BIM for FM

Developing information requirements to support facilities management systems

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Abstract

Purpose – This paper aims to identify a generic set of information requirements for facilities management (FM) systems, which should be included in BIM as-built models for efficient information exchange between BIM and FM systems, and to propose a process to identify, verify and collect the required information for use in FM systems during the project's lifecycle.

Design/methodology/approach – Both qualitative and quantitative approaches were applied at different stages of the study's sequential design. The collection and analysis of qualitative data was based on an extensive literature review of similar studies, standards, best practices and case study documentation. This was followed by a questionnaire survey of 191 FM practitioners in the UK. This formed the background of the third stage, which was the development of the information management process to streamline information exchange between building information models and FM systems.

Findings – The study identifies a generic list of information requirements of building information models to support FM systems. In addition, the study presents an information management process that generates a specific database for FM systems using an open data format.

Originality/value – The existing literature focuses on specific building types (educational buildings) or specific information requirements related to particular systems (mechanical systems). The existing standards, guidelines and best practices focus on the information requirements to support the operations and maintenance (O&M) phase in general. This study is different from previous studies because it develops a set of specific information requirements for building information models to support FM systems. FM organisations and owners can use the proposed list of information requirements as a base to generate specific data output for their FM systems' input, to decrease the redundant activity of manual data entry and focus their efforts on key activities.

Keywords Information management, Building information modelling (BIM), Information exchange, Construction operations building information exchange (COBie), Facilities management systems, Information requirements

Paper type Research paper

1. Introduction

Facilities management (FM) can be defined as an integrated process within an organisation to maintain and improve building and infrastructure assets to enhance the effectiveness of its key activities (EN15221-1, 2006). FM involves a wide range of multidisciplinary services with an overall purpose to maintain and enhance building assets to ensure occupants' wellbeing (Becerik-Gerber *et al.*, 2012). The key challenge for the FM teams is to have real-time, accurate and comprehensive information to perform their day-to-day activities and to provide their senior management with accurate information for decision-making (Atkin and Brooks, 2009).

Currently, there are various technology platforms, data repositories or database management systems such as Computer-Aided Facility Management (CAFM) and Computerised Maintenance Management Systems (CMMS) that are used for these purposes in different facilities. In most practices today, the data required for CAFM/CMMS systems, which come from various sources, are collected and entered manually into these systems, manipulated several times during the project lifecycle, and entered manually several times into each individual FM system, as they lack interoperability between each other, resulting in error-prone processes (Becerik-Gerber *et al.*, 2012; Teicholz, 2013; Patacas *et al.*, 2015).

In essence, using Building Information Modelling (BIM) in FM practice facilitates the management of information concerning a building's components and systems during its lifecycle (Teicholz, 2013). The more accurate and up-to-date the information available to the FM team, the greater the opportunity for the enhancement of processes throughout the O&M phase. One of the key success factors for BIM implementation in FM is to identify the required data for day-to-day activities (Liu and Issa, 2016). Accordingly, the FM industry is beginning to acknowledge the importance of having a standardised specification for the data format. Standards have been issued which support data management, such as UK PAS1192-3:2014, and provide a specification for information management for the operational phase of facilities using BIM. Suggestions have also been proposed to use the Construction Operations Building information exchange (COBie) as a data exchange method (BSI, 2014a). COBie is a neutral spread sheet format that organises non-geometric facility data in a structured, simple format for use by the owner and/or FM teams (Thabet *et al.*, 2016). However, even though different methods and tools have been developed to exchange information during a facility's lifecycle, there is still a lack of understanding of what type of information is needed for use by the FM team during the O&M phase and how to transfer this information seamlessly into existing FM systems.

Recent studies have acknowledged the necessity of identifying the required FM information for successful implementation of BIM in FM practice (Kassem *et al.*, 2015; Dias and Ergan, 2016; Cavka *et al.*, 2017; Farghaly *et al.*, 2018; Pishdad-Bozorgi *et al.*, 2018). Mayo and Issa (2016) concluded that the successful implementation of BIM in FM entails the owners' and FM teams' early involvement during the design stage, to include their information requirements and ensure their delivery at the handover stage. Liu and Issa (2016) highlighted the importance of identifying the required information for FM activities and defining the required level of detail. However, determining the information requirements and appropriate information exchange process for transferring BIM data to FM systems remains a challenge (Love *et al.*, 2015). To date, owners and FM teams are dependent on generic recommendations concerning the information they need to collect and the method to be used to collect the required information. To help owners and FM teams determine their information requirements, this study aimed to collect views on the information required to help them identify specific closeout deliverables. Furthermore, a process is proposed to identify, verify and collect the required information for use in FM systems during the project's lifecycle.

