS-based information extraction (Mignard and Nicolle 2014); [35]. Other works focused on FM required information and developed bespoke techniques to integrate heterogeneous data, including BIM, by introducing an application programming interface plug-in to extend COBie by synthesising semantic data requirements that explicitly meet the owner's needs [36] Edwards, 2017), and integration of BIM and BAS information through a developed middleware layer to support energy consumption benchmarking [37].

### 5.1.2 Sub-category: information requirements

This sub-category focuses on identifying the FM information requirements for successful facilities information management through BIM. The current research focused on very specific information requirements by identifying the required information of: healthcare facilities [38–41], HVAC systems [42–44], the building handover process [45–49]. Only one article was found that focused on creating a generic set of information requirements for a successful information exchange process [50]. Other authors in this area proposed an information classification and prioritization methodology (Rodriguez Trejo et al., 2017); (Hosseini et al., 2018).

### 5.1.3 Sub-category: information quality and information exchange standards

One of the earliest studies was conducted by Vanlande et al. [51] with a focus on BIM open standards. These authors proposed a semantic indexation method, based on the IFC open standard for lifecycle information management. In the same vein, Hjelseth [52] developed FM information specifications in different roles and phases of a building's life cycle. Recent studies in this area have shifted towards evaluation of BIM standards in asset register creation [54,108], lifecycle information management [53], and in developing an asset information model [54,108]. Recently, there has been an increasing interest in proposing different methods to evaluate BIM information quality [55–57]. However, in our review, we found an interesting example focused on examining a real-world case study, where BIM open standards, namely “COBie” were used for the information exchange process [58]. In this study, the authors reported the shortcomings of the existing data open standards and specifications and recommended more case studies to provide further insights into the evolving field of BIM in FM.

Within this context, there are 47 articles which tackled facilities information management using BIM in different ways. Interestingly, 58% of the selected articles were published between 2016 and 2018, which makes this the fastest growing among the categories. The earliest attempts in this field started in 2008 with a focus on the basic concept of creating BIM objects' information and libraries to include facility information in a BIM-IFC file. In 2013, the trend shifted towards integration of information between BIM models and external data sources. The evolution in facilities information management continued, using different techniques to collect and retrieve information, until 2016 when the focus of the research became more specific and researchers started to think holistically about FM information management. Several recent efforts to identify the required FM information of BIM models focused on either the handover of the required information or the mechanical, electrical and plumbing (MEP) information requirements. Only one study was found in this focus that identified a generic list of information requirements that could be used for any type of facilities [50]. Other attempts focused on collecting FM information automatically by developing plug-in applications (e.g. Ref. [36], and on integrating heterogeneous information sources by developing a middleware layer (e.g. Ref. [37]. Among the selected 47 articles in this category, only one interesting article presented a real-world case study that shows a holistic facilities information management system using BIM open standards and reported accordingly the information exchange process using COBie shortcomings and captured lessons learned for further future research [58]. Our review shows that there remains a lack of a standardized process for a seamless information exchange between BIM and FM systems and a lack of holistic guidance that encapsulates all the required FM information for efficient operations across all systems and building types. A future agenda involves: (1) mapping a clear process for seamless information exchange between BIM and FM systems, (2) developing specifications to identify specific information needs for FM, (3) providing more real-world case studies to provide insights on information exchange processes between BIM and FM, and (4) identifying an information quality evaluation process, to ensure all owner/FM requirements are considered carefully in BIM models.

## 5.2 Category: BIM in FM – value, applications and challenges

BIM provides the FM team with access to digital information about facility components and equipment from one unified source, which reduces the time and cost involved in searching for information from large fragmented unstructured data and increases the accuracy of FM information [20]. BIM can be a leverage for FM practice by improving the handover processes [102], reducing the time spent in localizing facility assets [59,60]; [111]), enhancing fault detection and identification in all construction phases, and it supports collaboration and visualisation of data [61–64]. BIM can enhance the efficacy of the work orders' execution process by providing comprehensive and accessible information [20,63]. Moreover, BIM can support other FM activities, such as market intelligence and satisfaction surveys [65], and in preparing the rental contracts [66]. Other benefits of BIM implementation in FM include: enabling efficient knowledge management throughout the facility life cycle [67], enhancing building performance and occupant value [62]. A comprehensive study conducted by Ref. [6] summarized the benefits of integrating BIM with FM, including, but not limited to, localization of facility components, real-time data accessibility, space management, maintainability assessment, digital asset creation, non-capital construction planning, energy monitoring, emergency management, visualisation and marketing, and personnel training. Another study conducted by Love et al. [68] concluded that BIM can improve FM workflow, maintenance efficacy, and safety management. Based on their study, Love et al. [69] developed a BIM benefits realization framework for asset owners.

Other studies focused more on the challenges of integrating BIM with FM (e.g. Refs. [61,70]. However, among the 25 reviewed articles under this category, some studies adopted the case study analysis approach [20,64]; [63]; [62,66,71] to investigate BIM implementation in FM in terms of BIM applications and challenges. The remaining articles adopted different approaches, including developing a conceptual framework, interviews and questionnaire surveys to investigate BIM adoption in FM. A future agenda for this category involves: (1) more real-world case studies with a focus on evaluating the current challenges that hinder BIM implementation in FM; (2) more real-world case studies with a focus on the quantified value of BIM implementation in FM.

