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# BIM for CREM: Exploring the Benefit of Building Information Modelling for Facility Management in Corporate Real Estate Management

**Maximilian Benn * and Christian Stoy**

Institute for Construction Economics, University of Stuttgart, Keplerstraße 11, 70174 Stuttgart, Germany; info@bauoek.uni-stuttgart.de
* Correspondence: maximilian.benn@bauoek.uni-stuttgart.de

**Abstract:** The implementation of BIM in FM has been of steadily growing interest for academic research. Yet the benefits of BIM for the FM in CREM have, to the present day, been explored to a limited extent. As research on BIM for FM in CREM remains narrowly investigated, this study follows an exploratory approach to formulate implications for further research directions. Therefore, a four-stage procedure was adopted: (1) identification and definition of BIM uses for FM in CREM; (2) validation of the BIM uses for FM in CREM and the expert survey questionnaire; (3) assessment of each BIM use's benefit by experts; and (4) analysis of the correlations between BIM uses' benefit assessments and the respondents' industries, the resulting associations, and the prioritisation for the development of BIM uses for FM in CREM. Based on that methodology, it was shown that the BIM use for FM in CREM with the highest priority for development is 46 Facilities and Equipment: Repair and Renewal. The BIM use with the lowest priority is 21 Visualisation. As a result, four implications on the development of BIM uses for FM in CREM were formulated regarding case studies, information requirements, and technical requirements, as well as process and personnel requirements.

**Keywords:** building information modelling (BIM); corporate real estate management (CREM); facility management (FM); BIM use; benefit; industry; expert survey; exploratory approach

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## 1. Introduction

Digitisation in the construction sector remains delayed compared to most other industries, even though it has been accelerated considerably by the advent of technologies such as the internet of things (IoT), 3D scanning, distributed ledger technologies (DLT), and—arguably most prominent—building information modelling (BIM) [1–4]. Accordingly, actors such as the EU BIM Task Group identified the implementation of BIM as "the construction sector's moment of digitisation" for all building life cycle phases [5] (p. 8). Among the beneficial implications of BIM implementation, direct or indirect financial benefits are among the most frequently mentioned. Estimations regarding the cost-saving potential through BIM are assessed between 8% and 23%, depending on the buildings' life cycle phase [6].

Concerning a building's life cycle cost, it is widely acknowledged that the cost accumulating during the operational phase greatly exceeds the cost of the design and construction phase combined. Nevertheless, estimations vary regarding the operational phase's precise percentage of the overall life cycle cost. This may extend from 60% [7] to 80% [8] and even up to 85% [9] of a building's total life cycle cost accumulating during the operational phase. Given the impact of a building's operational phase on its life cycle cost, potential cost savings by implementing BIM in that life cycle phase are expected to be considerable. Therefore the implementation of BIM in facility management (FM) has been of steadily growing interest for academic research [10].

However, the benefits of BIM for the FM in corporate real estate management (CREM)—i.e., the management of real estate that is related directly to an organisation's core business [11,12]—have, to the present day, been explored to a rather limited extent [13]. Corporate real estate can be defined as "all forms of properties that corporates need for the execution of their core business, including administrative buildings, social buildings, training centres, research and application technology buildings, agricultural buildings such as greenhouses, etc." [11] (p. 6).

In a prototypical case study, Gerbert et al. [6] evaluated the impact of BIM implementation on the life cycle cost of different building types. Results showed that of all buildings compared, the highest cost-saving potential of 14% to 23% was identified within the group of commercial and institutional buildings. These findings support the assumption that BIM offers great benefit for FM in CREM, as real estate operation often presents one of the biggest cost blocks for companies [11]. Nonetheless, BIM implementation in this specific context progresses unevenly. Of the many obstacles encountered, one that has been identified repeatedly lies within the identification of FM processes and corresponding BIM uses for implementation [14–16]. A second one lies within the subsequent implementation due to a lack of guides and standardisation documents for specific BIM uses, posing a challenge to many FM professionals [10,14]. Within this context, related research furthermore suggests that different industries might have different implementation priorities based on benefit assessments of specific BIM uses for FM in CREM [16,17].

In order to accelerate the implementation of BIM for FM in CREM, high-priority BIM uses for FM in CREM providing a high benefit for all industries must be identified. This allows the identification of further research directions regarding the development of guides and templates for high-priority BIM uses for FM in CREM.

Consequently, this study focuses on the benefit assessments of BIM uses for FM in CREM and their association with industries. In order to outline this study's objectives, four questions have been formulated:

1. RQ 1: Which BIM uses supporting FM processes in CREM can be identified?
2. RQ 2: How do experts assess the benefit of BIM uses for FM in CREM?
3. RQ 3: How strong are the associations between each BIM use's benefit assessment and the respondents' industries?
4. RQ 4: What prioritisation for the development of BIM uses for FM in CREM can be derived from the BIM uses' benefit assessments and their association with industries?

Regarding RQ 2, related studies by Becerik-Gerber et al. [18] and McArthur and Sun [19] investigated the benefit of selected BIM uses. Since both studies focus on the complete life cycle within a heavily public real-estate-related context, no prior hypothesis could be deduced from them. Regarding RQ 3, no prior hypothesis has been proposed as related research indicating such associations is still too limited to allow substantiated assumptions—notably by Munir et al. [17] and Cavka et al. [16]. Given the limited amount of prior related research, this study consequently follows an exploratory approach to distinguish implications and further research directions [20,21].

## 2. Methodology

To investigate BIM for FM in CREM and deduce implications as well as further research directions, this study follows an exploratory approach. Exploratory approaches are applied to fields with little or no prior body of knowledge or theories [20,21]. Thus, a four-stage mixed-methods procedure was adopted, as shown in Figure 1: (1) identification and definition of BIM uses for FM in CREM; (2) validation of the identified BIM uses for FM in CREM and the expert survey questionnaire; (3) assessment of each BIM use's benefit by experts; and (4) analysis of the correlations between BIM uses' benefit assessments and the respondent's industries, the resulting associations, and the conclusive prioritisation for the development of BIM uses for FM in CREM. Each stage conducted during this study is further elaborated in the following paragraphs of this section.