2. Research background

The late delivery of huge amounts of unstructured facility information to the FM team is recognised as a major challenge among the research and industry communities. BIM with its capabilities as a data repository provides possibilities to address this challenge. Several studies have been conducted with a focus on the geometric information requirements of BIM. However, there is still a need to focus on identifying non-geometric BIM information requirements to support successful implementation of BIM in FM, as recommended in

several studies (Becerik-Gerber *et al.*, 2012; Giel and Issa, 2016; Borhani *et al.*, 2017; Cavka *et al.*, 2017; Pishdad-Bozorgi *et al.*, 2018). Thus, this study aims to identify information requirements for efficient information exchange between BIM and FM systems, and to propose a process to transfer the identified information requirements to FM systems using an open data format.

2.1 Previous research studies
Several studies have been conducted with a focus on identifying the non-geometric information requirements of BIM models to support FM practice. However, these studies either focussed on producing a generic list of information requirements to support FM activities or a specific list to support particular building systems such as the HVAC system. Examples of the first group include Hunt (2011) who classified information requirements at two main levels:

(1) system level, with sublevels related to location, manufacturer information, vendor, identifier (ID) name, and number; and

(2) the technical content level, with sublevels related to warranties, maintenance instructions, etc.

Meanwhile, Wang *et al.* (2013) classified information requirements based on information type and grouped them into three categories:

(1) building systems and equipment, which include HVAC and sensors;

(2) asset attributes and data, such as vendor's information; and

(3) documents and portfolios, such as manuals and reports.

Lin *et al.* (2016) conducted a study aimed to develop a BIM execution plan to support FM teams during the pre-operation phase. They classified the required information into five categories:

(1) basic information;

(2) geometric information;

(3) equipment detail information;

(4) supplementary information; and

(5) maintenance records.

Cavka *et al.* (2017) identified the required information for building maintenance, systems monitoring and asset management using two large owner organisations in Canada. They identified three levels of information requirements:

(1) maintenance personnel;

(2) building management system; and

(3) asset management.

Finally, Lu *et al.* (2018) identified two types of information in their study: geometric and non-geometric information and they then listed ten parameters for the non-geometric information which were status of data collecting and monitoring equipment, specification and attributes of information, space management information, building asset information, list of manufacturer, operation records, maintenance history and status, latest O&M manuals, FM professionals' working schedules, and emergency protection information.

Examples of the second group, who focussed on producing specific lists of information requirements to support either a specific building type or system include Mayo and Issa (2016),

who identified 28 information requirements as closeout deliverables for educational buildings. These parameters were then grouped into five categories, as follows:

(1) maintenance and scheduling;
(2) system analysis;
(3) asset management;
(4) space management; and
(5) safety and emergency planning.

Thabet and Lucas (2017) aimed in their study to propose a process for BIM integrated FM, and identified a very specific data set of properties and attributes for air handling units only, as an example of data collection. Yang and Ergan (2017) focussed on the information requirements needed for HVAC maintenance management during O&M phase and produced six categories of information requirements: work orders; HVAC-related complaints logs; HVAC system/component static information; HVAC system/component dynamic information, HVAC system/component historical information; and space-related information. Most recently, Farghaly *et al.* (2018) developed a taxonomy of owner requirements which included 60 parameters for asset-consuming energy information requirements. They then grouped these parameters in six main categories: location, specifications, classifications, warranty, asset capex, and maintenance.

2.2 BIM-FM existing standards

Various standards have been developed during the past decade to facilitate the identification of information requirements of BIM models to support FM practice. PAS 1192-3 states that an Asset Information Requirement (AIR) document should be produced. This should be undertaken by the client and should state the information (in the form of data, documents and geometry) that is required in the Asset Information Model (AIM). The AIM should then be used by the facility management teams to operate and maintain the building. However, PAS 1192-3 is a specification only for information management for the O&M phase; it helps in specifying how AIM should be developed to support FM but it does not specify what items of information are required (PAS 1192-3:2014). BS 1192-4 provides guidance and recommendations for the UK government's usage of COBie for exchanging facility information between the owner and the supply chain (BS 1192-4: 2014). The Construction, Operations, Building information exchange (COBie) was developed as a subset of the Industry Foundation Class (ISO 16739) COBie Model View Definition for facility asset non-geometric information (East, 2013). COBie arranges the non-geometric information into ten main categories: facility, floor, space, zone, type, components, system, spares, job and resources. COBie is a repetitive process, with four defined data drops taking place at crucial stages of the project life cycle to capture the required and available data for FM (East and Carrasquillo-Mangual, 2013). COBie provides a system-to-system exchange of the space and equipment information without user intervention, which means that all data accumulated during the design and construction phases regarding the facility spaces and equipment can be imported directly into FM systems (East, 2013). However, as COBie can include a huge amount of information, specifying the required data output for input into FM systems could facilitate a seamless information exchange process.

The asset information requirements (AIRs) template was developed by the Chartered Institution of Building Services Engineers (CIBSE) (DE5T) in reference to PAS 1192-3:2014 and BS ISO 55000:2014, to ensure that information relating to the running of an asset is generated, collated and delivered during the life-cycle of the asset. The DE5T includes four

tables on information requirements: facility information, space information, system information, and component information (CIBSE, 2018). However, there is no information related to maintenance included in this template. The European Committee for Standardisation in cooperation with UK and open BIM standards developed a product data template (CEN 442 WG4) as a matrix of attributes that facilitates identifying asset information requirements.