## 5.3 Category: maintenance management

The review showed a high growth rate in this category: 60% of the total selected articles (14 articles) were published in the last three years. In the current FM practice, information is distributed between various FM systems such as computerized maintenance management system (CMMS), computer aided facilities management (CAFM), and building automation system (BAS). BIM with its capabilities as a data conduit can provide an easy retrieval of the FM information required for senior management decisions. Current solutions include integrating BIM and FM systems' information using different technologies, such as semantic web technology, to help maintenance personnel to efficiently track and control the whole maintenance management process [72], and integrating BIM and knowledge systems in a case-based reasoning module to enable maintenance information retrieval and knowledge sharing to solve maintenance problems [73,74]. Other attempts focused on developing automated approaches to define possible causes and retrieve related information to facilitate the process of HVAC troubleshooting [75,76]. Other automated approaches focused on providing FM teams with visualizations of the work order categories to enhance the work order execution process [77], and to schedule FM work orders [78] to help prioritize assignment of maintenance activities.

Among the 14 reviewed articles in this category, two articles focused on information exchange and interoperability between BIM and maintenance systems. The first one was conducted by Shalabi and Turkan [5]; who proposed an approach that utilises a BIM-IFC file to link BAS with related data from CMM, in order to optimize the corrective maintenance data collection process during the O&M phase. However, this study focused on collecting and retrieving actual data from BAS and CMMS systems using BIM as a data repository during the O&M phase. The second study was conducted by Katipamula et al. [79]; who developed an approach to integrate BIM and BAS to create actionable information that can lead to work orders being processed through the CMMS system using an open-source reference platform, VOLTTRON. However, the approach presented in this article was deployed in a limited number of buildings, due to the high cost of its implementation, which requires additional sensing devices and labour to discover and map devices into the BAS. In this context, this review shows that more research is still needed with a focus on: (1) mapping a process for information exchange and interoperability between maintenance systems, CMMS and other FM systems such as BEMS, using BIM as a data repository; (2) integrating BIM and mixed reality technologies to improve maintenance efficiency.

## 5.4 Category: energy management

Monitoring the energy performance of facilities during the O&M phase is essential to compare the actual energy performance with the designed parameters. To achieve this, BIM can be a promising tool as a data conduit that can collect data from different stakeholders during different phases and integrate the collected data with data from different energy management systems for further analysis. However, our review shows that very little research focused on using BIM for facilities' energy management. The very few identified studies presented different approaches to BIM implementation in energy management, which included: using BIM for monitoring, analysing and optimising the performance of facility systems and accordingly building an operational strategy to be implemented [80]; providing building energy consumption assessment that supports management decision-making [81], and visualizing sensor data in a BIM environment to support energy-saving management decision-making [82]. Other studies presented a conceptual framework that integrates COBie and energy assessment tools to develop data attributes with correct information for effective asset information modeling (AIM) [83], and a framework that integrates BIM, sensor data and regulatory information to facilitate the compliance checking process [84]. Recent research conducted by Francisco et al. [85] developed a Revit plug-in that enables visualisation and comparison between energy consumption values in 2D and 3D views, using a color-coding scheme in an as-built BIM model. The future research agenda involves: (1) integrating different energy information streams, including BIM models to enhance the visibility of facility performance and to promote better energy management, (2) utilizing information collected by capturing actual facility energy data in BIM-based simulations for more efficient energy performance analysis to support energy retrofit decisions, and (3) identifying the required energy data from BIM models from a FM perspective.

## 5.5 Category: existing building audits and surveys

Employing laser scanning technology in the context of BIM-based projects is a promising approach that enables spatial data acquisition to manage building operations after project commissioning. Integrating BIM as-built and point-cloud as-built data with FM systems can improve building operations [86]. The current literature focuses on investigating the benefits and limitations of using different techniques to develop as-built BIM models. These techniques include using: a pattern recognition concept [87], photogrammetric image processing [88], the thermography concept [89], and a point cloud technique [86,90,91]. Other research studies developed a semi-automated approach to enable quality control of as-built BIM models [92,93]. One article out of the nine reviewed articles in this area tackled the interoperability issue and proposed an automated real-time and interoperable method to perform the site-to-BIM data transfer to facilitate the process of generating accurate as-built BIM models [94]. To generate as-built BIM models for FM use, the future agenda involves: (1) developing an automated checking process with COBie for FM use to improve FM information quality, (2) integrating rich semantic data in as-built BIM models by using recognition techniques, and (4) automating data extraction and transfer for information exchange and integration purposes.

## 5.6 Category: engagement of facilities management in design stage through BIM

To achieve efficient facility performance during the O&M phase, specific requirements related to space management, occupancy and maintainability have to be considered at an earlier stage of the facility life cycle. BIM has the capability to support assessment of space management, occupancy and maintainability during the concept and design stages. Wang et al. (2013) concluded that the early adoption of FM requirements in the design stage with BIM enables the building life cycle costs to be considerably reduced. Existing research in this area focuses on feedback loops between the O&M phase and the design phase to facilitate the designer-client communication in the architectural design process for pre-occupancy evaluation [22], and using BIM as a platform to engage building stakeholders collaboratively in building performance improvement decisions [95].

Other research focused on developing a Revit add-in application for maintainability checking [96], and on developing a tailored approach that incorporates BMS information in a BIM environment to close the feedback loop between the operation and design phases of the building's life-cycle [97]. The future agenda in this category involves: (1) developing a process for automated feedback loops between O&M and design phases.