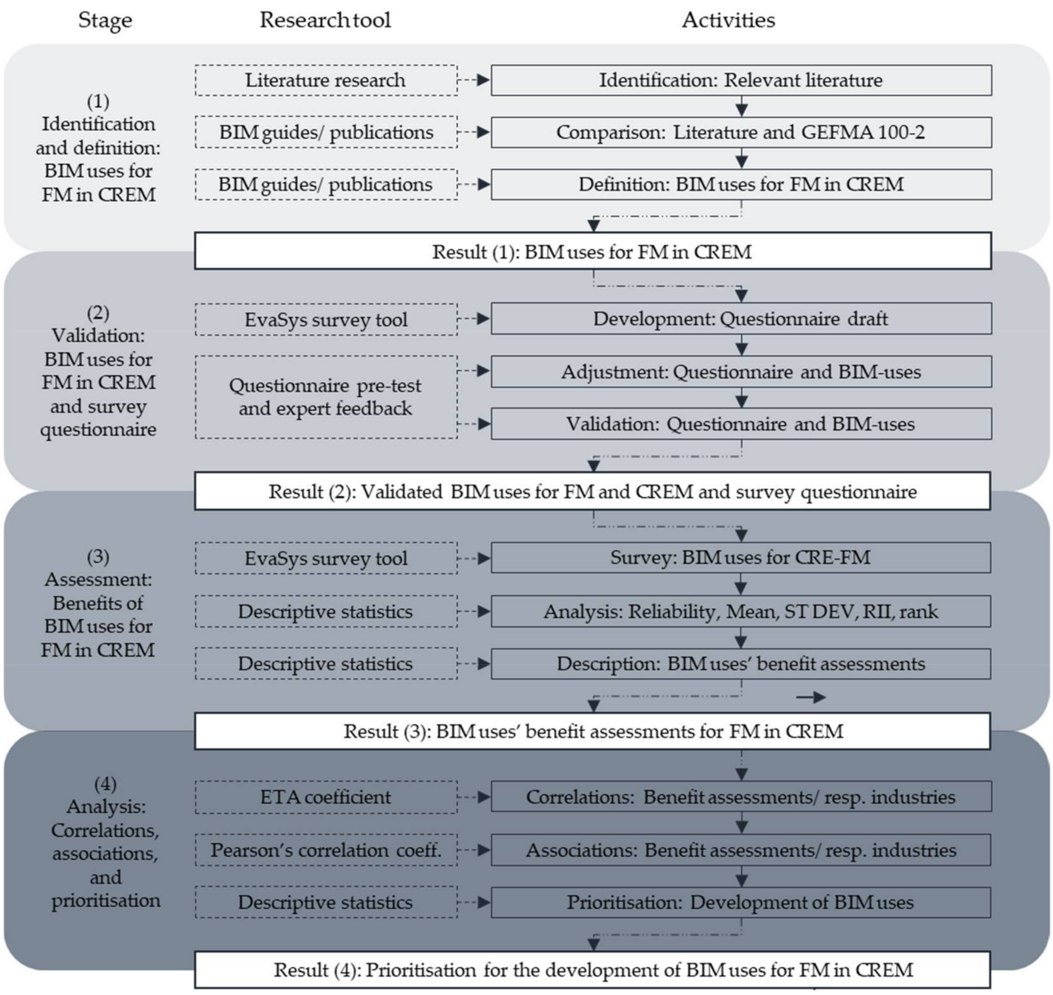


**Figure 1.** Research methodology.

Stage (1) aims at identifying literature for creating a baseline catalogue of BIM uses supporting FM processes in CREM. To do so, three steps were conducted during this stage. Initially, the determination of sources was accomplished through systematic literature research and analysis of reports on international BIM maturity to identify leading nations in BIM implementation. The literature research aimed at identifying BIM guides provided and published by state organisations or NGOs that outline terminology and BIM uses that are already established, thus known by experts. The keywords included: BIM; Building Information Modelling; BIM guide; BIM guideline; BIM standard; BIM use; BIM use case. The databases for literature research included: Web of Science, Google Scholar, and Engineering Village. In terms of internationally leading countries with high BIM maturity levels, the UK, Singapore, China, Hong Kong, Finland, Norway, and the United States were identified [22]. On a European level, the Netherlands, Spain, France, and Germany are also rapidly accelerating their BIM implementation efforts [23]. A total of 14 international BIM guides were identified and used as a source for BIM uses in FM. Subsequently, the BIM guides identified were systematically analysed and matched with the list of FM processes provided by the German Facility Management Association e.V. [24] in their GEFMA 100-2 guideline. This guideline contains a comprehensive list of categorised FM main processes and corresponding FM processes developed by an expert committee, making it a reliable reference structure. Comparative analysis of the 14 international BIM guides with GEFMA 100-2 resulted in the first list of 34 BIM uses for FM as a base for further elaboration. To define the BIM uses specifically for FM in CREM, a second literature analysis addressing this specific context was conducted [11,25].

The second literature review aimed at the identification of scientific publications on BIM in a CREM context. The keywords included: BIM; Building Information Modelling; BIM use; BIM use case; Facility Management (FM); Operations; Maintenance; O&M; Corporate Real Estate (CRE). The databases for literature research included: Web of Science, Google Scholar, and Engineering Village. A comparative analysis of the guides used in the first stage as well as the scientific publications identified in the second stage allowed the development of specific definitions of BIM uses supporting FM processes in CREM. The result of the comparative analysis is shown in Table A1.

Stage (2) comprises the expert validation of the BIM uses for FM in CREM as well as the validation of the survey questionnaire. Preparatory expert validation was conducted during a pretest involving FM experts in CREM with BIM experience. Therefore, the list of BIM uses for FM in CREM from stage (1) and a draft of the survey questionnaire were prepared for validation. The pretest then allowed the validation of both the list of BIM uses and the survey questionnaire. Participants were explicitly informed of the pretest status, encouraging a critical view of the questionnaire to improve feedback [26]. Based on the pretest feedback, the questionnaire's processing time could be asserted and one further BIM use was added: 63 Cleaning Management: Outdoor Facilities Cleaning. As a result, stage (2) provided a validated expert survey questionnaire comprising a comprehensive list of BIM uses for FM in CREM, answering this study's RQ 1.

Stage (3) consists of an initial online survey targeting experts for FM in CREM with prior BIM experience. The pool of possible participants was assumed to be rather limited due to the prerequisite of having experience in the fields of CREM and BIM. Hence, a cross-section online survey was chosen for data collection to reach a larger number of potential participants [27]. Questionnaire distribution by the Austrian IFMA Austria, the German RealFM e.V., and the Swiss SVIT FM Schweiz ensured that purposive sampling was restricted to the predefined target group of experts for FM in CREM with BIM experience [27]. Starting the questionnaire, participants were asked to (1) confirm that they have understood the prerequisites for participating in the study regarding FM and BIM experience, (2) state their position in the organisation they work for, and (3) state their own or their customers' industry, following the SNA/ISIC intermediate aggregation A 38 of economic activities by the European Commission [28]. Question (1) actively reminds the respondents of the requirements to ensure purposive sampling. Question (2) considers the participants' point-of-view from an operational, tactic, or strategical level. Question (3) ensures that only data from experts with experience in CREM are included in the analysis. Eventually, all participants were asked to assess each BIM use's benefit on a 5-point scale from (1—very low benefit) to (5—very high benefit). Concerning terminology, the term "benefit" was selected due to its utilisation for the evaluation of positive effects of BIM in FM in several related publications [3,29], notably [19]. The results' internal consistency was measured by determining Cronbach's alpha [30]. The subsequent analysis of valid responses was performed conducting data description and analysis techniques.

Stage (4) aimed at answering RQ 3 and 4 by further analysing the results from stage (3). The measurement of correlations was conducted by calculating each BIM use's ETA coefficient depending on the respondents' industries. As a result of the calculated ETA coefficients, the association between each BIM use's benefit assessment and the respondents' industries could be determined by applying Pearson's correlation coefficient [31]. Conclusively, each BIM use's benefit assessment and their association with the respondents' industries were used to derive a prioritisation for the development of BIM uses for FM in CREM to answer RQ 4.