2.3 BIM-FM best practice guidelines
The US General Services Administration (GSA) BIM guide for facility management was developed in 2011 to facilitate BIM implementation for its future projects. The GSA identified the minimum COBie requirements, which involved space, zone, building systems or equipment. However, information items related to preventive maintenance in the job and resource sheet and the spares sheet were not required as BIM outputs, since this type of data would be collected in a central repository from different data sources in different formats to support FM systems (GSA, 2011).

The Ministry of Justice in the UK developed a client best practice guidance, which was reviewed by the government BIM Task Group, to provide support in identifying information requirements for government Level 2 BIM projects. The guide provides concise instructions on how to identify information requirements using the Employer Information Requirements (EIRs) and Asset Information Requirements (AIRs) to develop the Asset Information Model (AIM). In this guidance, COBie was considered for the information exchange process and a matrix of COBie parameters was prepared with the corresponding responsible stakeholder. However, all COBie parameters were required, except those related to preventive maintenance in the job and resource sheets, and information related to spares in the spares sheet (Ministry of Justice, 2016).

A guide for asset information requirements was developed by the University of Reading (UoR) for projects at the handover stage. Part of this guide comprised BIM information requirements to support FM practice. UoR developed a matrix for the COBie level of information, in which shows all the information related to preventive maintenance and spares was not required at the project handover stage. In addition, UoR developed another matrix for the required attribute data, which included 14 attribute requirements for particular components (University of Reading, 2016). In 2018, University College London (UCL) developed an information delivery plan in which the information exchange format to support FM practice was COBie. The COBie information requirements assigned included information concerning the facility spaces and equipment. Information related to preventive maintenance and spares was left for FM team to fill in manually during the O&M phase (University College London, 2018).

The University of Cambridge developed a BIM document suite for its construction projects in general that includes EIRs, a BIM capability assessment, a BIM Execution Plan (BEP) and a CIC BIM protocol. According to the EIR documents, COBie is required for non-geometric information exchange and, accordingly, a matrix has been developed for COBie requirements and responsibilities related to contact, facility, floor, space, zone, type, component, and system sheets. This document suite does not include any information requirements related to the resource, spares and job document sheets. However, in the University of Cambridge Capella project, BIMXtra, different parties were allowed to input the objects' geometry data using the cloud-based CDE. Information related to O&M data were entered in the same CDE using an Excel file format and COBie outputs were then created using the data collected on BIMXtra and an "intelligently" linked O&M manual (University of Cambridge, n.d).

The Pennsylvania State University Office of Physical Plant (PSU OPP) team developed BIM requirements for all new construction projects costing over five million dollars. These requirements cover both the owner requirements and the existing Enterprise Asset Management System (EAM) requirements. The OPP Asset Attribute List was developed to detail the required attributes to be embedded in the BIM models for information to be transferred seamlessly between BIM and FM systems. To accomplish this, the team researched various standards, including COBie, but determined that Uniformat II was the most compatible with the team's needs. The team identified particular systems and a customised list of parameters for each system. Among those parameters, asset name, asset number, type, model number, manufacturer and serial number are the common parameters (PennState Physical Plant, n.d).

The University of Southern California (USC) (2012) developed BIM guidelines to define BIM deliverables for USC construction projects. The COBie 2.4 standard spreadsheet was required to be submitted by the general contractor at the project handover to include all fields related to contact, facility, floor, space, zone, type, components, system, documents, and specific attribute sheets for particular systems. Information related to preventive maintenance activities was not included in the USC information requirements (USC, 2012).

3. Research methods

In identifying the required BIM data outputs for FM systems' inputs, this study adopted a three-stage procedure proposed by Giel and Issa (2016): comparison, prioritisation and development, with each phase corresponding to a specific research aim, as shown in Figure 1. In the first stage of this study a qualitative approach was adopted, involving an extensive review of the existing academic literature, standards and best practice guidelines to develop a