## 5.7 Category: refurbishment/retrofit

The main objective of performing building refurbishment is to extend the existing building's life and to improve its performance [11], while the retrofit solution focuses specifically on enhancing building energy performance to reduce the O&M costs [98]. Although refurbishment/retrofit is an important component of FM, there has been less research focusing on this area. Only five articles were identified in this category and they were focused mainly on developing a virtual retrofit model to support energy retrofitting decisions [98], benchmarking different facilities using BIM to support decision-making in retrofits of aging commercial buildings [99], presenting BIM benefits for renovation/retrofit using a case study approach [100][109] and linking BIM and aging housing stock data, for sustainable retrofitting [101]. However, the very few identified studies in this area also highlight the potential for more research to explore BIM implementation in refurbishment/retrofit. Thus, the future agenda in this area involves: (1) integrating different facility performance information sources to perform retrofit simulations for decision making, and (2) integrating mixed reality along with BIM to facilitate refurbishment decisions.

## 5.8 Category: health and safety management

Our review highlights the noticeably small number of research papers focusing on BIM application in health and safety management. Although FM tasks require safety data to ensure safe operation and maintenance, only two articles were identified in this category with a focus on BIM's capabilities in improving fire safety management practices and supporting the maintenance of fire safety equipment [91], and identifying safety attributes required for safe maintenance and repair activities during the O&M phase [7]. The future agenda in this category involves (1) integrating health and safety information along with BIM information to provide a rich database for FM systems, and (2) utilizing BIM visualisation capabilities to evaluate if safety measures for maintenance work are considered during the design stage.

# 6 Conclusion

This paper has presented an overview of the current status of BIM implementation in FM, with a focus on information exchange and interoperability between BIM and FM systems. A total of 113 articles, published between 2008 and 2018, were identified and reviewed. Existing literature gaps and future agenda have been outlined. The content analysis of the existing literature shows that current research tends to focus on BIM-based technologies integration to enhance FM practice, rather than resolving the issues regarding facilities information management, which is considered as the backbone for successful FM practice. Moreover, the main concept behind extending BIM implementation to the O&M phase is to utilise the benefits of BIM capabilities as a data conduit that can solve the interoperability issue between the various FM systems. Although the research trends and patterns reveal that there is a continuously growing interest in facilities information management using BIM, and a steep rise in the number of publications during the last three years on identification of information requirements and integration of different information sources, nevertheless, a seamless information exchange process between BIM and FM systems does not yet exist. A successful implementation of BIM in FM requires a seamless information exchange between the different BIM-FM systems. Once the information is transferred and shared between the different BIM-FM systems seamlessly, any other solution can be possible. However, in our review we identified very few attempts to transfer building information between different FM systems such as the CMMS and BAS using BIM as a data conduit. The main focus of the studies was on providing real-time data access, rather than a process for seamless information exchange to overcome the interoperability issue between BIM and FM systems. Our review of the current literature concluded that a successful implementation of BIM in FM can be achieved with (1) a seamless information exchange process between BIM and FM systems, (2) a holistic guidance that encapsulates all the FM information required for efficient operations across all systems and building types, (3) a well-defined information quality process that ensures owner/FM needs are considered carefully in BIM models, (4) a set of standardized practical processes to integrate different information sources related to maintenance management and health & safety management tasks, to provide a rich semantic database to support FM systems, (5) a standardized process for feedback loops between operations and design phases to provide rich actual feedback to support efficient facilities design, and (6) more real-world case studies to investigate the current status of BIM implementation in FM. Finally, it is hoped that this paper will contribute to further developing a seamless information exchange process between BIM and FM systems to overcome the interoperability issue and facilitate BIM implementation in FM. Notwithstanding the strengths of this study, one limitation of this review is that it focuses only on the O&M phase. Further review studies should extend the discussion to review the information exchange and interoperability issues throughout the whole building life cycle. BIM implementation in FM will remain a growing area of research for many years to come. Developments in this area require joint efforts of academia and industry practitioners to overcome the current challenges.

# Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jobe.2019.100755.

# Uncited references

[105], [106], [107], [110].

# References


**[1]** W. Brodt, Adopt information exchange standards and harvest benefits, *Facilit. Manag. J.* 2013, 40–42.

**[2]** M.P. Gallaher, A.C. O'Connor, J.L. Dettbarn, Jr. and L.T. Gilday, Cost Building Information Modeling (BIM) for Facilities Management – Literature Review and Future Needs Analysis of Inadequate Interoperability in the US Capital Facilities Industry, 2004, US Department of Commerce Technology Administration, National Institute of Standards and Technology (NIST); Maryland.

**[3]** A. Sattenini, S. Azhar and J. Thuston, Preparing a building information model for facility maintenance and managemen, available at:In: *28th International Symposium on Automation and Robotics in Construction, Seoul, South Korea,* 2011, 144–149, (accessed Jan. 2018) http://toc.proceedings.com/26405webtoc.pdf.

**[4]** L. Sabol, BIM technology for FM, In: P. Teicholz, (Ed), *BIM for Facility Managers,* 2013, John Wiley & Sons; New Jersey, 17–45.