## 3. Scientific Background

### *3.1. CREM*

Concerning the precise definition and delimitation of CREM, the term corporate real estate (CRE) requires a prior definition. Heywood and Kenley [12] describe two possible definitions: either including all real estate owned by a company—core-business-related or not core-business-related—or only including real estate being related directly to the core business of a company, provided that the core business is not real estate. As Heywood and Kenley [12] favour the latter definition, Glatte [11] equally defines CRE as core-business-related, “including all forms of properties that corporates need for the execution of their core business, including administrative buildings, social buildings, training centres, research and application technology buildings, agricultural buildings such as greenhouses, etc.” [11] (p. 6). Predominant building types in CRE are buildings for offices, storage, production, and/or retail, depending on the company’s industry [8,32]. In this context of direct relation to a company’s core business, aligning CREM objectives with a company’s strategic goals can contribute greatly to its success. This can be achieved in multiple ways, including “property management, handling facilities, reducing operating cost, and many other contributions [ . . . ]” [33] (p. 61). According to Glatte [11], CREM, therefore, includes the aspects of asset management, property management, and building management of FM, whereas infrastructural facility services of FM stand apart, as shown in Figure 2.


**Figure 2.** Disciplines of corporate real estate management and infrasturctural facility services.

### 3.2. CREM and FM

The exact relationship between CREM and FM gives rise to discussions within the community of FM and CREM experts [34,35]. van der Voordt [34] affirms that FM and CREM do share similarities regarding conferences and organisations and that both align to corporate strategies. Concerning disparities, van der Voordt [34] distinguishes two main differences between FM and CREM: (1) FM focuses on non-core business services and their management whereas CREM focuses on the integration of management disciplines and cost control; and (2) CREM focuses on real estate as an asset used for its purpose, whereas FM is service-oriented and therefore focuses on demands related to space, infrastructure, people, and organisations.

Nonetheless, van der Voordt [34] observes a clear convergence between CREM and FM and an ever-increasing integration and alignment of both. This raises the question of future terminology, as shown in Figure 3.

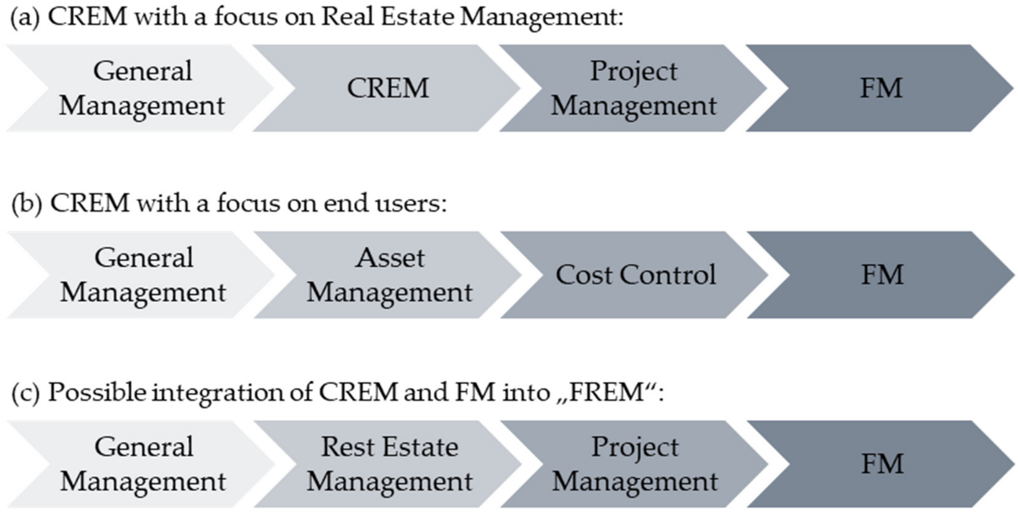


**Figure 3.** (**a**) CREM with a focus on real estate management; (**b**) CREM with a focus on end users; (**c**) Possible integration of FM and CREM into FREM (according to van der Voordt [34]).

As the question of the exact relationship of CREM and FM remains disputed and the question of the terminology itself provides ample material for discussion, this publication cannot give terminology describing the relationship of CREM and FM conclusively. Instead, the term "FM in CREM" is applied to describe all aspects of asset, property, and building management and those of infrastructural facility services, constituting FM in CREM.

### *3.3. BIM for FM*

ISO 41011:2017 defines FM as an "organizational function which integrates people, place and process within the built environment to improve the quality of life of people and the productivity of the core business" [36] (p. 1).

Previous studies have shown that FM can benefit in several ways from the implementation of BIM: gains in efficiency due to automatic generation of geometric information for FM [37], advanced decision-making and data management [38], optimised communication and coordination of FM processes [15], enhanced collaboration [39], improved building performance [40], and enhanced levels of competitiveness [41] are some examples. Even though research on BIM implementation in FM has intensified recently, its application in the FM industry remains rather limited compared to design and construction [10,25,42,43]. In this context, the identification of FM processes and corresponding BIM uses for implementation constitutes a major obstacle hampering BIM implementation in FM [14–16].

BIM uses can be defined as "a method or strategy of applying Building Information Modelling during a facility's lifecycle to achieve one or more specific objectives" [44] (p. 5). The achievement of these specific objectives through BIM uses is a core concept of BIM implementation. In the case of FM, these specific objectives often describe generating a benefit for FM processes through information stored in or extracted from a BIM [16,45].

Due to the BIM workflow concentrating efforts in earlier planning phases, the identification of BIM uses shifts to earlier project phases accordingly, as shown in Figure 4. Therefore, BIM uses need to be identified in early project phases, beginning with the end in mind [46]. Since FM has highly accurate and specific information requirements, early identification of beneficial BIM uses is essential for information collection and delivery to effectively implement identified BIM uses [37,45,47–49].

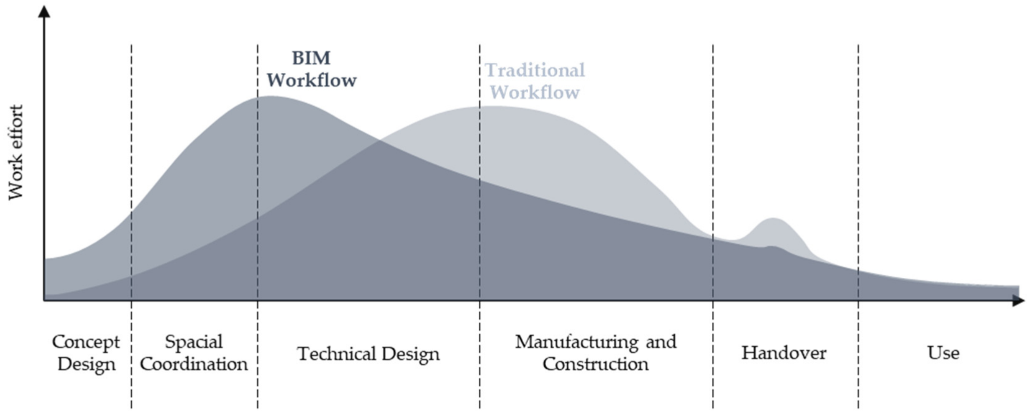


**Figure 4.** Effort distribution on the life cycle phases in the traditional workflow compared to the BIM workflow [50].