Flow diagram of research design and methods
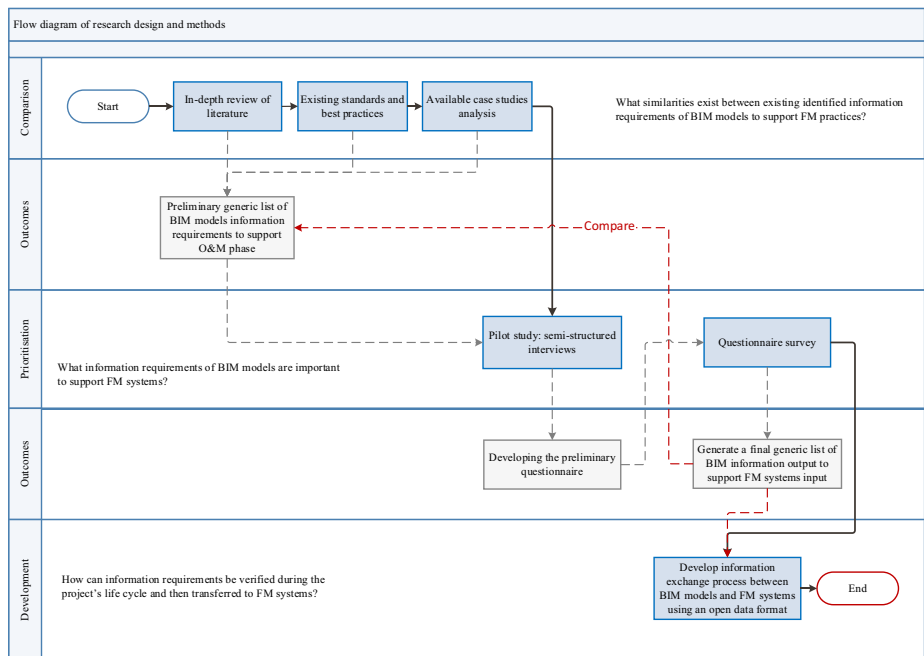
generic set of information requirements of BIM models to support FM practice. A matrix was then created to compare different information requirements. The second stage of this study adopted a quantitative approach which involved the development of a questionnaire survey based on the outcomes of the first stage, to prioritise the information requirements of BIM models to support FM systems specifically. A preliminary questionnaire survey was developed using the generic list created in stage one. The preliminary questionnaire then was revised and finalised, based on a pilot study in which semi-structured interviews were conducted with sixteen FM practitioners in the UK to solicit comments on the readability, accuracy, and comprehensiveness of the questionnaire. The final questionnaire survey was then distributed to FM practitioners in the UK using the British Institute of FM (BIFM, 2017) database. The FM practitioners were asked to rank the importance of the provided information requirements to support FM systems and they were given an opportunity to add more information requirements. As a product of the prioritisation stage, 39 information requirements were identified and prioritised according to their importance to support FM systems, as suggested by the FM practitioners. On the basis of these results, the subsequent stage involved the development of a generic list of information requirements of BIM models to support FM systems and a process of identification and exchange of information requirements between BIM models and FM systems using an open data format.

4. Results and discussion

4.1 Stage I: comparison between the existing information requirements of BIM models to support FM practice

At this stage of the research, all the identified information requirements collated from previous research, existing standards and best practice guidelines were organised in one matrix to compare them based on their frequencies and discover what similarities exist between the various identified information requirements of BIM models to support FM practice. The outcome of this stage was a list of information requirements of BIM models to support FM practice as listed in Table I.

4.2 Stage II: prioritising information requirements based on their importance to support FM systems

To prioritise the required BIM information to support FM systems, a questionnaire survey was conducted. The preliminary questionnaire was developed based on the literature review findings of stage I and revised based on a pilot study in which sixteen interviews were conducted with FM practitioners in the UK, to solicit comments on the readability, accuracy and comprehensiveness of the questionnaire. The interviewees were requested to rate the importance of 45 information requirements of BIM models to support FM systems using a five-point Likert scale (1 = unimportant, 2 = of little importance, 3 = moderately important, 4 = important, and 5 = very important). Interviewees were also requested to add further information requirements, based on their experience, to those listed in the questionnaire. Finally, the participants were requested to provide their feedback to develop the questionnaire instruments. In analysing the collected responses, it was noted that six participants suggested adding consumables to the generic list of information requirements, while nine of them suggested eliminating ownership, as it refers to the ownership of rented equipment during the O&M phase, and to merge inspection reports, certificates, key plans and installation guide under construction handover documents. After the list refinement task was completed, the final list, including 41 information requirements, was collated from different sources to be used as a base for stage two, in order to identify specific information requirements to support FM systems in particular.