**[5]** F. Shalabi and Y. Turkan, IFC BIM-based facility management approach to optimize data collection for corrective maintenance, *J. Perform. Constr. Facil.* **31** (1), 2017, 1–13, 04016081.

**[6]** B. Becerik-Gerber, F. Jazizadeh, N. Li and G. Calis, Application areas and data requirements for BIM-enabled facilities management, *J. Constr. Eng. Manag.* **138** (3), 2012, 431–442.

**[7]** E.M. Wetzel and W.Y. Thabet, The use of a BIM-based framework to support safe facility management processes, *Autom. ConStruct.* **60**, 2015, 12–24.

**[8]** C.J. Roberts, E.A. Pärn, D.J. Edwards and C. Aigbavboa, Digitalising asset management: concomitant benefits and persistent challenges, *Int. J. Build. Pathol. Adapt.* **36** (2), 2018, 152–173.

**[9]** J.K.W. Wong, J. Ge and S.X. He, Digitisation in facilities management: a literature review and future research directions, *Autom. ConStruct.* (92), 2018, 312–326.

**[10]** R. Edirisinghe, K.A. London, P. Kalutara and G. Aranda-Mena, Building information modelling for facility management: are we there yet?" Engineering, *Constr. Arch. Manag.* **24** (6), 2017, 1119–1154.

**[11]** D. llter and E. Ergen, BIM for building refurbishment and maintenance: current status and research directions, *Struct. Surv.* **33** (3), 2015, 228–256.

**[12]** L. Sanhudo, N.M.M. Ramos, J.P. Martins, R.M.S.F. Almeida, E. Barreira, M.L. Simões and V. Cardoso, Building information modeling for energy retrofitting – A review, *Renew. Sustain. Energy Rev.* **89**, 2018, 249–260.

**[13]** A. GhaffarianHoseini, T. Zhang, O. Nwadigo, A. GhaffarianHoseini, N. Naismith, J. Tookey and K. Raahemifar, Application of nD BIM integrated knowledge-based building management system (BIM-IKBMS) for inspecting post-construction energy efficiency, *Renew. Sustain. Energy Rev.* (72), 2017, 935–949.

**[14]** E.A. Pärn, D.J. Edwards and M.C.P. Sing, The building information modelling trajectory in facilities management:A review, *Autom. ConStruct.* (75), 2017, 45–55.

**[15]** R. Volk, J. Stengel and F. Schultmann, Building information modelling (BIM) for existing buildings: literature review and future needs, *Autom. ConStruct.* **38**, 2014, 109–127, March 2014.

**[16]** Q. Lu and S. Lee, Image-based technologies for constructing as-is building information models for existing buildings, *J. Comput. Civ. Eng.* **31** (4), 2017, 1–14, 04017005.

**[17]** B. Atkin and A. Brooks, Total Facilities Management, third ed., 2009, Blackwell publisher; Chichester, UK, 6–12.

**[18]** P. Teicholz, (Ed), *BIM for Facility Managers,* 2013, available at: www.graphicsystems.biz/gsi/articles/Bridging%20the%20AEC_FM%20Gap_r2.pdf.

**[19]** C. Eastman, P. Teicholz, R. Sacks and K. Liston, BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors, second ed., 2011, John Wiley & Sons Inc; New York, NY.

**[20]** M. Kassem, G. Kelly, N. Dawood, M. Serginson and S. Lockley, BIM in facilities management applications: a case study of a large university complex, *Built. Environ. Proj. Asset. Manag.* **5** (3), 2015, 261–277.

**[21]** A. Ahmed, J. Ploennigs, K. Menzel and B. Cahill, Multi-dimensional building performance data management for continuous commissioning, *Adv. Eng. Inf.* **24**, 2010, 466–475.

**[22]** W. Shen, Q. Hao and Y. Xue, A loosely coupled system integration approach for decision support in facility management and maintenance, *Autom. ConStruct.* **25**, 2012, 41–48.

**[23]** E. Curry, J. O'Donnell, E. Corry, S. Hasan, M. Keane and S. O'Riain, Linking building data in the cloud: integrating cross-domain building data using linked data, *Adv. Eng. Inf.* **27**, 2013, 206–219.

**[24]** Y. Jiao, Y. Wang, S. Zhang, Y. Li, B. Yang and L. Yuan, A cloud approach to unified lifecycle data management in architecture, engineering, construction and facilities management: Integrating BIMs and SNS, *Adv. Eng. Inform.* **27**, 2013, 173–188.

**[25]** B. Dong, Z. O'Neill and Z. Li, A BIM-enabled information infrastructure for building energy Fault Detection and Diagnostics, *Autom. ConStruct.* **44**, 2014, 197–211.

**[26]** W. Solihin, C. Eastman, Y.-C. Lee and D.-H. Yang, A simplified relational database schema for transformation of BIM data into a query-efficient and spatially enabled database, *Autom. ConStruct.* **84**, 2017, 367–383.

**[27]** M. Niknam and S. Karshenas, A shared ontology approach to semantic representation of BIM data, *Autom. ConStruct.* **80**, 2017, 22–36.

**[28]** K. Kim, H. Kim, W. Kim, C. Kim, J. Kim and J. Yu, Integration of ifc objects and facility management work information using Semantic Web, *Autom. ConStruct.* **87**, 2018, 173–187.

**[29]** T.W. Kang and H.S. Choi, BIM-based data mining method considering data integration and function extension, *KSCE J. Civ. Eng.* **22** (5), 2018, 1523–1534.