As many FM professionals still struggle with adopting BIM for FM in general, the initial identification of BIM uses based on supported FM processes poses an additional challenge to many [15,49,51]. Alshorafa and Ergen [14] point out that "there is no guidance to determine what information should be included in a BIM model for different BIM uses" [14] (p. 564). Correspondingly, Miettinen et al. [52] identified insecurity about BIM benefits and applications in FM as one of the biggest concerns for professionals. To tackle these barriers to BIM implementation in FM, Edirisinghe et al. [10] conclude that further research is required concerning the development of specific BIM applications for FM. Recently, the German standardisation organisation DIN correspondingly proposed the analysis of BIM uses to lay the ground for standardisation and template development [53].

### *3.4. BIM for FM in CREM*

CREM portfolios are often large and diverse, comprising a variety of sometimes highly complex buildings [25]. Hence, FM in CREM represents a particularly intriguing field of BIM application with a variety of potential applications. It is essential to determine which information for which FM processes is relevant for CREM to efficiently operate buildings, as data and information management itself can be a considerable cost factor [13]. The definition of BIM uses should therefore be conducted carefully and in direct correspondence to objectives and FM processes.

Research also suggests that organisation types are a factor influencing the identification of beneficial BIM uses for FM in CREM. In their 2020 study, Munir et al. [17] analysed and compared the type and nature of information needs of different organisation types. The authors concluded that there is a strong relationship between an organisation's industry and the FM processes it wants to support with BIM, based on its objectives and asset management strategy. Cavka et al. [16] made a similar observation when investigating the BIM information requirements of large owner organisations. They found that requirements vary considerably between organisations from different industries, as BIM-supported FM processes vary. Based on Munir et al. [17] and Cavka et al. [16], it can therefore be assumed that different industries assess the benefit of specific BIM uses for FM in CREM differently.

## 4. Research Background

### *4.1. Related Studies: BIM in FM*

In recent years, research on BIM uses for FM has intensified considerably [54]. Several studies concerning their identification and definition in different contexts have been published. However, the focus often lies on the information requirements themselves. Without a link to specific FM processes within a specific context, BIM use identification may only be conducted during project execution, jeopardising the principles of "beginning with the end in mind" [46]. Table 1 shows related studies that have been analysed for the identification of BIM uses for FM.

**Table 1.** Related studies investigating BIM uses for FM.

| Authors | Year | Approach |
|---|---|---|
| Becerik-Gerber et al. [18] | 2012 | Potential FM application areas that BIM can be used for, mainly within the context of PRE |
| McArthur and Sun [19] | 2015 | Analysis and prioritisation of BIM uses in public-private partnerships in different industries |
| Mayo and Issa [55] | 2016 | Examination of BIM use information requirements based on categories within the context of PRE |
| Cavka et al. [16] | 2017 | Definition of owner information requirements based on O&M functions within the context of PRE |
| Miettinen et al. [52] | 2018 | Analysis of the current state of implementation of BIM for FM within the context of PRE |
| Alshorafa and Ergen [14] | 2020 | Definition of specific IR and their LOD, depending on BIM uses for FM identified during an expert survey |

### *4.2. Related Studies: BIM Uses for CREM*

Even though research on BIM in FM has been growing steadily, studies focusing on its implementation in the context of CREM are rare. Within the studies identified, two approaches could be determined. The first one started with the information that can be stored in a BIM and investigated which information might be potentially beneficial to CREM professionals or processes [56]. The second approach identified CREM processes initially and, based on that, looked for potential benefits through BIM and useful information [25]. Table 2 shows related studies analysed for the identification of BIM uses for CREM.

**Table 2.** Related studies investigating BIM uses for CREM.

| Authors | Year | Approach |
|---|---|---|
| Lazar and McArthur [56] | 2016 | Case study demonstration of BIM data visualisation benefits within the context of CRE |
| Carbonari et al. [25] | 2018 | Analysis of possible BIM application areas for operations within the context of CRE |

## 5. BIM Uses for FM in CREM

As described in Section 2, the list of FM processes provided by the German Facility Management Association e.V. [24] in the GEFMA 100-2 guideline constitutes the baseline for identifying BIM uses for FM in CREM. It defines nine FM main processes and their corresponding FM processes for the operational phase. Eight out of nine FM main processes and their FM processes are included in this study. FM main process number nine was excluded as it covers refurbishment projects during the operational phase, making it construction-related. For clarity, BIM uses were clustered based on the GEFMA 100-2 FM main processes, as shown in Table 3.

Based on Table 3, a total of 35 distinct BIM uses for FM in CREM could be identified, answering RQ 1.

**Table 3.** Identified BIM uses for FM in CREM.

| FM Main Process | No. | BIM Use |
|---|---|---|
| 1 Commissioning | 11 | Handover and Commissioning |
| | 12 | As-Built Modelling and Documentation |
| 2 Manage Operations | 21 | Visualisation |
| | 22 | Disaster Planning and Emergency Preparedness |
| | 23 | Wayfinding and Tracking |
| | 24 | Generate: 2D Plans and 3D Details |
| | 25 | FM Documentation: Management and Maintenance |
| | 26 | Ticket Management |
| | 27 | FM Quality Management |
| | 28 | FM Sustainability and Environmental Protection |
| 3 Provide Workplaces | 31 | Space and Room Management |
| | 32 | Relocation Management |
| | 33 | Equipment and Furnishing |
| 4 Operations | 41 | BIM 2 Field |
| | 42 | Structural Health Monitoring |
| | 43 | Facility Identification System |
| | 44 | Facilities and Equipment: Periodic Inspections |
| | 45 | Facilities and Equipment: Inspection and Maintenance |
| | 46 | Facilities and Equipment: Repair and Renewal |
| 5 Supply and Disposal | 51 | Real-time Acquisition and Display of Sensor Data |
| | 52 | Energy Management |
| | 53 | Waste Management |
| 6 Cleaning and Maintaining | 61 | Cleaning Management: Maintenance Cleaning |
| | 62 | Cleaning management: Glass and Facade Cleaning |
| | 63 | Cleaning Management: Outdoor Facilities Cleaning |
| 7 Asset Management | 71 | Security Management |
| | 72 | Locking Management |
| | 73 | Rent Management |
| | 74 | Generate: Inventory, Component, and Equipment Lists |
| | 75 | FM Accounting and FM Controlling |
| | 76 | Perform Contract and Insurance Management |
| | 77 | Defect Management |
| 8 Provide Support | 81 | Room Booking and Occupancy Systems |
| | 82 | Event Planning |
| | 83 | Perform Procurement |

## 6. Online Survey

### *6.1. Questionnaire*

For the assessment of each BIM use's benefit and the investigation of potential correlations between benefit assessments and respondents' industries, an online expert survey was designed and distributed via German-speaking FM associations as described in Section 2. The questionnaire itself targeted the study's RQ 2–4. Experts were asked to state their industry based on the SNA/ISIC intermediate aggregation A 38 of economic activities by the European Commission [28] as well as their position before assessing the benefit of each BIM use from (1—very low benefit) to (5—very high benefit).

### *6.2. Survey Distribution*

The distribution of the finalised questionnaire was supported by three leading FM associations, as described in Section 2. To maximise the number of potential participants, each association distributed invitations to the survey by their respective newsletters. As the participants' experience within the fields of CREM and BIM was a prerequisite for receiving valid and meaningful results, the letter also explicitly stated that the survey addressed experts with experience in both fields.

### 6.3. Data Collection

After the survey distribution, the data collection lasted from September 2021 until January 2022. The rather extended data collection phase was due to different distribution dates of the online survey by each supporting association. During the data collection, a total of 38 responses from CREM experts were collected. One response had to be excluded due to implausible data, resulting in 37 responses included in the data description and analysis.