No.	Information requirements	References	Frequency
1	Design criteria	[4]; [7]; [12]; [14]	4
2	Handover documentation	[1]; [4]; [5]; [9]; [15]; [17]; [20]	7
3	Spare part information	[2]; [4]; [6]; [5]; [9]; [8]; [12]; [15]; [17]	9
4	Manufacturer/vendor info	[1]; [2]; [3]; [4]; [5]; [8]; [10]; [11]; [12][13]; [15]; [18]; [16]; [17]; [19]; [20]; [21]	17
5	Serial number	[2]; [4]; [5]; [6]; [10]; [11]; [18]; [15]; [19]; [20]	10
6	Asset location	[1]; [3]; [4]; [6]; [7]; [8]; [9]; [10]; [11]; [13]; [14]; [15]; [18]; [16]; [17]; [19]; [20]; [21]	18
7	Warranty info	[1]; [2]; [3]; [4]; [5]; [6]; [8]; [9]; [10]; [11]; [12]; [13]; [18]; [14]; [15]; [16]; [17]; [19]; [20]; [21]	21
8	Replacement cost	[1]; [4]; [10]; [11]; [15]; [16]; [17]; [18]; [20]	9
9	Installation guide	[2]; [4]; [9];	3
10	System/equipment performance	[4]; [7]; [9]; [12]	4
11	Expected life	[10]; [11]; [12]; [15]; [16]; [17]; [18]; [20]	8
12	Sequence of operations	[4]; [7]; [14]	3
13	Maintenance history	[1]; [2]; [4]; [7]; [8]; [14]	6
14	Preventive maintenance schedules	[1]; [2]; [4]; [7]; [8]; [9]; [12]; [14]; [15]; [16]; [17]; [21]	12
15	Inspection reports	[2]; [4]; [7]; [9]; [14]	5
16	Key plans	[4]; [7]; [16]; [17]	4
17	Asset name	[2]; [3]; [5]; [8]; [10]; [11]; [15]; [18]; [19]; [20]	10
18	Systems and their associated systems	[3]; [4]; [5]; [7]; [10]; [12]; [15]; [18]	8
19	Equipment lists	[4]; [16]; [17]	3
20	Asset description	[3]; [5]; [7]; [8]; [10]; [11]; [12]; [13]; [14]; [15]; [18]; [19]; [20]	13
21	Identification number	[1]; [2]; [5]; [6]; [9]; [8]; [10]; [11]; [13]; [15]; [16]; [17]; [18]; [21]	14
22	Spatial information	[1]; [2]; [3]; [5]; [7]; [9]; [10]; [11]; [15]; [18]; [20]	11
23	Legal regulations and compliance	[2]; [5]; [9]; [12]; [16]; [17]	6
24	Make and/or model	[2]; [9]; [15]; [16]; [17]; [18]; [19]	7
25	Installation date	[1]; [5]; [15]; [16]; [17]	5
26	Asset specification	[1]; [2]; [4]; [8]; [10]; [13]; [14]; [15]; [16]; [17]; [20]	11
27	Purchase information	[1]; [2]; [6]; [9]; [14]	5
28	Bar code information	[2]; [5]; [8]; [9]; [10]; [11]; [15]; [18]; [20]	9
29	Performance code	[5]; [15]; [16]; [17]	4
30	O and M manuals	[3]; [7]; [9]; [13]; [14]; [16]; [17]; [20]	8
31	Classification	[2]; [3]; [5]; [6]; [10]; [11]; [15]; [16]; [17]; [18]; [20]	11
32	Asset Condition	[5]; [12]; [16]; [17]	4
33	Life cycle cost	[2]; [5]; [16]; [17]	4
34	Room tag	[10]; [11]; [18]; [20]	4
35	Accessibility performance	[7]; [15]; [16]; [17]	4
36	Certificates	[2]; [9]; [13];	3
37	Sustainability performance	[5]; [9]; [10]; [15]; [16]; [17]	6
38	Facility general information	[2]; [3]; [5]; [10]; [11]; [14]	6
39	Contracts	[16]; [17]	2
40	Occupancy ratio	[5]; [7]; [9]; [14]	4
41	Capacity	[5]; [6]; [7]; [18]	4
		(*continued*)	

No.	Information requirements	References	Frequency
42	Ownership	[16]; [17]	2
43	GIS coordinates	[3]; [9]; [10]; [14]; [15]	5
44	Risk assessments	[5]; [9]; [14]; [16]; [17]	5
45	Locations of control panels/valves	[2]; [4]	2

Notes: [1] Lu *et al.*, 2018; [2] Farghaly *et al.*, 2018; [3] UCLBIM, 2018; [4] Cavka *et al.*, 2017; [5] CIBSE, 2017; [6] Thabet and Lucas, 2017; [7] Yang and Ergan, 2017; [8] Lin *et al.*, 2016; [9] Mayo and Issa, 2016; [10] MoJ, 2016; [11] UoR BIM Guidance, 2016; [12] PAS 1192-3:2014; [13] Wang *et al.*, 2013; [14] Becerik-Gerber *et al.*, 2012; [15] COBie-UK, 2012; [16] BS 8210:2012; [17] BS 8587:2012; [18] USC BIM Guidelines, 2012; [19] PSU OPP, 2011; [20] GSA, 2011; [21] Hunt, 2011

Table I.

Accordingly, the 41 variables of information requirements to support FM systems were organised into an online questionnaire survey which was then distributed to FM practitioners registered with the BIFM. The online questionnaire survey was sent through the BIFM to all active FM members in UK and 191 responses were collected. Responses were analysed using SPSS and the results are presented in the following sub-sections.

4.2.1 Demographic distribution. A wide range of FM professionals with rich experience and knowledge in the field of building O&M participated in the survey. Two thirds of the respondents had worked for more than 15 years in the industry; of these, 37 per cent had worked between 16 and 20 years and 27 per cent for over 20 years. A further 17 per cent had worked between 10 and 15 years in the industry, while 11 per cent had worked for 6 to 10 years and 8 per cent had worked for less than 5 years in the FM industry.

Respondents were asked about their organizations' functional responsibilities and they were asked to select one or more functions from the five functions provided. The majority were responsible for maintenance management (80 per cent), while almost half (46 per cent) were involved in asset management and 31 per cent in energy management. Over a quarter were also CAFM/CMMS specialists and 15 per cent undertook space management functions. The 4 per cent of the respondents who indicated they were involved in other functions mentioned information management, health and safety, building management systems, statutory compliance management, and being an FM systems software provider.