**[30]** Y. Peng, J.-R. Lin, J.-P. Zhang and Z.-Z. Hu, A hybrid data mining approach on BIM-based building operation and maintenance, *Build. Environ.* **126**, 2017, 483–495.

**[31]** A. Motamedi, R. Saini, A. Hammad and B. Zhu, Role-based access to facilities lifecycle information on RFID tags, *Adv. Eng. Inf.* **25**, 2011, 559–568.

**[32]** A. Motamedi, M.M. Soltani, S. Setayeshgar and A. Hammad, Extending IFC to incorporate information of RFID tags attached to building elements, *Adv. Eng. Inf.* **30**, 2016, 39–53.

**[33]** A.C. Bogen, M. Rashid, E.W. East and J. Ross, Evaluating a data clustering approach for life-cycle facility control, *J. Inf. Technol. Constr.* **18**, 2013, 99–118 http://www.itcon.org/2013/6.

**[34]** Y.C. Lin, Y.C. Su and Y.P. Chen, Developing mobile BIM/2D barcode-based automated facility management system, *Sci. World J.* 2014, 16.

**[35]** T.W. Kang and C.H. Hong, A study on software architecture for effective BIM/GIS-based facility management data integration, *Autom. ConStruct.* **54**, 2015, 25–38.

**[36]** E.A. Pärn and Edwards, Conceptualising the FinDD API plug-in: a study of BIM-FM integration, *Autom. ConStruct.* (80), 2017, 11–21.

**[37]** A. Kučera and T. Pitner, Semantic BMS: allowing usage of building automation data in facility benchmarking, *Adv. Eng. Inf.* **35**, 2018, 69–84.

**[38]** J. Irizarry, M. Gheisari, G. Williams and K. Roper, Ambient intelligence environments for accessing building information, *Facilities* **32** (3/4), 2014, 120–138.

**[39]** J. Lucas, T. Bulbul and W. Thabet, An object-oriented model to support healthcare facility information management, *Autom. ConStruct.* **31** (May 2013), 2013a, 281–291.

**[40]** J. Lucas, T. Bulbul and W. Thabet, A pilot model for a proof of concept healthcare facility information management prototype, *J. Inf. Technol. Constr.* **18**, 2013b, 76–98.

**[41]** J. Lucas, T. Bulbul, W. Thabet and C. Anumba, Case analysis to identify information links between facility management and healthcare delivery information in a hospital setting, *J. Archit. Eng.* **19** (2), 2013c, 134–145.

**[42]** Z.-Z. Hu, J.-P. Zhang, F.-Q. Yu, P.-L. Tian and X.-S. Xiang, Construction and facility management of large MEP projects using a multi-Scale building information model, *Adv. Eng. Software* **100**, 2016, 215–230.

**[43]** Z.-Z. Hu, P.-L. Tian, S.-W. Li and J.-P. Zhang, BIM-based integrated delivery technologies for intelligent MEP management in the operation and maintenance phase, *Adv. Eng. Software* **115**, 2018, 1–16.

**[44]** X. Yang and S. Ergan, BIM for FM: information requirements to support HVAC-related corrective maintenance, *J. Archit. Eng.* **23** (4), 2017, 04017023.

**[45]** H.B. Cavka, S. Staub-French and E.A. Poirier, Developing owner information requirements for BIM-enabled project delivery and asset management, *Autom. ConStruct.* **83**, 2017, 169–183.

**[46]** H.B. Cavka, S. Staub-French and R. Pottinger, Evaluating the alignment of organizational and project contexts for BIM adoption: a case study of a large owner organization, *Buildings* **5**, 2015, 1265–1300.

**[47]** W.E. East, N. Nisbet and T. Liebich, Facility management handover model view, *J. Comput. Civ. Eng.* **27** (1), 2013, 61–67.

**[48]** G.K. Mayo and R.R.A. Issa, Nongeometric building information needs assessment for facilities management, *J. Manag. Eng.* **32** (3), 2016.

**[49]** W. Thabet and J.D. Lucas, A 6-step systematic process for model-based facility data delivery, *J. Inf. Technol. Constr.* **22**, 2017, 104–131.

**[50]** K. Farghaly, F.H. Abanda, C. Vidalakis and G. Wood, Taxonomy for BIM and asset management semantic interoperability, *J. Manag. Eng.* **34** (4), 2018, 04018012, 2018.

**[51]** R. Vanlande, C. Nicolle and C. Cruz, IFC and building lifecycle management, *Autom. ConStruct.* **18** (1), 2008, 70–78.

**[52]** E. Hjelseth, Exchange of relevant information in BIM objects defined by the role- and life-cycle information model, *Architect. Eng. Des. Manag.* **6** (4), 2010, 279–287.

**[53]** H. Hoeber and D. Alsem, Life-cycle information management using open-standard BIM, *Eng. Construct. Architect. Manag.* **23** (6), 2016, 696–708 https://doi.org/10.1108/ECAM-01-2016-0023.

**[54]** J. Patacas, N. Dawood, D. Greenwood and M. Kassem, Supporting building owners and facility managers in the validation and visualisation of asset information models (AIM) through open standards and open technologies, *J. Inform. Technol. Constr.* **21**, 2016, 434–455, Special issue: CIB W78 2015 Special track on Compliance Checking.