## 7. Data Description and Analysis

Regarding the respondents' demographic distribution, it was shown that the largest groups of respondents are those from the construction and human health services industries, followed by the chemicals and chemical products industry, as shown in Figure 5.


**Figure 5.** Distribution of respondents' industries ($n$ = 37).

Regarding the respondents' positions within their respective companies, 19% of the respondents have a position on the executive level, 57% on the management level, and 24% on the operational level, as shown in Figure 6. It can therefore be assumed that assessments collected during this survey mainly display the management perspective, i.e., the tactical perspective, on BIM in FM for CREM.

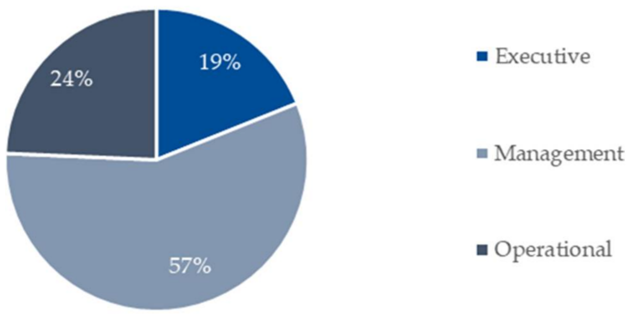


**Figure 6.** Distribution of respondents' positions ($n$ = 37).

The calculation of each BIM use's benefit assessment was conducted by determining their arithmetic mean (AM). Thirty-five items were included in the benefit assessment and the formula was applied accordingly. The arithmetic mean was calculated using the formula:

$$\widetilde{x} = \frac{1}{n} \times \left( \sum_{i=1}^{n} x_i \right)$$

With $\widetilde{x}$ = weight given to response, $n$ = number of items in the sample, and $\sum_{i=1}^{n} x_i$ = the sum of the sampled values, the arithmetic mean of each BIM use's benefit assessment was calculated based on the respondents' assessments. The arithmetic mean of each BIM use's benefit assessment is shown in Figure 7, answering RQ 2.

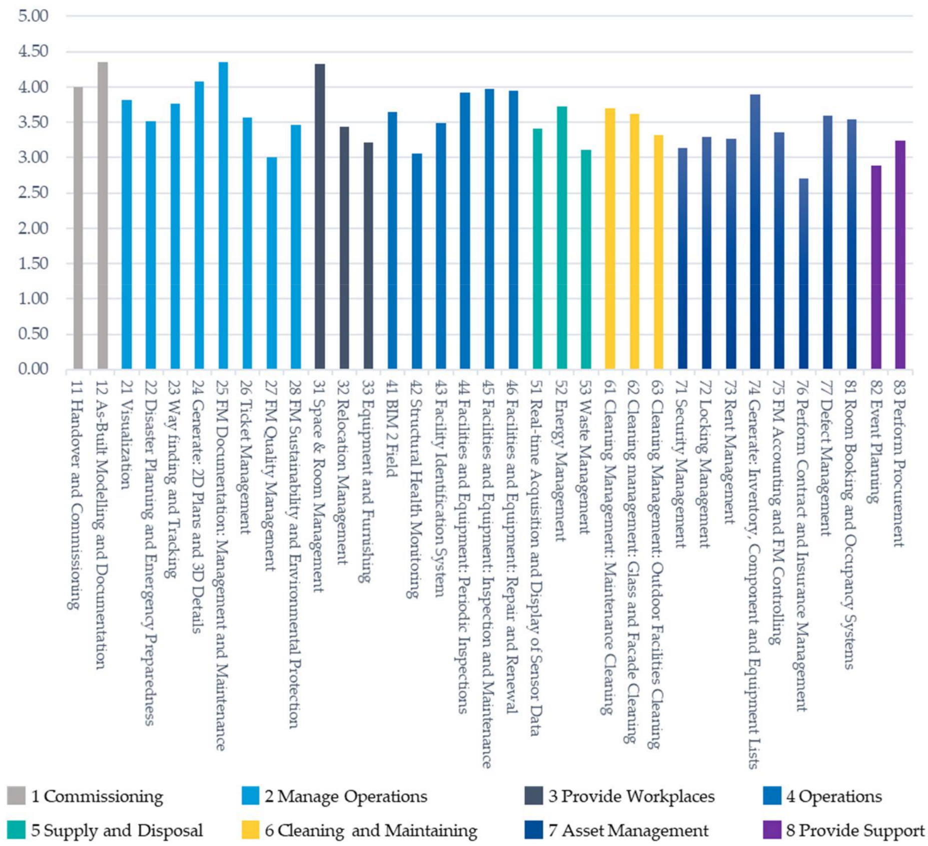


**Figure 7.** The arithmetic mean of BIM uses' benefit assessments from (1—Very Low Benefit) to (5—Very High Benefit) ($n$ = 38).

The internal consistency measurement of the constructs examined in the survey was performed by analysing Cronbach's alpha for each FM main process. The reliability for each FM main process was therefore calculated based on the BIM uses constituting them, meaning a total of 35 variables. When analysing Cronbach's alpha, values of $\alpha \geq 0.6$ per construct are acceptable for exploratory studies while $\alpha \geq 0.7$ is considered desirable, with the limitation that too high values of $\alpha \geq 0.9$ may indicate redundancies within the construct [20,57]. As Table A2 shows, the values for each main process range from $\alpha = 0.683$ to 0.932, indicating adequate interrelatedness of the BIM uses within each FM main process.

The determination of the association between each BIM use's benefit assessment and the respondents' industries was conducted by calculating their respective ETA coefficients. The ETA coefficient is a method to determine the correlation between an independent categorical variable (e.g., blood type, profession, hair colour) and a dependent scale variable (e.g., Likert, temperature, weight) [31].

For this study, the respondents' industries were captured as a categorical variable and each BIM use's benefit assessment as a scale variable. The calculation of the ETA coefficients was conducted using the formula:

$$\eta = \frac{\frac{1}{n-1} \times \sum_j^k \times n_j (\overline{y}_j - \overline{y})^2}{s_y^2}$$

With $n$ = number of items, $\overline{y}$ = mean value of the variable, and $s_y$ = variance of $\overline{y}$. Interpretation of the Pearson's correlation coefficient shown in Table 4 indicated the association between each BIM use's benefit assessment and the respondents' industries.

**Table 4.** Pearson's correlation coefficient for the interpretation of the ETA coefficient.

| Pearson's Correlation Coefficient | Interpretation |
|---|---|
| 0.00 | No association between the two variables |
| 0.01–0.19 | No or negligible association between the variables |
| 0.2–0.39 | A weak association between the variables |
| 0.4–0.69 | Medium association between the variables |
| 0.70–1.0 | Strong association between the variables |

Only questionnaires from industries with at least two responses could be included in the correlation analysis. Thus, $n = 33$ for the ETA coefficient calculation and subsequent association determination.

By interpreting Pearson's correlation coefficient presented in Table 4, the results shown in Figure 8 can be analysed to determine the association between each BIM use's benefit assessment and the respondents' industries. As described in Table 4, an ETA coefficient of $\geq$0.7 indicates a strong association, an ETA coefficient of 0.4–0.69 indicates a medium association, and an ETA coefficient of 0.2–0.39 indicates a weak association between the variables. Thus, a low ETA coefficient suggesting that a BIM use's benefit assessment only has a weak association with specific industries is desirable in this context.