4.2.2 Current information management status. In order to understand the current information management status in the FM industry, respondents were asked to indicate by which of three methods they usually received the handover documents at the project completion and handover. The most frequent response was a mix of both electronic and paper copy (89 per cent). Nine per cent of the respondents reported that they received only the electronic copy (CAD drawings and scanned construction documentation) and only two per cent indicated that they the received the paper copy alone.

Respondents were asked which of two data entry methods, manual or electronic, they used to enter facility information into FM systems. The great majority of respondents (87 per cent) reported that they used manual data entry while only 13 per cent used the automatic data entry method.

Finally, respondents were asked about the accuracy of the data they entered into their FM systems and they were able to select one description out of five provided. The majority of respondents believed that the facility data entered into their FM systems was 'somewhat accurate' (63 per cent). A further 28 per cent believed that the data they entered in FM systems was 'accurate', and 3 per cent even believed that the data was "very accurate". Very

few of the respondents believed that the data was "not accurate" (5 per cent) or not accurate at all (1 per cent).

4.2.3 Reliability analysis. Cronbach's alpha test was used to examine the reliability of the factors extracted from the rating questions with these multi-point structured scales. The 41 variables identified from the qualitative analysis results and their associated Likert scale were examined using SPSS software, to verify if they consistently showed the construct the study aimed to measure (Field, 2005). Cronbach's alpha coefficient is considered acceptable if $\alpha = 0.7$, and if it is higher than 0.8 then it represents good internal consistency (Field, 2005). The average Cronbach's alpha coefficient of this study was calculated as 0.962, which represents a very good internal consistency.

4.2.4 Mean ranking. The mean rank reveals the top ten most important information items required by FM teams, as ranked by respondents, shown in bold in Table II. These are: *Asset name* and *Asset location* followed by *Systems and associated sub-systems*, *Periodic preventive maintenance*, *Warranties and Guarantee information*, *Service contracts*, *Asset type*, *Asset category*, *Legislative compliance requirements* and *Asset identification number*. It is not surprising that the top ten requirements are related to asset and maintenance management activities, which are a major concern for FM teams to maintain and sustain the facility and its systems to assure that the facility will perform its intended function.

4.2.5 Exploratory factor analysis. Factor analysis is a statistical method normally used to reduce the number of variables by identifying the underlying dimensions and replacing them with manageable groups of a set of variables, which are recognised as factors or latent variables (Field, 2005; Howitt and Cramer, 2011). However, according to Lu *et al.* (2016), the method of reduction of various factors according to their rank is not 'clean and concise'. Thus, because the mean ranking conducted in the previous sub-section may have led to overlooking important variables, the analysis alone was not considered to be sufficient for understanding the required information for FM systems. In this study, Exploratory Factor Analysis (EFA) was adopted using the Principal Components Analysis (PCA) method and Varimax rotation for the 41 identified variables. According to Field (2005), factors with loadings greater than 0.4 can be considered for the purpose of data interpretation. However, it is not necessary to consider each variable meeting this criterion in the factor analysis (Howitt and Cramer, 2011).

The Kaiser–Meyer–Olkin (KMO) test is used to establish whether the collected data is suitable for factor analysis. KMO values range between zero and one; values greater than 0.8 and close to the maximum value (1) indicate the sampling is adequate, while values below 0.6 indicate the sampling is not adequate for factor analysis. In this study, the KMO value was 0.892, which is greater than 0.60 and close to the maximum value (1), which indicates the suitability and adequacy of the data to be further analysed using factor analysis. Accordingly, the EFA was conducted and, based on the results, the 41 variables were grouped initially in seven groups, with eigenvalues greater than one, accounting for 78.021 per cent of the total variance. Factors' communalities ranged between 0.72 and 0.93, which was more than the desirable value of 0.7 for retaining as many variables as possible (Field, 2005). The results showed that group 7 included three variables which were in common with those in group 1. These three variables were more relevant to group 1, so, accordingly, group 7 was eliminated. In addition, group 6 included four variables; three of these (tag number, serial number and bar code number) were merged into one variable, *Asset identification*, and added along with the other variable, *Consumables*, to group 5, since they are most likely to be relevant to that group. It can be seen in Table II that the final results after reorganising the duplicated variables were grouped and labelled in five categories, based on the relation between variables within the same group.