**[55]** T. Hartmann, R. Amor and W. East, Information model purposes in building and facility design, *J. Comput. Civ. Eng.* **31** (6), 2017, 04017054.

**[56]** Y.-C. Lee, C.M. Eastman and W. Solihin, Logic for ensuring the data exchange integrity of building information Models, *Autom. ConStruct.* **85**, 2018, 249–262.

**[57]** P.A. Zadeh, G. Wang, H.B. Cavka, S. Staub-French and R. Pottinger, Information quality assessment for facility management, *Adv. Eng. Inf.* **33**, 2017, 181–205.

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

**[59]** C. Koch, M. Neges, M. König and M. Abramovici, Natural markers for augmented reality-based indoor navigation and facility maintenance, *Autom. ConStruct.* **48**, 2014, 18–30.

**[60]** S. Lee and O. Akin, Augmented reality-based computational fieldwork support for equipment operations and maintenance, *Autom. ConStruct.* **20** (4), 2011, 338–352.

**[61]** M. Gheisari and J. Irizarry, Investigating human and technological requirements for successful implementation of a BIM-based mobile augmented reality environment in facility management practices, *Facilities* **34** (1/2), 2016, 69–84.

**[62]** U. Gurevich, R. Sacks and P. Shrestha, BIM adoption by public facility agencies: impacts on occupant value, *Build. Res. Inf.* **45** (6), 2017, 610–630, https://doi.org/10.1080/09613218.2017.1289029.

**[63]** K. Kensek, BIM guidelines inform facilities management databases: a case study over time, *Buildings* **5** (3), 2015, 899–916.

**[64]** R.A. Kivits and C. Furneaux, BIM: enabling sustainability and asset management through knowledge management, *Sci. World J.* 2013, https://doi.org/10.1155/2013/983721.

**[65]** G. Carbonari, S. Stravoravdis and C. Gausden, Improving FM task efficiency through BIM: a proposal for BIM implementation, *J. Corp. Real Estate* **20** (1), 2018, 4–15 https://doi.org/10.1108/JCRE-01-2017-0001.

**[66]** R. Miettinen, H. Kerosuo, T. Metsälä and S. Paavola, Bridging the life cycle: a case study on facility management infrastructures and uses of BIM, *J. Facil. Manag.* **16** (1), 2018, 2–16 https://doi.org/10.1108/JFM-04-2017-0017.

**[67]** M. Tucker and M.R.A. Masuri, The development of facilities management-development process (FM-DP) integration framework, *J. Build. Eng.* **18**, 2018, 377–385.

[68] P.E. Love, I. Simpson, A. Hill and C. Standing, From justification to evaluation: building information modeling for asset owners, *Autom. ConStruct.* **35**, 2013, 208–216.

[69] P.E. Love, J. Matthews, I. Simpson, A. Hill and O.A. Olatunji, A benefits realization management building information modeling framework for asset owners, *Autom. ConStruct.* **37**, 2014, 1–10.

[70] O.A. Olatunji and A. Akanmu, BIM-FM and consequential loss: how consequential can design models be?, *Built. Environ. Proj. Asset. Manag.* **5** (3), 2015, 304–317.

[71] J. Korpela, R. Miettinen, T. Salmikivi and 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, *Constr. Manag. Econ.* **33** (1), 2015, 3–17.

[72] Y.-C. Lin and Y.-C. Su, Developing mobile-and BIM-based integrated visual facility maintenance management system, *Sci. World J.* **2013**, 2013, 7.

[73] I. Motawa and A. Almarshad, A knowledge-based BIM system for building maintenance, *Autom. ConStruct.* **29** (January), 2013, 173–182.

[74] I. Motawa, A. Almarshad, M. Kumaraswamy and P. Love, Case-based reasoning and BIM systems for asset management, *Built. Environ. Proj. Asset. Manag.* **5** (3), 2015, 233–247.

[75] A. Golabchi, M. Akula and V. Kamat, Automated building information modeling for fault detection and diagnostics in commercial HVAC systems, *Facilities* **34** (3/4), 2016, 233–246.

[76] X. Yang and S. Ergan, Design and evaluation of an integrated visualization platform to support corrective maintenance of HVAC problem–related work orders, *J. Comput. Civ. Eng.* **30** (3), 2016, 1–13, 04015041.

[77] J.J. McArthur, N. Shahbazi, R. Fok, C. Raghubar, B. Bortoluzzi and A. Anb, Machine learning and BIM visualization for maintenance issue classification and enhanced data collection, *Adv. Eng. Inf.* **38**, 2018, 101–112.

[78] W. Chen, K. Chen, J.C.P. Cheng, Q. Wang and V.J.L. Gan, BIM-based framework for automatic scheduling of facility maintenance work orders, *Autom. ConStruct.* **91**, 2018, 15–30.

[79] S. Katipamula, K. Gowri and G. Hernandez, An open-source automated continuous condition-based maintenance platform for commercial buildings, *Sci. Technol. Built Environ.* **23** (4), 2017, 546–556, https://doi.org/10.1080/23744731.2016.1218236.

[80] A. Costa, M.M. Keane, J.I. Torrens and E. Corry, Building operation and energy performance: monitoring, analysis and optimisation toolkit, *Appl. Energy* **101**, 2013, 310–316.

[81] A. Abdelalim, W. O'Brien and Z. Shi, Data visualization and analysis of energy flow on a multi-zone building scale, *Autom. ConStruct.* **84**, 2017, 258–273.