The interpretation of the results shown in Figure 8 thus answer RQ 3. Particularly strong associations can be identified for the BIM uses 11 Handover and Commissioning; 21 Visualisation; 25 FM Documentation: Management and Maintenance; and 31 Space and Room Management.

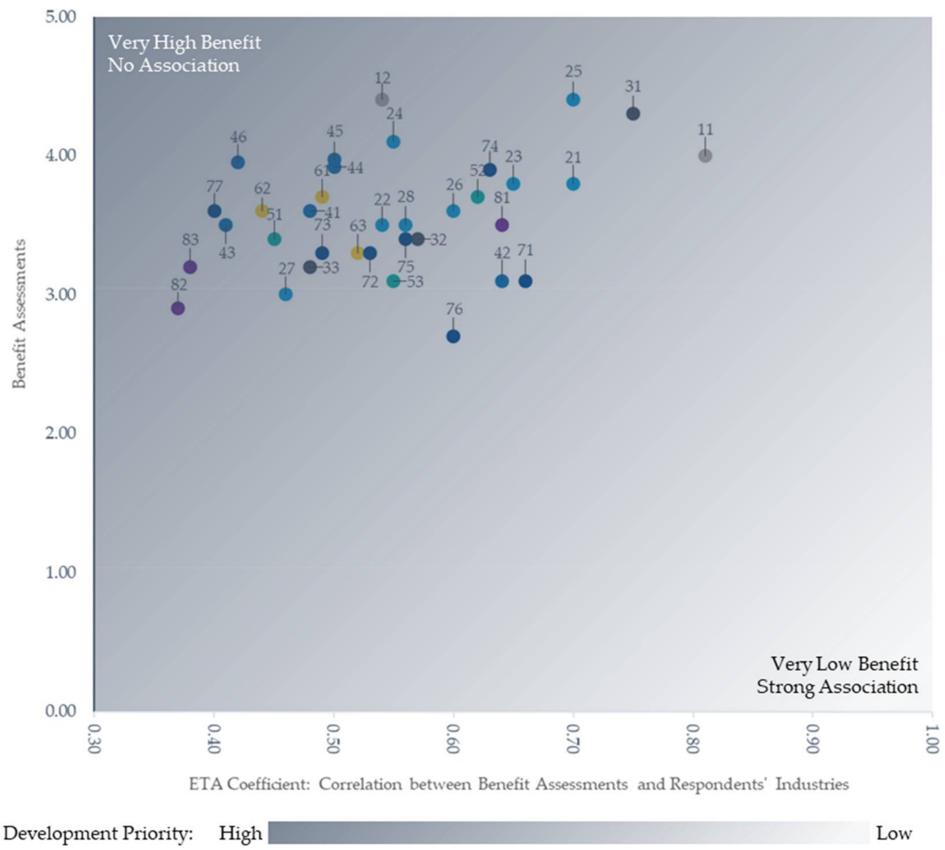


**Figure 8.** BIM uses' benefit assessments and their respective correlation to the respondents' industries as ETA coefficient ($n = 33$).

The BIM uses' benefit assessments in connection with the determination of their respective associations with the respondents' industries also allow one to derive a prioritisation for the development of BIM uses for FM in CREM. Given the measured differences regarding the BIM uses' benefit assessments as well as the strength of their respective association, it can be assumed that some BIM uses are of high or very high benefit for FM in CREM in general, regardless of the specific industry. This assumption is based on the observation that those BIM uses' benefit assessments show only medium to weak associations with the respondents' industries. Consequently, it can also be assumed that some BIM uses are of high to very high benefit for FM in CREM but that their benefit assessments are highly associated with the respondents' industries, questioning their benefit for CREM in general.

Following these assumptions, prioritisation for the development of those BIM uses can be derived, answering this study's RQ 4. Due to their assumed benefit for FM in CREM regardless of the specific industry, BIM uses with a weak to medium association with the respondents' industries are by default considered to be of higher priority than BIM uses with strong associations with the respondents' industries, as shown in Figure 9.

The prioritisation for the development of BIM uses for FM in CREM has been conducted based on their respective benefit assessments and ETA coefficients. Since the benefit assessments and the ETA coefficients are not directly comparable, the weighted product model was chosen for determining each BIM use's score. The weighted product model can be applied in multi-criteria analysis to determine the value of non-comparable units, as it is dimensionless. This means it eliminates units and can be applied to relative values instead of actual ones, making it a more suitable choice than the weighted sum model [58,59]. Each BIM use's weighted product has been calculated using the formula:

$$A_j^{WPM} = \prod_{j=1}^{n} x_{ij}^{w_i}$$

With $A_j^{WPM}$ = weighted product score, $n$ = number of criteria, $x_{ij}$ = the actual value of the $i$th alternative in terms of the $j$th criterion, and $w$ = the weight of importance of the $j$th criterion. Weightings have been determined neither for the BIM uses' benefit assessments nor for the ETA coefficients. Regarding each BIM use's ETA coefficient, $\left(1 - x_{ij}\right)$ = the actual value of the $i$th alternative in terms of the $j$th criterion. Thus, by multiplying each BIM use's benefit assessment with its respective ETA coefficient, each BIM use's multiplicative score could be determined [59]. Based on the weighted product model, BIM uses with a high benefit assessment and weak to medium associations are considered to be of high priority for the development of BIM uses for FM in CREM in general. Accordingly, BIM uses with a low benefit assessment and strong associations are considered to be of low priority for the development of BIM uses for FM in CREM in general.


**Figure 9.** Prioritisation for the development of BIM uses for FM in CREM [60].

## 8. Discussion

Utilising the potential of BIM for FM in CREM remains a challenge and numerous obstacles remain to be tackled and overcome. Of those obstacles, one lies within the initial identification and definition of BIM uses supporting FM processes in CREM. A second obstacle lies within the selection of specific BIM uses to be implemented, as insecurities about the benefit and application of BIM persist. To overcome these obstacles, this study answers the following research questions:

1. RQ 1: Which BIM uses supporting FM processes in CREM can be identified?
2. RQ 2: How do experts assess the benefit of BIM uses for FM in CREM?
3. RQ 3: How strong are the associations between each BIM use's benefit assessment and the respondents' industries?
4. RQ 4: What prioritisation for the development of BIM uses for FM in CREM can be derived from the BIM uses' benefit assessments and their association with industries?

Concerning RQ 1, a comprehensive, literature-based and expert-validated list of BIM uses for FM in CREM is provided, as shown in Table 3.

As for RQ 2, a survey with BIM-experienced CREM experts assessed each BIM use's benefit, identifying the most beneficial BIM uses for FM in CREM, as shown in Figure 7.

Furthermore, research suggests that the benefit of BIM uses is strongly influenced by the implementing organisation's industry [15,16]. RQ 3 thus analysed the associations between each BIM use's benefit assessment and respondents' industries. It showed that the benefit assessments of certain BIM uses had strong associations with the respondents' industries—namely 11 Handover and Commissioning; 21 Visualisation; 25 FM Documentation: Management and Maintenance; and 31 Space and Room Management. These results confirm the findings of Munir et al. [15] and Cavka et al. [16] highlighting the strong influence of an organisation's industry background on its BIM priorities and requirements for supporting specific FM processes. This study affirms the results by Munir et al. [17] and Cavka et al. [16] by showing that different industries assess the benefit of BIM uses for FM differently.