Code	Groups of variables	Factor loading	Cronbach's alpha (α)	Rank	COBie
Group I: Facility general Information			*0.934*		
V2	Asset specifications	0.679		18	Type
V7	Construction documentation link	0.754		28	Documents
V19	Nominal width, height and length	0.705		33	Type
V24	Accessibility performance	0.792		32	Type
V28	Installation date	0.809		23	Component
V32	Floor elevation	0.850		29	Floor
V33	Floor height	0.880		31	Floor
V40	Replacement cost	0.545		24	Type
V41	Purchase information	0.614		31	Contact
Group II: Energy management			*0.936*		
V8	Calibration information	0.884		24	Document
V9	Standard operating producers	0.859		26	Document
V17	Occupancy ratio	0.864		25	Attribute
V18	Expected life	0.691		20	Type
V20	Operating status threshold	0.857		26	Issue
V25	Design parameters	0.478		22	Attribute
V26	Code performance	0.515		30	Type
V27	Sustainability performance	0.761		27	Type
Group III: Maintenance management			*0.896*		
V1	*Periodic preventive maintenance*	*0.871*		*4*	Job
V3	Spare parts list	0.899		11	Spare
V4	*Warranties and guarantee info*	*0.918*		*5*	Type
V5	Manufacturer information	0.423		17	Type
V6	O&M manual link	0.688		16	Document
V10	*Service contracts*	*0.694*		*6*	Contact
V11	*Systems and associated sub-systems*	*0.734*		*3*	System
V16	*Legislative compliance req.*	*0.668*		*9*	Job
Group IV: Space management			*0.877*		
V31	Floor names	0.673		13	Floor
V34	Room (space) names and function	0.729		14	Space
V35	Room (space) tags	0.761		15	Space
V36	Room (space) location	0.789		12	Space
V37	Room (space) areas	0.439		21	Space
V38	Zone names and associated spaces	0.662		15	Zone
V39	Zone classifications	0.678		19	Zone
Group V: Asset management			*0.891*		
V12	*Asset name*	*0.804*		*1*	Type
V13	*Asset category*	*0.773*		*8*	Type
V14	*Asset type*	*0.846*		*7*	Type
V15	*Asset location*	*0.582*		*2*	Component
V30	Facility name and classification	0.647		17	Facility
V21	*Asset identification*	*0.782*		*10*	Component
V29	Consumables	0.467		16	Spare

The categorised groups are:

- Group I: Facility general information.
- Group II: Energy management information.
- Group III: Maintenance management information.

- Group IV: Space management information.
- Group V: Asset management information.

Finally, the reliability test, Cronbach's alpha (α), was applied to check and confirm the factor analysis results (Cortina, 1993), where a Cronbach's alpha value greater than 0.70 indicates the group is considered to be consistent and reliable (Field, 2005). In this study, the Cronbach's alpha (α) reliability test was conducted again to provide more evidence that each set of the grouped variables is a unique group. Table I shows that the Cronbach's coefficient (α) value for each group was more than 0.70 (with the lowest value 0.877) for the space management information group, which indicates a very good reliability and supports the EFA results for the proposed groups.

4.3 Stage III: developing an information identification and exchange process using an open data format
Identifying and formalising the information required by FM teams is an essential step for efficient facility operations. The results of this study showed that currently, in most FM practice, data is entered manually into FM systems. Although FM teams spend considerable time and effort entering facility data into their FM systems, this data is considered to be only somewhat accurate. However, to reduce the O&M costs there is a need to provide FM teams with accurate and available data.

In order for BIM to support FM activities and operations as an information conduit and repository, information requirements should be identified at an early stage, to facilitate a seamless data exchange between BIM and FM systems. This study has identified the required information for FM systems as viewed by FM practitioners. The results of the study have shown that FM practitioners are mostly concerned with maintaining and sustaining their facilities, as the top ten required information items were related to maintenance and asset management, as illustrated in Table II.

Comparing the categorised information requirements identified in this study with the COBie spreadsheet data, it can be seen in Table II that most of the identified information requirements can be provided by the COBie format. COBie is generally used to transfer all non-geometric information about the facility throughout the lifecycle in a structured way; this commonly results in producing a huge amount of unnecessary information that is collected from various sources during the project lifecycle, which makes COBie unmanageable and cumbersome to FM teams (Anderson *et al.*, 2012; Farghaly *et al.*, 2018). To avoid this, only the identified information requirements shown in Table II were considered to be included in the COBie spreadsheet.