[82] K.-M. Chang, R.-J. Dzeng and Y.-J. Wu, An automated IoT visualization BIM platform for decision support in facilities management, *Appl. Sci.* **8**, 2018, 1–18, https://doi.org/10.3390/app8071086, 1086.

[83] Z. Alwan and B.J. Gledson, Towards green building performance evaluation using asset information modelling, *Built. Environ. Proj. Asset. Manag.* **5** (3), 2015, 290–303 https://doi.org/10.1108/BEPAM-03-2014-0020.

[84] B. Zhong, C. Gan, H. Luo and X. Xing, Ontology-based framework for building environmental monitoring and compliance checking under BIM environment, *Build. Environ.* **141**, 2018, 127–142.

[85] A. Francisco, H. Truongb, A. Khosrowpour, J.E. Taylora and N. Mohammadia, Occupant perceptions of building information model-based energy visualizations in eco-feedback systems, *Appl. Energy* **221**, 2018, 220–228.

[86] T. Randall, Construction engineering requirements for integrating laser scanning technology and building information modeling, *J. Constr. Eng. Manag. ASCE* **137** (10), 2011, 797–805.

[87] Y. Arayici, Towards building information modelling for existing structures, *Struct. Surv.* **26** (3), 2008, 210–222.

[88] L. Klein, N. Li and B. Becerik-Gerber, Imaged-based verification of as-built documentation of operational buildings, *Autom. ConStruct.* **21**, 2012, 161–171.

[89] S. Lagüela, L. Díaz-Vilariño, J. Martínez and J. Armesto, Automatic thermographic and RGB texture of as-built BIM for energy rehabilitation purposes, *Autom. ConStruct.* **31**, 2013, 230–240.

[90] J. Jung, S. Hong, S. Jeong, S. Kim, H. Cho, S. Hong and J. Heo, Productive modeling for development of as-built BIM of existing indoor structures, *Autom. ConStruct.* **42**, 2014, 68–77.

[91] Z. Wang, T. Bulbul and J. Lucas, "A Case Study of BIM-Based Model Adaptation for Healthcare Facility Management – Information Needs Analysis, 2015, Computing in Civil Engineering, 395–402.

[92] F. Bosché, A. Guillemet and Y. Turkan, Tracking the built status of MEP works: assessing the value of a scan-vs.-BIM system, *J. Comput. Civ. Eng.* **28** (4), 2014, 05014004, pp.1-13.

[93] Y.-C. Lin, C.-P. Lin, H.-T. Hu and Y.-C. Su, Developing final as-built BIM model management system for owners during project closeout: a case study, *Adv. Eng. Inf.* **36**, 2018, 178–193.

**[94]** H. Hamledari, E.R. Azar and B. McCabe, IFC-based development of as-built and as-is BIMs using construction and facility inspection data: site-to-BIM data transfer automation, *J. Comput. Civ. Eng.* **32** (2), 2018, 04017075, pp.1-15.

**[95]** ö. Göçer, U. Hua and K. Göçer, Completing the missing link in building design process: enhancing post-occupancy evaluation method for effective feedback for building performance, *Build. Environ.* **89**, 2015, 14–27.

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

**[97]** A.H. Oti, E. Kurul, F. Cheung and J.H. Tah, A framework for the utilization of Building Management System data in building information models for building design and operation, *Autom. ConStruct.* **72**, 2016, 195–210

**[98]** J.H. Woo and C. Menassa, Virtual retrofit model for aging commercial buildings in a smart grid environment, *Energy Build.* **80** (September), 2014, 424–435.

**[99]** J.H. Woo, M.A. Peterson and B. Gleason, Developing a virtual campus model in an interactive game-engine environment for building energy benchmarking, *J. Comput. Civ. Eng.* **30** (5), 2016, C4016005, pp.1–10.

**[100]** J.R. Scherer and P. Katranuschkov, BIMification: how to create and use BIM for retrofitting, *Adv. Eng. Inf.* **38**, 2018, 54–66.

**[101]** Z. Alwan, BIM performance framework for the maintenance and refurbishment of housing stock, *Struct. Surv.* **34** (3), 2016, 242–255 https://doi.org/10.1108/SS-03-2015-0018.

**[102]** A. Bosch, L. Volker and A. Koutamanis, BIM in the operations stage: bottlenecks and implications for owners, *Built. Environ. Proj. Asset. Manag.* **5** (3), 2015, 331–343 https://doi.org/10.1108/BEPAM-03-2014-0017.

**[103]** R. Eadie, M. Browne, H. Odeyinka, C. McKeown and S. McNiff, BIM implementation throughout the UK construction project lifecycle: an analysis, *Autom. ConStruct.* **36**, 2013, 145–151.

**[104]** R. Howard and B.-C. Björk, Building information modelling- Experts' views on standardisation and industry deployment, *Adv. Eng. Inf.* **22** (2008), 2008, 217–280.

**[105]** C. Lindkvist, Contextualizing learning approaches which shape BIM for maintenance, *Built. Environ. Proj. Asset. Manag.* **5** (3), 2015, 318–330.

**[106]** A. Motamedi, M.M. Soltani and A. Hammad, Localization of RFID-equipped assets during the operation phase of facilities, *Adv. Eng. Inf.* **27**, 2013, 566–579.