As the implementation of BIM for FM in CREM requires the identification of further research directions regarding the development of guides and templates, this study also aims at deriving a prioritisation for the development of BIM uses for FM in CREM by answering this study's RQ 4. As shown in Figure 9, prioritisation for the development of BIM uses for FM in CREM can be derived from each BIM use's benefit assessment in connection with its respective association with the respondents' industries. The BIM use with the highest priority for further development is 46 Facilities and Equipment: Repair and Renewal. The BIM use with the lowest priority for further development is 21 Visualisation.

The findings described above result in four implications concerning the development of BIM uses for FM in CREM:

(1) It is important to emphasise that the benefit assessments collected in this study are not or are only partly based on experience gathered during the BIM uses' implementation in reality. This means the benefit assessments rely largely on the experts' experience in the fields of BIM and FM in CREM and do, to a certain extent, reflect expectations of each BIM use's potential benefit. Therefore, further research in the form of case studies is suggested to develop and implement BIM uses under real conditions for quantifiable benefit assessments.

(2) Based on this study's results regarding the prioritisation for the development of BIM uses for FM in CREM and implication (1), further research is suggested to define information requirements for high-priority BIM uses. Since an obstacle to the implementation of BIM for FM in CREM lies within a lack of guides and templates, basic information requirements need to be identified to support the implementation of BIM in this context [10,14].

(3) An additional implication comes from the identification of technical requirements. Regarding the implementation of high-priority BIM uses within the context of FM in CREM, an investigation of the technical requirements is suggested. Given the diversity of software solutions and programmes used within CREM, further research might address questions of information exchange and data formats within this specific context.

(4) On a process and personnel level, the definition of processes and personnel activities to support the implementation of high-priority BIM uses within the context of FM in CREM is suggested as further research. This fourth implication derives from the fact that established FM processes may require the development of new processes to allow personnel to adapt the processes and personnel activities of FM tasks to the BIM-based processes and personnel activities.

## 9. Conclusions

The number of current state initiatives, road maps, and associations promoting the implementation of BIM illustrates the expectations it raises regarding the digitisation of the construction industry as a whole. However, most efforts and research projects still target its application in the design and construction phases. Even though buildings accumulate the largest part of their life cycle cost during their operational phase, the implementation of BIM in this life cycle phase has been investigated to a comparably small extent. Related research suggests that one of the main obstacles hampering BIM implementation in FM lies within the identification of FM processes that can be supported with BIM and the subsequent definition of information requirements. In other terms, FM professionals often do not know which FM process can or should be supported with BIM and which information a BIM should contain to do so. Due to the complexity of modern FM, professionals frequently rely on guides and templates to perform certain tasks. Currently, a lack of guides or templates for the definition of specific BIM requirements for FM has been observed. In this current state, the process of information requirement definition for FM requires deeper knowledge of BIM and active participation in the design and construction process to assure that FM requirements are sufficiently considered during these phases—prerequisites that not all FM professionals can fulfil. Given this lack of guides or templates, this study lays the ground for further research aiming at the provision of such supporting documents.

As a result, a total of 35 BIM uses were identified and defined. As related research suggests that different industries expect different benefits from BIM uses due to their specific real estate portfolios, BIM uses that benefit all industries had to be identified subsequently.

It showed that the BIM use with the highest priority for development is 46 Facilities and Equipment: Repair and Renewal whereas the BIM use with the lowest priority is 21 Visualisation. Based on the study's results, the following conclusions can be drawn:

1. Many of the FM processes from GEFMA 100-2 can be supported with BIM, opening up a multitude of application areas for BM in FM.
2. The implementation of BIM in CREM remains narrow, as the limited number of available participants illustrates.
3. High-priority BIM uses can be identified for a variety of FM main processes, namely 1 Commissioning, 4 Operations, 6 Cleaning and Maintaining, and 8 Provide Support.
4. Further research will need to develop reliable quantitative methods to measure how beneficial the implementation of a BIM use is compared to the current solutions.

The present study extends the knowledge on BIM in the context of CREM by providing a base for further research. It provides a literature-based list of potential applications of BIM for FM in CREM, opening up a variety of case studies to accelerate digitisation within this context. In order to identify further research directions with high impact, it also provides a prioritisation of BIM uses expected to generate high benefit, regardless of the industry concerned.

## 10. Limitations

Furthermore, the limitations of this study might also be addressed in future research:

(1) The list of BIM uses supporting FM processes in CREM may not apply in other countries as the identification of BIM uses is based on FM processes listed in the GEFMA 100-2. This is because there is no international standard defining specific FM processes. This limitation could not be overcome at this point and it may impact the studies' findings regarding the definition of the BIM uses identified. Future research could repeat the study using other national standards as a base. Alternatively, by using a yet-to-be-published international standard, further research could help to define a list of internationally acknowledged and standardised BIM uses supporting FM processes in CREM.

(2) The identification of significant relationships between industries and beneficial BIM uses may be affected by the limited sample size. Due to the two prerequisites for participating in the online survey conducted—being a CREM expert and possessing prior BIM experience—the potential number of participants was highly restricted by default. As the implementation of BIM in the field of FM, in general, and in CREM, in particular, remains narrow, this limitation could not be overcome at this point. Thus, the study's findings may be biased as several industries have not engaged in

the implementation of BIM in FM yet, exempting their perspective from the survey. This may impact the study's findings, as it may limit the extent to which they can be generalised. Further research could address this limitation by either repeating the survey as a whole or investigating specific industries individually.

Subsequent application of the proposed analysis approach for limitations (1) and (2) would allow further identification of high-priority BIM uses and BIM uses with strong associations with certain industries. Subsequently, comparisons with the results presented in this study could be conducted.

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## Appendix A

**Table A1.** Identified BIM uses for FM in CREM—FM main processes, sources, and frequency.

| FM Main Process | No. | BIM Use | Sources | Frequ. |
|---|---|---|---|---|
| 1 Commissioning | 11 | Handover and Commissioning | [16,61–69] | 10 |
| | 12 | As-Built Modelling and Documentation | [18,52,61–73] | 15 |
| 2 Manage Operations | 21 | Visualisation | [18,61–63,65–68,70,71,74] | 11 |
| | 22 | Disaster Planning and Emergency Preparedness | [18,19,25,55,61–66,68,70,74] | 13 |
| | 23 | Wayfinding and Tracking | [16,18,55,61–65] | 8 |
| | 24 | Generate: 2D Plans and 3D Details | [16,19,56,61–72,74] | 16 |