Starting with COBie specifications at the project planning stage will support owners and FM teams in identifying their information requirements to support FM systems at an early stage. The COBie spread sheet can then be used as a quality check-list to ensure that the owner's/FM team's requirements are included in every phase of the project's lifecycle, through which a rich database can be created and handed over successfully to the FM team. Moreover, the COBie spread sheet can facilitate a seamless information exchange between the BIM and FM systems as an open data format. Figure 2 illustrates the proposed process to identify the owner's/facilities manager's requirements at an early stage and to verify that the identified requirements were considered during the project lifecycle to ensure a successful handover of facility information that meets the FM system's requirements and a seamless information exchange between the BIM and FM systems.
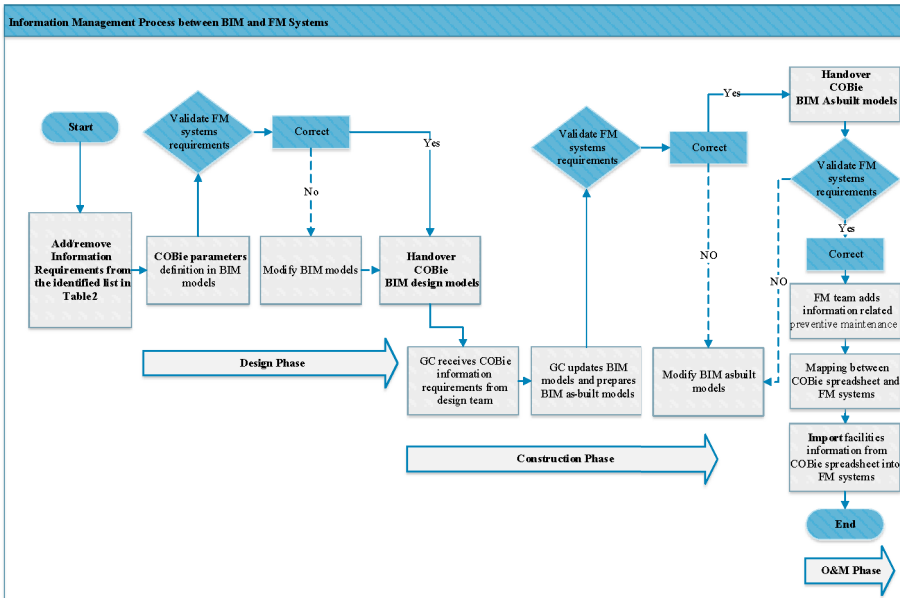
Figure 2.
Overall process
supporting data
acquisition, update
and exchange, using
COBie spread sheet

The proposed process consists of four steps, as detailed below:

- Owners and FM teams verify the identified information requirements in Table II to add or remove information requirements to support their FM systems. Owners and FM teams then submit their final information requirements to the design team as a COBie-compliant Excel file.

- The design team considers carefully the owner's/FM teams' information requirements within their design models. Owners and FM teams in conjunction with design teams check if the pre-identified information requirements have been considered at the completion of the design phase. The design team will then handover BIM design models, along with the COBie spread sheet – compliant to FM systems' requirements – to the construction team.

- The construction team develop further COBie-compliant BIM models and ensure that the pre-identified FM systems' information requirements were developed and included in the BIM as-built models. The construction team will then deliver the COBie spread sheet, along with the BIM as-built models at project handover to owners and FM teams.

- The owner/FM teams verify the submitted COBie spread sheet to ensure that all their pre-identified requirements have been included, and then add to the same COBie spread sheet all required information related to preventive maintenance schedules.

- Finally, the owner/FM teams map between the COBie parameters and FM system software parameters to import the required data outputs into their FM systems, using the open data standard COBie.

Identifying specific parameters reduces the redundant effort made and time taken to sort, manage and extract specific parameters of the COBie spread sheet to support FM systems; however, in most cases these parameters are not available, as they were not considered during the project's design and construction phases. The proposed process presents a practical method of utilising a COBie spreadsheet to generate specific information requirements that meet the needs of FM systems. The proposed process agrees with the concept of the COBie compliance process in PAS 1192-4: however, instead of focussing on the information provider and receiver, as illustrated in PAS 1192-4, the proposed process details the information management process of specific information requirements during the project lifecycle, using the open standard specification COBie.

5. Conclusion and future work

This study aimed to address the challenges faced by FM practitioners in information management. The overall study objective was to identify a generic set of information requirements of BIM to support FM systems, which can be used as the base for developing an automated information exchange process. Information items were collected and identified through the literature review of similar studies, existing standards, and best practices. The qualitative analysis found 45 information items that are required to construct BIM models to support FM practice. These findings of the first stage were organised in a questionnaire survey which included 41 information items, after excluding four items which were considered unimportant for FM systems, according to the interviewee's feedback in the pilot study.

The quantitative findings of the questionnaire survey identified 39 information items (after merging three factors into one) and these were grouped into five groups, namely:

(1) facility general information;
(2) maintenance management information;
(3) energy management information;
(4) space management information; and
(5) asset management information.

Among the 39 information items, the top ten most important items, as ranked by respondents were all related to maintenance and asset management groups. This is because FM practitioners view maintenance as a priority to ensure maximum utilisation of both facility and equipment assets.

The study also developed the proposed process of data identification and exchange using an open standard format such as COBie to develop facility information requirements at an early stage, to check for compliance to these requirements and, finally, to transfer the identified specific information requirements into FM systems. The proposed process is different from the current information exchange process, in that it suggests capturing information and retrieving specific requirements which are needed as an output for subsequent input into FM systems. This will reduce the redundant efforts of sorting and organising the COBie spread sheet to extract the required output to support FM input.

The contribution of this study is the identification of a generic set of information requirements for FM systems, which should be included in BIM as-built models for efficient facility operations and maintenance. The study findings provide the basis of

the integration of BIM with FM systems. Such integration will enable automated data exchange between BIM and FM systems, which will support efficient operations and reduce O&M costs. The study findings also provide the key data exchange requirements to support and complement the existing standards and formats, such as COBie. The study's findings also lay the foundation for future research studies on using the identified set of information to automate a seamless data exchange process between BIM and FM systems.

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