**[107]** A. Motamedi, A. Hammad and Y. Asen, Knowledge-assisted BIM-based visual analytics for failure root cause detection in facilities management, *Autom. ConStruct.* **43** (July), 2014, 73–83.

**[108]** J. Patacas, N. Dawood, V. Vukovic and M. Kassem, BIM for facilities management: evaluating BIM standards in asset register creation and service life, *J. Inf. Technol. Constr.* **20**, 2016, 313–331 http://www.itcon.org/2015/20.

**[109]** S. Rodriguez-Trejo, A.M. Ahmad, M. At Hafeez, H. Dawood, V. Vukovic, M. Kassem, K.K. Naji and N. Dawood, Hierarchy based information requirements for sustainable operations of buildings in Qatar, *Sustain. Cities Soc.* **32**, 2018, 435–448.

**[110]** W. Thabet, J. Lucas and S. Johnston, A case study for improving BIM-FM handover for a large educational institution, In: *Construction Research Congress 2016, San Juan, Puerto Rico,* 2016.

**[111]** G. Williams, M. Gheisari, P. Chen and J. Irizarry, BIM2MAR: an efficient BIM translation to mobile augmented reality applications, *J. Manag. Eng.* **31**, 2015, 1–8, Special Issue.

# Appendix A. Supplementary data

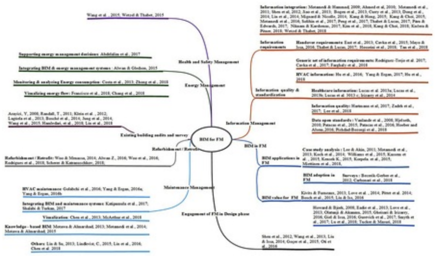
The following is the Supplementary data to this article:

Multimedia Component 1

**Multimedia component 1**

alt-text: Multimedia component 1

**Graphical abstract**




alt-text: Image 1

**Highlights**

Information exchange between BIM models and FM systems is not a straightforward process, as software interoperability remains a significant challenge. Bridging this gap requires:

- a seamless information exchange process between BIM and FM systems,
- Holistic guidance for facility owners and managers that encapsulates all required information for efficient FM operations across all systems and building types,
- a well-defined information quality process that ensures owner/FM needs are considered carefully in BIM models,
- Standardized practical processes to integrate different information sources related to maintenance management and health & safety management tasks, to provide a rich semantic database to support FM systems,
- a standardized process for feedback loops between operations and design phases to provide rich actual feedback to support efficient facilities design, and
- More real-world case studies to investigate the current status of BIM implementation in FM.

# Queries and Answers

**Query:** Please confirm that the provided email “sandra.matarneh@port.ac.uk” is the correct address for official communication, else provide an alternate e-mail address to replace the existing one, because private e-mail addresses should not be used in articles as the address for communication.
**Answer:** confirmed

**Query:** Refs. “Motamedi and Hammad 2009; Mignard and Nicolle 2014; Rodriguez Trejo et al., 2017; Hosseini et al., 2018” are cited in the text but not provided in the reference list. Please provide them in the reference list or delete these citations from the text.
**Answer:** Motamedi A, Hammad A (2009). Lifecycle management of facilities components using radio frequency identification and building information model, ITcon Vol. 14, Special issue **Next Generation Construction IT: Technology Foresight, Future Studies, Roadmapping, and Scenario Planning**, pg. 238-262, http://www.itcon.org/2009/18
Mignard C, Nicolle C. (2014). Merging BIM and GIS using ontologies application to Urban facility management in ACTIVe3D, Computers in Industry 65(9):1276–1290
DOI: 10.1016/j.compind.2014.07.008
S. Rodriguez-Trejo et al. (2017). Hierarchy based information requirements for sustainable operations of buildings in Qatar, Sustainable Cities and Society 32 (2017) 435–448
http://dx.doi.org/10.1016/j.scs.2017.03.005 2210-6707/© 2017 Elsevier Ltd.
M. Reza Hosseini, Rogier Roelvink, Eleni Papadonikolaki, David John Edwards, Erika Pärn, (2018) "Integrating BIM into facility management: Typology matrix of information handover requirements", International Journal of Building Pathology and Adaptation, Vol. 36 Issue: 1, pp.2-14, https:// doi.org/10.1108/IJBPA-08-2017-0034

**Query:** Correctly acknowledging the primary funders and grant IDs of your research is important to ensure compliance with funder policies. We could not find any acknowledgement of funding sources in your text. Is this correct?
**Answer:** Correct, the research is not funded by any party

**Query:** Please note that the reference style has been changed from a Name-Date style to a Numbered style as per the journal specifications.
**Answer:** Confirmed

**Query:** This section comprises references that occur in the reference list but not in the body of the text. Please position each reference in the text or, alternatively, delete it. Any reference not dealt with will be retained in this section. Thank you.
**Answer:** Delete reference 105, 106, 107 and keep 110

**Query:** Please confirm that given names and surnames have been identified correctly and are presented in the desired order and please carefully verify the spelling of all authors' names.
**Answer:** confirmed

**Query:** Your article is registered as a regular item and is being processed for inclusion in a regular issue of the journal. If this is NOT correct and your article belongs to a Special Issue/Collection please contact p.kumar.7@elsevier.com immediately prior to returning your corrections.
**Answer:** correct, it belongs to regular issue