**Table A1.** *Cont.*

| FM Main Process | No. | BIM Use | Sources | Frequ. |
|---|---|---|---|---|
| | 25 | FM Documentation: Management and Maintenance | [14,16,19,52,56,61–74] | 19 |
| | 26 | Ticket Management | [56,61,63,68,72] | 5 |
| | 27 | FM Quality Management | [25] | 1 |
| | 28 | FM Sustainability and Environmental Protection | [19,25,62,64–67,70–72,74] | 11 |
| 3 Provide Workplaces | 31 | Space and Room Management | [18,19,25,55,56,61–68,70–72,74] | 17 |
| | 32 | Relocation Management | [62,63,68] | 3 |
| | 33 | Equipment and Furnishing | [61,62,68,72] | 4 |
| 4 Operations | 41 | BIM 2 Field | [52,61–63,65] | 5 |
| | 42 | Structural Health Monitoring | [62,63,65,67,68,71,72,74] | 8 |
| | 43 | Facility Identification System | [14,63,65,68,71] | 5 |
| | 44 | Facilities and Equipment: Periodic Inspections | [14,16,18,55,56,62,63,65,68,71,72] | 11 |
| | 45 | Facilities and Equipment: Inspection and Maintenance | [14,16,18,19,25,55,56,61–70,72,74] | 19 |
| | 46 | Facilities and Equipment: Repair and Renewal | [14,16,18,25,55,56,61–65,67–74] | 19 |
| 5 Supply and Disposal | 51 | Real-time Acquisition and Display of Sensor Data | [18,62,63,65,68,72] | 6 |
| | 52 | Energy Management | [16,18,19,55,62–74] | 17 |
| | 53 | Waste Management | [62,68,72] | 3 |
| 6 Cleaning and Maintaining | 61 | Cleaning Management: Maintenance Cleaning | [61,63,65,67,68,72,74] | 7 |
| | 62 | Cleaning Management: Glass and Facade Cleaning | [61,63,65,67,68,72,74] | 7 |
| | 63 | Cleaning Management: Outdoor Facilities Cleaning | [Pretest] | - |
| 7 Asset Management | 71 | Security Management | [25,61,62,65,68,72] | 6 |
| | 72 | Locking Management | [25,61,62,65,68,72] | 6 |
| | 73 | Rent Management | [16,19,25,68,72] | 5 |
| | 74 | Generate: Inventory, Component, and Equipment Lists | [16,19,61,62,64–66,68–72,74] | 13 |

**Table A1.** *Cont.*

| FM Main Process | No. | BIM Use | Sources | Frequ. |
|---|---|---|---|---|
| | 75 | FM Accounting and FM Controlling | [16,18,19,25,61–63,65,68,70–74] | 14 |
| | 76 | Perform Contract and Insurance Management | [16,19,25,62,63,65,72] | 7 |
| | 77 | Defect Management | [16,19,62,63,65,68,72] | 7 |
| 8 Provide Support | 81 | Room Booking and Occupancy Systems | [25,62,63,65,72] | 5 |
| | 82 | Event Planning | [62] | 1 |
| | 83 | Perform Procurement | [16,25,61–63,65,68,72] | 8 |

Alshorafa and Ergen [14]; Cavka et al. [16]; Becerik-Gerber et al. [18]; McArthur and Sun [19]; Carbonari et al. [25]; Miettinen et al. [52]; Mayo and Issa [55]; Lazar and McArthur [56]; buildingSMART International [61]; Institut für Technologie und Management im Baubetrieb [62]; BIMe initiative [63]; Statsbygg [64]; Bouw Informatie Raad [65]; NATSPEC [66]; Construction Industry Council [67]; Direction générale de l'Aménagement, du Logement et de la Nature [68]; buildingSMART France [69]; College of Engineering [70]; New York City Department of Design and Construction [71]; buildingSMART Finland [72]; Building and Construction Authority [73]; AEC [74].

**Table A2.** Main processes' Cronbach's alpha and the arithmetic mean (AM) of each BIM uses' benefit assessment with corresponding standard deviation (ST DEV), and rank.

| FM Main Process | Cronbach's Alpha | No. | BIM Use | AM | ST DEV | Rank |
|---|---|---|---|---|---|---|
| 1 Commissioning | 0.683 | 11 | Handover and Commissioning | 4.00 | 0.85 | 5 |
| | | 12 | As-Built Modelling and Documentation | 4.35 | 0.68 | 1/2 |
| 2 Manage Operations | 0.729 | 21 | Visualisation | 3.81 | 0.97 | 10 |
| | | 22 | Disaster Planning and Emergency Preparedness | 3.51 | 0.99 | 19 |
| | | 23 | Wayfinding and Tracking | 3.76 | 0.93 | 11 |
| | | 24 | Generate: 2D Plans and 3D Details | 4.08 | 0.86 | 4 |
| | | 25 | FM Documentation: Management andMaintenance | 4.35 | 0.75 | 1/2 |
| | | 26 | Ticket Management | 3.57 | 1.01 | 17 |
| | | 27 | FM Quality Management | 3.00 | 1.18 | 33 |
| | | 28 | FM Sustainability and Environmental Protection | 3.46 | 1.17 | 21 |
| 3 Provide Workplaces | 0.702 | 31 | Space and Room Management | 4.32 | 0.75 | 3 |
| | | 32 | Relocation Management | 3.43 | 1.07 | 22 |
| | | 33 | Equipment and Furnishing | 3.22 | 1.03 | 29 |

**Table A2.** *Cont.*

| FM Main Process | Cronbach's Alpha | No. | BIM Use | AM | ST DEV | Rank |
|---|---|---|---|---|---|---|
| 4 Operations | 0.799 | 41 | BIM 2 Field | 3.65 | 1.01 | 14 |
| | | 42 | Structural Health Monitoring | 3.05 | 1.18 | 32 |
| | | 43 | Facility Identification System | 3.49 | 1.04 | 20 |
| | | 44 | Facilities and Equipment: Periodic Inspections | 3.92 | 1.12 | 8 |
| | | 45 | Facilities and Equipment: Inspection andMaintenance | 3.97 | 1.04 | 6 |
| | | 46 | Facilities and Equipment: Repair and Renewal | 3.95 | 1.10 | 7 |
| 5 Supply and Disposal | 0.716 | 51 | Real-time Acquisition and Display of Sensor Data | 3.41 | 1.07 | 23 |
| | | 52 | Energy Management | 3.73 | 1.07 | 12 |
| | | 53 | Waste Management | 3.11 | 1.07 | 31 |
| 6 Cleaning and Maintaining | 0.932 | 61 | Cleaning Management: Maintenance Cleaning | 3.70 | 1.02 | 13 |
| | | 62 | Cleaning Management: Glass and FacadeCleaning | 3.62 | 1.04 | 15 |
| | | 63 | Cleaning Management: Outdoor Facilities Cleaning | 3.32 | 1.18 | 25 |
| 7 Asset Management | 0.841 | 71 | Security Management | 3.14 | 1.08 | 30 |
| | | 72 | Locking Management | 3.30 | 1.02 | 26 |
| | | 73 | Rent Management | 3.27 | 1.02 | 27 |
| | | 74 | Generate: Inventory, Component, and Equipment Lists | 3.89 | 0.81 | 9 |
| | | 75 | FM Accounting and FM Controlling | 3.35 | 1.01 | 24 |
| | | 76 | Perform Contract and Insurance Management | 2.70 | 1.00 | 35 |
| | | 77 | Defect Management | 3.59 | 1.04 | 16 |
| 8 Provide Support | 0.734 | 81 | Room Booking and Occupancy Systems | 3.54 | 1.04 | 18 |
| | | 82 | Event Planning | 2.89 | 1.07 | 34 |
| | | 83 | Perform Procurement | 3.24 | 1.09 | 28 |

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